# Marine Monitoring Handbook
# March 2001

JOINT NATURE CONSERVATION COMMITTEE

# Marine Monitoring Handbook
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UK Marine SACs Project

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# Preface

The 1990s saw a 'call to action' for marine biodiversity conservation. The global Convention on Biological Diversity, the European Union's Habitats Directive, and recent developments to the Oslo and Paris Convention have each provided a significant step forward. In each case marine protected areas are identified as having a key role in sustaining marine biodiversity.

The Habitats Directive requires the maintenance or restoration of natural habitats and species of European interest at favourable conservation status, with the management of a network of Special Areas of Conservation (SACs) being one of the main vehicles for achieving this. Among the habitats and species specified in the Annexes I and II of the Directive, several are marine features and SACs have already been selected for many of these in the UK. But to manage specific habitats and species effectively there needs to be clear understanding of their distribution, their biology and ecology and their sensitivity to change. From such a foundation, realistic guidance on management and monitoring can be derived and applied.

One initiative now underway to help implement the Habitats Directive is the UK Marine SACs LIFE Project, involving a four year partnership (1996–2001) between English Nature, Scottish Natural Heritage, Countryside Council for Wales, Environment and Heritage Service, Joint Nature Conservation Committee, and Scottish Association for Marine Science.

The overall goal of the Project is to establish management schemes on 12 of the candidate marine SAC sites. A key component of the Project is to assess the interactions that can take place between human activities and the Annex I and II interest features on these sites. This understanding will provide for better management of these features by defining those activities that may have a beneficial, neutral or harmful impact and by giving examples of management measures that will prevent or minimise adverse effects.

Task 3.2 of the UK Marine SACs project set out to 'identify and develop appropriate methods for recording, monitoring and reporting natural characteristics and conditions of Annex I/II interests and relevant environmental factors'. A key output of Task 3.2 is a 'published book on monitoring methods and procedures' to be used as guidance by the UK government's statutory nature conservation agency staff and their key partners in drawing up monitoring schemes for European Marine Sites. The *Marine Monitoring Handbook* fulfils this requirement.

The *Marine Monitoring Handbook* addresses the principles behind, and the procedures for, monitoring Annex I habitats, and selected Annex II species, within marine SACs in British waters to assess their condition in accordance with the relevant requirements of the Directive and the UK's common standards for site monitoring.

The *Marine Monitoring Handbook* provides guidance on the different options and their relative costs and benefits and describes the current best practice for monitoring Annex I habitats and for the bottlenose dolphin, grey seal and common seal within marine SACs, to assist in the assessment of their condition. It draws on the information provided by the field trials undertaken under Task 1.2 of the UK Marine SACs project to ensure all advice has a sound practical basis. The Handbook is intended to provide a toolkit for marine site monitoring, enabling those carrying out monitoring to select and use appropriate methodologies. It is not prescriptive about the nature of the monitoring required but enables good monitoring decisions to be taken in the light of resource availability and other practicalities.

Dr Malcolm Vincent
Projects Director
Joint Nature Conservation Committee

# Acknowledgements

Many people have assisted in the production of the Handbook.

Dr Keith Hiscock (Marine Biological Association) initiated the project and oversaw the production of the first version in 1997. Eleanor Murray (English Nature) further developed the Handbook during the first two years of the UK Marine SACs Project.

The Marine Monitoring Group (Martin Bradley, Environment and Heritage Service Northern Ireland; David Connor, JNCC; Janet Khan, - Scottish Natural Heritage; Eleanor Murray, English Nature; and Bill Sanderson, Countryside Council for Wales) put considerable time and effort into the whole production of this Handbook.

John Torlesse, the UK Marine SACs project co-ordinator, and Malcolm Vincent (JNCC) provided comments on earlier draft texts, and much-needed encouragement throughout the preparation and production of this volume.

The following people provided comments on the draft text: Eamonn Kelly and Ian Reach (JNCC), Paul Brazier, Rohan Holt and Mandy McMath (Countryside Council for Wales), Paul Gilliland (English Nature), and John Baxter, Ben James and Alexander Downie (Scottish Natural Heritage).

Emily Strong (English Nature) started the revision of the procedural guidelines and did much of the initial literature research. Kate Bull (JNCC) copy-read the text and provided considerable assistance with the final production.

## Contact points for further advice

The source of advice will depend on the nature of the query. In general:

- For clarification of any points in the text in this Handbook, queries should be addressed to the authors who are listed under each section, including the Procedural Guidelines;
- General queries, queries of a UK nature, or advice on common standards monitoring for marine SACs should be addressed to Jon Davies (JNCC); or
- Any query specific to one of the countries of UK should be addressed to the relevant person on the Marine Monitoring Group (see Acknowledgements above).

# Preamble

## *Development of the Marine Monitoring Handbook*

While the monitoring of terrestrial protected areas in the United Kingdom has a long history, the monitoring of protected marine areas has been limited to a very few localities. As a result there has, to date, been no single volume available which provides guidance on the monitoring of marine protected areas. The selection and, in due course, designation of marine Special Areas of Conservation (SACs) under the EC Habitats Directive, has highlighted the need for comprehensive guidance on the monitoring of the marine environment.

The Marine Monitoring Handbook is a stage in the development of such comprehensive guidance, and has been developed by the *UK Marine SACs project* through a series of literature reviews, workshops and practical trials. The overall approach to monitoring taken in the Handbook is that adopted by the UK nature conservation agencies in their Common Standards for Monitoring of designated sites. The Handbook utilises this approach to analyse the possible monitoring requirements of marine protected areas designated as SACs, summarises the principles of good monitoring practice, and analyses the appropriateness of available monitoring techniques. In addition, Procedural Guidelines have been prepared for a wide range of techniques to assist practitioners to carry out monitoring.

The Handbook has been organised in sections at different levels of detail designed to offer assistance to a range of users, from those who need to be aware of the general approach to be taken in marine monitoring, to those who will need to design, commission, or undertake the monitoring. This organisation of the Handbook is summarised in Figure i.

The Handbook is a toolkit for the monitoring of marine SACs. It does not attempt to prescribe monitoring programmes for particular features listed on Annex I or Annex II of the Habitats Directive. The optimum type and level of monitoring on sites across the SAC network has still to be determined, and this is likely to be an important component of future work within the UK.

Furthermore, as our practical knowledge of monitoring increases, and the marine monitoring requirements are addressed in greater detail within the European Union, the guidance set out in the Handbook is likely to change. The Handbook should, therefore, be considered as a ***live working document.***

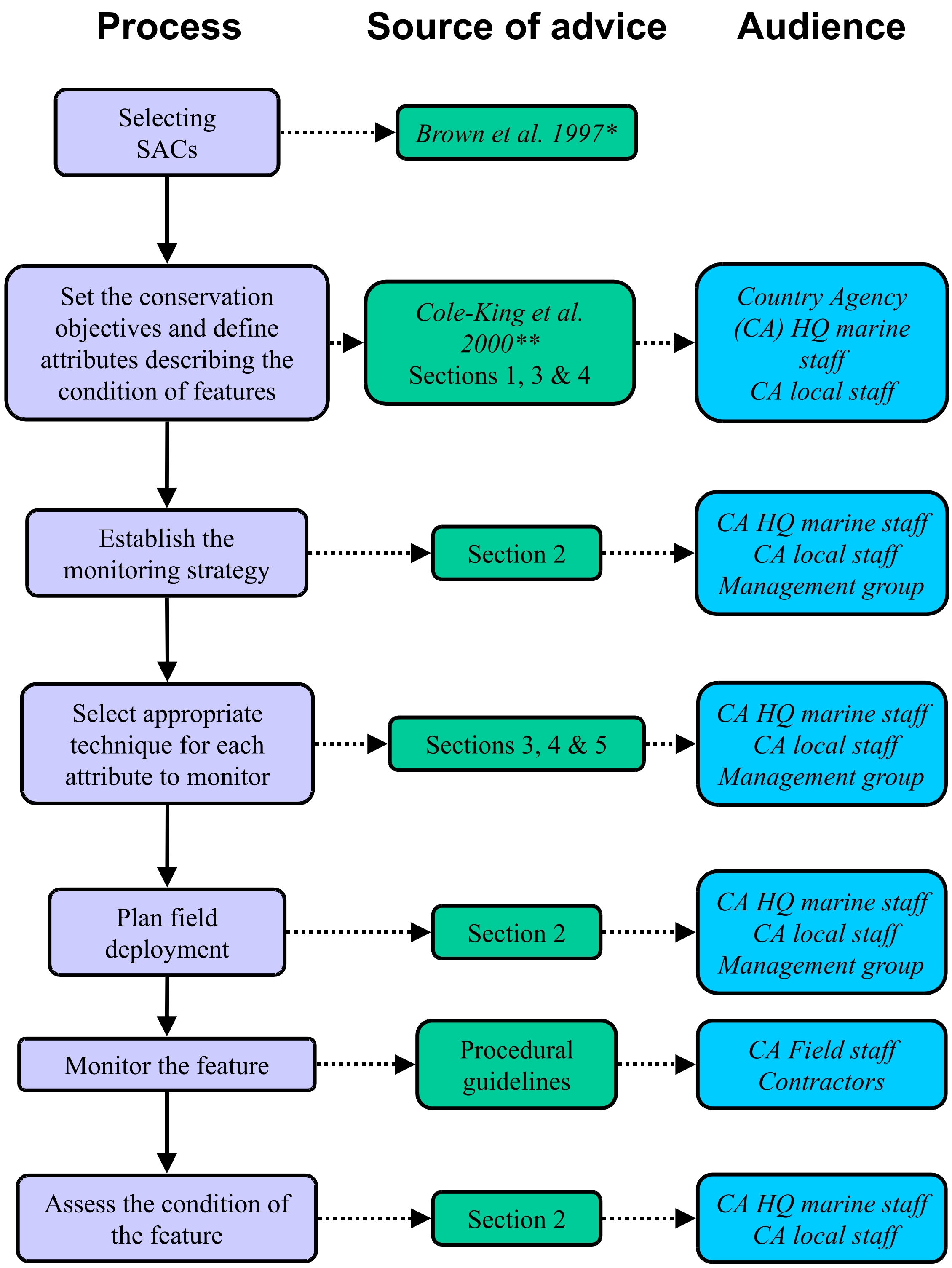
## *Future progress of the Marine Monitoring Handbook*

During 2001, further work will be carried out to improve the coverage and content of the Handbook. In particular:

- we will increase the number and range of Procedural Guidelines to cover all the techniques listed in Section 6 of the Handbook;
- we will revise Sections 3 and 4 of the Handbook, taking account of further work to identify the most cost-effective design of monitoring programmes for particular Annex I habitats and Annex II species, and the level of skills needed to carry out the work;
- we will improve the level of guidance in relation to Annex II species;
- we will provide a glossary of terms and a bibliography divided by topic.

The Marine Monitoring Handbook will be maintained on the JNCC Internet site (**http://www.jncc.gov.uk**), and this electronic version will be the most up-to-date copy available. Modifications to the Handbook, following the further work referred to above, will be incorporated into this version. We will provide a 'notice board' on this website to enable users to provide feedback on the Handbook. A mechanism, probably e-mail, will be established to alert users when new material, or revision of existing material, is published.

Comments on this text, and suggestions for improvement, will be welcomed. All comments should be sent to Dr Jon Davies at JNCC (**Jon.Davies@jncc.gov.uk**) and, if necessary, they will be incorporated into later electronic versions.




* Brown, A E, Burn, A J, Hopkins J J and Way, S F (1997) *The Habitats Directive: selection of Special Areas of Conservation in the UK*. JNCC Report 270. Joint Nature Conservation Committee, Peterborough.
** Cole-King, A (In prep.) *UK Marine SACs Project: Setting Conservation Objectives for marine SACs.*

**Figure i** An overview of marine SAC monitoring, showing the relevant sources of advice in the Marine Monitoring Handbook (together with other published texts) and the anticipated readership. *Country Agency - CA*: UK Government's Conservation Agencies. *Management group*: most marine SACs will have a co-ordinating group of representatives from local relevant authorities.

# 1 Background

Malcom Vincent and Jon Davies

# Introduction

The European Community has adopted two Directives which aim to conserve nature within the territory of the European Union. Firstly, Council Directive 92/43 EEC of 21 May 1992 on the *Conservation of natural habitats and of wild fauna and flora* (the Habitats Directive) requires that Member States designate Special Areas of Conservation for specified habitats and the habitats of specified species of wild plants and animals. Secondly, Council Directive 79/409 EEC of 2 April 1979 on the *Conservation of wild birds* (the Birds Directive) requires Member States to designate Special Protection Areas for the conservation of specified wild birds, and for regularly occurring migratory birds. Both these Directives apply to the marine environment of the European Union as well as to the terrestrial and freshwater environments.

The requirement to designate Special Areas of Conservation (SACs) and Special Protection Areas (SPAs) is implemented in Great Britain by the *Conservation (Natural Habitats etc.) Regulations 1994* and in Northern Ireland by the *Conservation (Natural Habitats, etc.) Regulations (Northern Ireland) 1995*. These Regulations make provision for the implementation of the Directives in the marine environment, including the preparation of Schemes of Management (hereafter called *Management Schemes*) for marine SACs and SPAs. The Regulations refer to marine SACs and SPAs collectively as European marine sites. The Regulations, and the Management Schemes prepared under them, are intended to maintain the conservation value of the European marine sites for the particular habitats or species for which they were designated.

Monitoring of European marine sites is necessary to determine the condition of the sites, to indicate whether management measures undertaken under the Management Schemes are proving effective, and to identify, where possible, any detrimental effects. Where such effects are recorded, they are likely to act as a trigger for further investigative studies to determine what, if any, remedial action can be taken.

The UK Marine SACs project has investigated methods and strategies to monitor the condition of those marine habitats and species listed on Annexes I and II of the Habitats Directive which occur in the 12 trial sites covered by the project. As part of this investigation, a number of these methods were tested on site to examine their cost-effectiveness and practicality. The trials concentrated either on applying developing technologies such as airborne remote sensing to SAC monitoring, or on new methods for deploying existing techniques. It did not test techniques that are well established for site monitoring.

The *Marine Monitoring Handbook* explains the need for monitoring on marine SACs, sets out the approach to such monitoring which is being adopted by the United Kingdom, provides assistance with the design of monitoring programmes, gives specific guidance on monitoring methods appropriate to a range of marine SAC habitats and species, and provides information on the practical application of the monitoring methods. Figure i on page 11 provides an overview of the monitoring process and shows where in the *Marine Monitoring Handbook* advice may be sought.

The Handbook is intended, primarily, for those responsible for designing and implementing monitoring programmes for marine SACs (Box 1-1). While the guidance provided is relevant to the habitat attributes of marine SPAs, methods for assessing bird populations have already been published [a,b] and are not included in this Handbook.

**Box 1-1** Aim

The Marine Monitoring Handbook provides advice on monitoring marine Special Areas of Conservation to assess their condition in accordance with the requirements of the Habitats Directive and UK common standards for monitoring.[c]

# Legislative background for monitoring on SACs

The purpose of designating and conserving Special Areas of Conservation is to maintain or restore the habitats listed on Annex I and the species listed on Annex II of the Directive to *Favourable Conservation Status*. Favourable Conservation Status is defined in Article 1 of the Directive. In summary, for Annex I habitats, it means that conditions have been established which will ensure that the extent and range of the habitat, and the populations of the constituent species of that habitat, will be maintained or increased over time. For Annex II species, it means that conditions have been established which will ensure that the viability, population size and range of that species will be maintained in the long term.

The term Favourable Conservation Status relates to the individual habitats and species over their natural range within the European Union. However, because the selection of the European network of SACs is seen as fundamental to achieving Favourable Conservation Status, the European Commission considers that the concept should also be applied at the site level.[d] A key purpose of SAC monitoring, therefore, will be to determine whether Favourable Conservation Status of the habitats and species is being achieved at the level of individual SACs. The UK conservation agencies use the term *favourable condition* to represent the concept of Favourable Conservation Status for the interest features of an individual SAC.

In addition to this general point, the Habitats Directive also includes a number of specific provisions which require the undertaking of monitoring on SACs. The most important of these are:

- ***Article 11***

  *Member States shall undertake surveillance of the conservation status of the natural habitats and species referred to in Article 2 with particular regard to priority natural habitat types and priority species.*

  This Article requires Member States to undertake surveillance of the conservation status of the natural habitats and species listed on the Annexes of the Directive, with particular regard to priority habitats and species. This surveillance requirement relates to the conservation status of the habitats and species throughout the territory of the Member State. It is reasonable to infer that the importance of surveillance of a given habitat or species on an individual marine SAC can be viewed as being proportionate to the importance of the site to the status of the habitat or species within the territory of the Member State as a whole.

- ***Article 17(1)***

  *1. Every six years from the date of expiry of the period laid down in Article 23, Member States shall draw up a report on the implementation of the measures taken under this Directive. This report shall include in particular information concerning the conservation measures referred to in Article 6 (1) as well as evaluation of the impact of those measures on the conservation status of the natural habitat types of Annex I and the species in Annex II and the main results of the surveillance referred to in Article 11. The report, in accordance with the format established by the committee, shall be forwarded to the Commission and made accessible to the public.*

  This Article requires Member States to prepare a report by June 2000,[1] and every six years afterwards, on the measures taken to achieve the conservation of SACs, and also to undertake an evaluation of the effect of these measures on the conservation status of Annex I habitats and Annex II species. Monitoring is needed in order to carry out this evaluation. The main results of the surveillance carried out under Article 11 are also to be included in the Report.

In addition to the requirements of the Habitats Directive, Article 8 of the EC Water Framework Directive will require Member States to ensure the establishment of programmes for monitoring the status of protected areas (including SACs). The purpose of such monitoring is to gauge whether the water-related ecological requirements (e.g. the water quality) of the SACs are being met.

1 The report due in June 2000 has been deferred for one year to June 2001.

### Summary

The EC legislation requires the condition of the habitats and species for which an SAC has been designated to be monitored, in a manner which enables the condition of the feature to be estimated, and whether management measures undertaken on the site are proving effective in achieving their favourable condition.

## The UK approach to SAC monitoring

In the United Kingdom, an approach to the monitoring of wildlife sites which have been designated under both national and EC legislation has been developed which meets the requirements for monitoring of SACs. In this approach, a distinction is made between *surveillance* and *monitoring*.

**Box 1-2** Definitions

Surveillance is a continued programme of biological surveys systematically undertaken to provide a series of observations in time.
Monitoring is surveillance undertaken to ensure that formulated standards are being maintained.

Because the purpose of SACs is to contribute to achieving Favourable Conservation Status for the habitats and species for which they were selected, work undertaken to assess whether SACs are making the contribution expected of them falls into the category of monitoring as defined in Box 1-2.

The Annex I habitats and Annex II species for which SACs have been selected are referred to collectively in the United Kingdom as *interest features*. Table 1-1 lists those marine interest features which occur in the United Kingdom and are covered by this handbook.

**Table 1-1** Marine interest features occurring in the UK for which advice on monitoring the feature's condition is provided in Sections 3 and 4 of this handbook.

| *Annex I habitats* | *Annex II species* |
|---|---|
| Sandbanks which are slightly covered by seawater at all times | *Phoca vitulina* (Common seal) |
| Mudflats and sandflats not covered by seawater at low tide | *Halichoerus grypus* (Grey seal) |
| Reefs | *Tursiops truncatus* (Bottlenose dolphin) |
| Submerged or partially submerged sea caves | |
| Lagoons | |
| Estuaries | |
| Large shallow inlets and bays | |

The approach to monitoring SACs in the UK is based on the requirement to assess whether the interest feature for which the site has been selected is in *favourable condition*. Favourable condition is the state which needs to be achieved by an interest feature and corresponds to Favourable Conservation Status at the level of the individual SAC (Figure 1-1).

Favourable condition, therefore, is the 'formulated standard' referred to in the definition of monitoring given in Box 1-2, and has to be defined for each interest feature on each SAC. To accomplish this, and to achieve as far as possible a full alignment with management measures and controls established under Management Schemes, the UK has formulated standards based on the *conservation objectives* developed for each interest feature on each SAC.

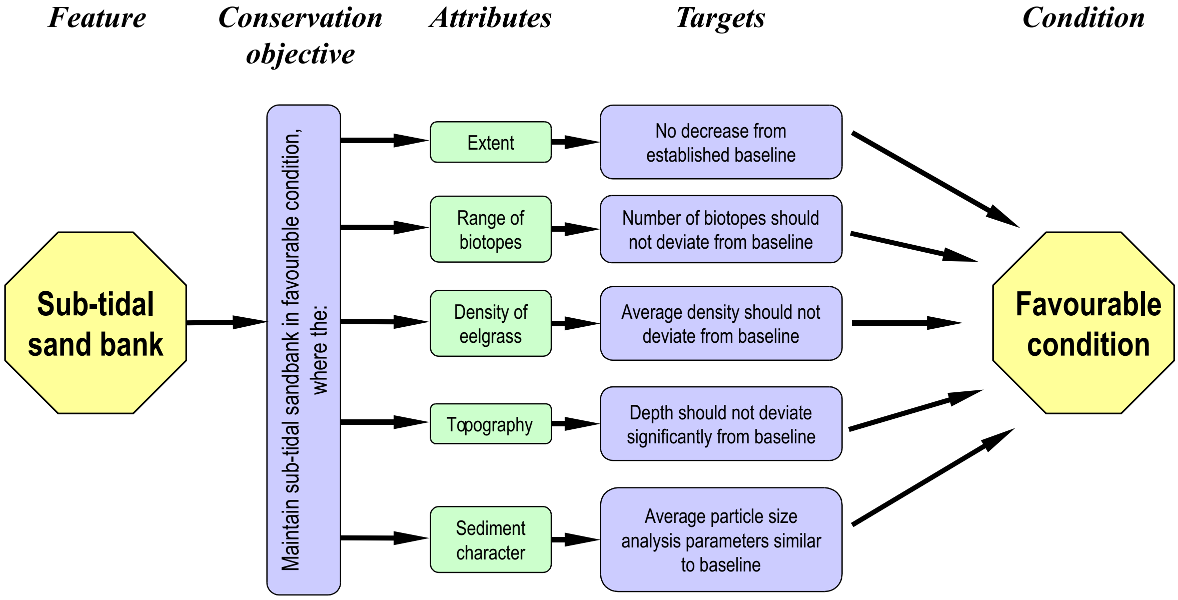



**Figure 1-1** Diagrammatic representation of the UK's approach to setting a conservation objective for a marine SAC feature.

## Conservation objectives

The Habitats Directive implies that conservation objectives will be developed for SACs, and explicitly refers to these in the context of appropriate assessment of plans and projects under Article 6. The UK's national implementing Regulations have developed the concept further and require the country nature conservation agencies to advise all relevant authorities of the conservation objectives for each marine SAC. A conservation objective is a statement of the nature conservation aspirations for the interest features on an SAC, expressed in terms of broad targets that define favourable condition.[e]

The process of defining favourable condition of an interest feature can be thought of as consisting of two elements:

1) Identifying the most important characteristics of the interest feature that define its condition. Depending on the feature concerned, this will usually include some combination of the:

   – quantity of the feature, for example the extent of habitat, or habitat of the species, or abundance of the species, and related characteristics such as range of distribution, and whether its spatial occurrence is patchy or continuous;

   – quality of the feature, for example for a habitat, the presence or abundance of component species, or the quality of inorganic components of the habitat such as substrata; for a species population, measures of quality could include characteristics such as age or size structure, productivity rate, and even aspects of the 'health' of individuals;

   – processes supporting the feature, such as physical environmental factors like water quality, water movement (levels and flows) or sediment processes, where they are of overriding importance to the condition of a habitat or species; for example, the salinity patterns observed in a lagoon.

2) Identifying the state or value, or range of values, for the selected characteristics which the feature needs to have if it is to be considered as being in favourable condition. These values need to recognise, so far as possible, the fluctuations which are part of the feature's natural dynamics.

As a guide, and in the absence of information on which to base a different conclusion, the 'value' of the characteristics at the time when the feature was selected is assumed to be representative of favourable condition. The United Kingdom refers to the characteristics described above as *attributes*.

## Sub-features

The marine Annex I habitats are very broadly defined habitats that are often represented by large and complex sites. To effectively describe, monitor and manage such complex features, it has been necessary to divide some of them into smaller units called *sub-features*. Sub-features are distinctive biological communities (e.g. eelgrass beds, maerl beds, horse-mussel reefs), or particular structural or geographical elements of the feature (see Figure 1-2). Sub-features have often proved helpful, both in the development of conservation objectives, and of monitoring programmes, to separate the feature into a number of constituent sub-features, and then to identify attributes and targets for the sub-features. The use of sub-features has been found to be particularly helpful for those marine Annex I features that represent whole physiographic units,[2] and permits a level of flexibility in the application of the UK's Common Standards Monitoring which has been found necessary when applying the standards at the site level.

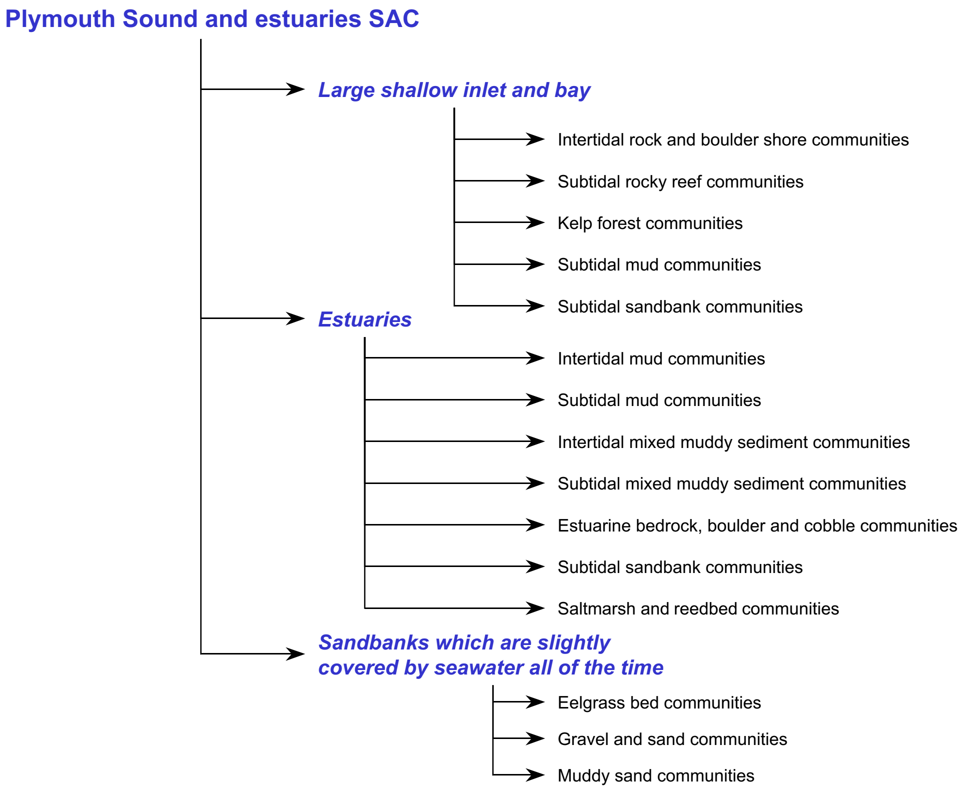



**Figure 1-2** An example of how complex Annex I features (bold italic) are divided into sub-features (normal text) for a large SAC.

## Attributes

As explained above, conservation objectives for each feature on each SAC are developed by identifying the attributes which describe and support the (sub) feature, and by the setting of values, or a range of values, for each of these which reflect the best judgement as to what is required to define the feature as being in good condition. It is quite impractical to set conservation objectives for every conceivable attribute for a particular feature and, even if this were done, the cost of monitoring all of these to assess the condition of the feature would be prohibitive.

For this reason, conservation objectives are developed for those attributes considered to be essential. The nature conservation agencies in the United Kingdom are currently increasing their experience in developing conservation objectives for marine interest features, and the understanding of which attributes are the most important may need to change as our understanding improves. Examples of attributes are given in Box 1-3. The United Kingdom refers to the attribute values which help to define favourable condition as *targets*.

In practice, in the marine environment it has proved useful to consider attributes in meaningful groups under a range of sub-features.

2 Estuaries, large shallow inlets and bays, caves, and lagoons.

**Box 1-3** Examples of Attributes

Extent of the feature

Diversity of constituent biotopes
Extent of important constituent biotopes
Distribution of important constituent biotopes
Species composition of important biotopes

Important topographic features such as bathymetry
Water temperature
Turbidity
Nutrient status
Sediment (or other substratum) character

### Summary

A summary of the approach used to define favourable condition for an interest feature on an individual SAC is, therefore, as follows:

1) Identify and define any sub-features that are important components of the feature.

2) Identify the attributes for the interest feature, and any sub-features, which are considered, on best judgement, to be essential to assess its condition.

3) Set targets for those attributes.

4) Formulate conservation objectives for the feature based on the aggregation of all the selected attributes and their targets.

These conservation objectives then define favourable condition for the feature.

## The role of monitoring in judging favourable condition

Monitoring the selected attributes provides the information to compare their actual values at the time of recording with the target values, to enable an assessment of whether or not the feature (or sub-feature) is in favourable condition.

The United Kingdom uses this approach in the monitoring of all sites designated under national and EC nature conservation Directives, and refers to the approach as *Common Standards Monitoring* . The approach has a number of advantages:

- At a local level, it provides a framework for those responsible for developing and implementing monitoring programmes to do so with the confidence that this framework is supported nationally and is being implemented throughout the country.
- It enables judgements to be made about the condition of features which are consistent between one person and another, and between one site and another.
- Collecting, managing and exchanging monitoring information using accepted standards can be done at a much lower cost than would otherwise be possible, and use of the standards also facilitates the comparison of results over time and between different localities.
- It enables the UK to report on the condition of each feature at the national level to the EC.

### Frequency of monitoring

The Habitats Directive requires Member States to report on the status of the habitats and species of Community interest every six years. In conformity with this, the UK has adopted the practice of monitoring all designated sites, including SACs, on a six-year cycle. Within this overall six-year monitoring cycle, each interest feature within a site must be monitored, preferably within the same year, but certainly within a three-year period.

Some features within sites will be monitored more frequently than this. Marine SAC features particularly will need more frequent monitoring in forthcoming years to adequately establish their inherent variation and better judge the appropriateness of target values already set, or define target values for those attributes where there are few existing data.

## Judging the condition of sites

The condition of designated features is judged to fall into one of seven categories (see Box 1-4). The first two of these are termed *favourable* and features which are assessed as falling into these categories meet the requirements of favourable condition. The remainder do not.

The Common Standards Monitoring model for designated nature conservation sites adopted by the United Kingdom also includes the monitoring of management measures and activities, but these are not included within the Handbook. The Common Standards Monitoring procedures are summarised in Box 1-4.

**Box 1-4** Some key aspects of the framework of Common Standards Monitoring

***Features to be monitored***

*The features to be monitored and reported will be, in the case of Natura 2000, the features for which the site is designated.*

For monitoring purposes, the special interest of the site may not always be dealt with as a single entity since many sites have a complex mix of Annex I habitats or Annex II species, which provide the justification for the designation of the site. However, the individual features of interest should be identified, monitored and reported on separately. These interest features are described in the notification documents and are the reasons for designating the site. Until SACs are formally designated the interest features are those for which the site was selected.

***Conservation objectives***

*Conservation objectives will be prepared for interest features on all sites. Each objective will define what constitutes favourable condition of each feature by describing broad targets which should be met if the feature is to be judged favourable.*

Each interest feature of a site will have one or more attributes that can be used to help define Favourable Condition. For species these may include population size, structure, habitat requirements and distribution. Attributes of habitats may include area covered, key species, composition and structure and supporting processes.

Broad targets will be identified for those attributes that most economically define Favourable Condition of the interest feature. Because all features are subject to some degree of change, the targets may express how much change we would accept while still considering the feature to be in Favourable Condition. If a feature changes to the extent that it falls outside the thresholds expressed then this acts as a trigger for remedial action or further investigation.

***Monitoring cycle***

*The overall cycle will ensure that the interest features will be monitored at least once within six years. However, for any particular site each interest feature should be monitored within a three-year period.*

Within the overall monitoring cycle, it will be useful to form a view of the overall condition of the features within a proportion of the statutory sites on a more frequent basis. Each interest feature within a site should therefore be monitored, preferably within the same year, but certainly within a three-year period.

***Judging the condition of sites***

The condition of site features will be assigned against the following categories:

**Favourable – maintained.** An interest feature should be recorded as maintained when its conservation objectives were being met at the previous assessment, and are still being met.

**Favourable – recovered.** An interest feature can be recorded as having recovered if it has regained Favourable Condition, having been recorded as unfavourable on the previous assessment.

**Unfavourable – recovering.** An interest feature can be recorded as recovering after damage if it has begun to show, or is continuing to show, a trend towards Favourable Condition.

**Unfavourable – no change.** An interest feature may be retained in a more-or-less steady state by repeated or continuing damage. It is unfavourable but neither declining nor recovering. In rare cases, an interest feature might not be able to regain its original condition following a damaging activity, but a new stable state might be achieved.

**Unfavourable – declining.** Decline is another possible consequence of a damaging activity. In this case, recovery is possible and may occur either spontaneously or if suitable management input is made.

**Partially destroyed.** It is possible to destroy sections or areas of certain features or to destroy parts of sites with no hope of reinstatement because part of the feature itself, or the habitat or processes essential to support it, has been removed or irretrievably altered.

**Destroyed.** The recording of a feature as destroyed will indicate the entire interest feature has been affected to such an extent that there is no hope of recovery, perhaps because its supporting habitat or processes have been removed or irretrievably altered.

These categories will be used to assess and report on the condition of features of interest.

Judgements on the overall condition of a feature will be influenced by a variety of factors and in some cases a feature may be assessed as being in Favourable Condition when only some of the targets set for it have been met.

***Reporting arrangements***

A full report will be produced once every six years. The monitoring framework will generate information on the condition of features across the statutory site network as a whole, or on the status of features within individual sites, and will be used to fulfil reporting requirements under the Habitats Directive (and other International Conventions).

# Context of SAC monitoring within the Scheme of Management

The context of monitoring within the Management Scheme prepared for an individual SAC is illustrated in Figure 1-3. The monitoring of the condition of SACs is co-ordinated by the statutory nature conservation agencies, though other authorities may actually carry out monitoring activities where this is appropriate.

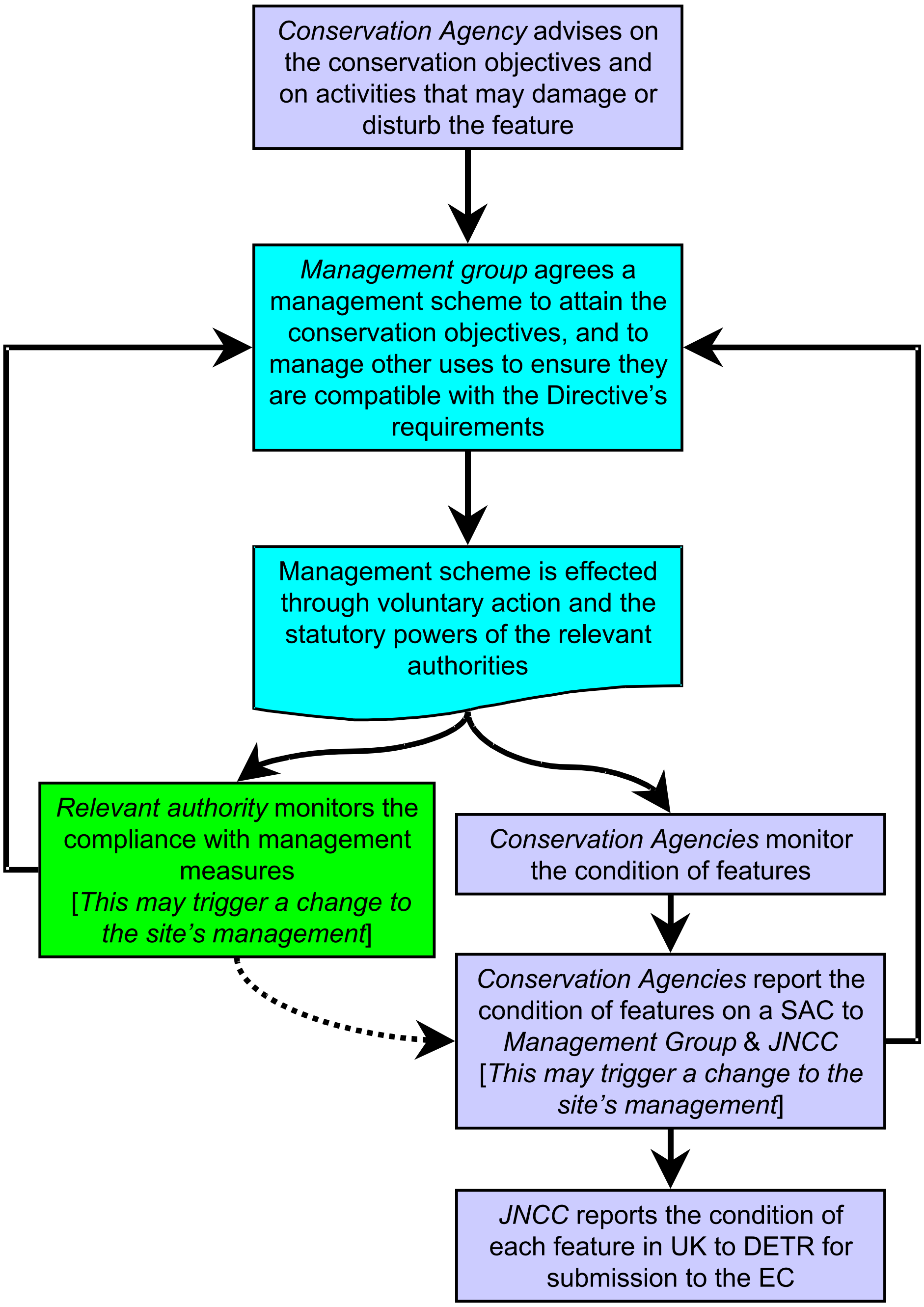



**Figure 1-3** Outline of the process of establishing a management scheme incorporating a monitoring programme on an SAC, showing the organisations responsible for each stage (after Anon 1998[f]). *Conservation Agency*: Countryside Council for Wales, English Nature, Environment and Heritage Service (Northern Ireland), Scottish Natural Heritage. *Relevant Authority*: the specific competent authority[3] which has powers or functions which have, or could have, an impact on the marine environment within or adjacent to a SAC. *Management Group* comprises the relevant authorities and conservation agency members. DETR: Department for the Environment, Transport and the Regions.

3 A competent authority is any minister, government department, public or statutory undertaker, public body or person holding public office that exercises statutory powers.

# Using data from existing monitoring programmes

The United Kingdom has a long history of long-term investigations in the marine environment, both at a local and national scale. Universities and research institutes have generally pursued local programmes such as the benthic investigations by the University of Newcastle's Dove Marine Laboratory off the coast of NE England (Buchanan and Moore 1986).[g] National monitoring programmes have been undertaken by statutory agencies, usually as part of their regulatory functions; for example, the Ministry of Agriculture, Fisheries and Food monitor the physio-chemical parameters of seawater in relation to the disposal of contaminants (MAFF 1994).[h] Existing monitoring programmes are expected to make a significant contribution to SAC monitoring, in terms of providing data at a site where sampling stations fall within the SAC boundary, and provide wider contextual information on the state of the environment. Also, these existing programmes can make an important contribution to the development of SAC monitoring strategies and the interpretation of results. When developing site-based objectives, these long-term programmes can contribute data on the variability of an attribute to help set realistic targets. During a monitoring programme, comparing the results gathered at a local level with any national trends may provide additional insights into an explanation of a local change. It is, therefore, prudent for those establishing SAC monitoring schemes to undertake a comprehensive review to identify any existing long-term programmes that may contribute to future monitoring effort. National monitoring in the marine environment is undertaken *inter alia* under the auspices of the Marine Pollution Management and Monitoring Group (MPMMG)[4] established by the Department of the Environment, Transport and the Regions. One such scheme is the UK National Marine Monitoring Programme.

## The UK National Marine Monitoring Programme

The UK National Marine Monitoring Programme[5] (NMMP) was devised in response to the 1986 House of Lords Select Committee on Marine Science and Technology, who recommended that a common approach to monitoring should be established. This should provide all the information required to comply with the full range of national and international commitments (e.g. under the OSPAR Convention and EC Directives). Overall responsibility for the NMMP rests with the MPMMG. The NMMP is described in the *Green Book*,[i] which includes procedural guidelines for the collection, processing and analysis of samples.[6]

Sampling is undertaken annually by the Environment Agency and Centre for Environment, Fisheries and Aquaculture Science in England and Wales, the Scottish Environment Protection Agency and the Fisheries Research Service in Scotland, and the Department of Agriculture and Rural Development and the Environment and Heritage Service in Northern Ireland. It focuses on stable depositional sediment sites and records data on sediment chemistry, biological communities, bioaccumulation of mercury, cadmium and lead, and their ecological effects. Samples are collected at each of approximately 115 stations around the UK (Figure 1-4): there are 40 estuarine sites, 45 intermediate (coastal) sites and 30 offshore sites. The programme has become biology-led because the prevailing biological assemblage is considered to integrate and reflect the effects of the wide range of physical and chemical conditions occurring at each site. However, a perceived weakness is the difficulty of linking cause and effect. A National Marine Biology Analytical Quality Control Scheme (NMBAQC) was established in 1992 and has undertaken various exercises and workshops involving more than 25 laboratories to establish quality assurance standards for the biological aspects of the NMMP. Similar schemes exist for chemical monitoring (NMCAQC) and ecotoxicological monitoring (NMEAQC).

4 See: **http://www.environment.detr.gov.uk/marine/mpmmg/index.htm**

5 See: **http://www.marlab.ac.uk/NMPR/NMP.htm** for a list of links and **http://www.environment-agency.gov.uk/s-enviro/viewpoints/5change-ltrs/3nmmp/5-3.html** for an explanation.

6 The Green Book is a controlled document distributed by Fisheries Research Service, Marine Laboratory, Aberdeen: contact Dr Gill Rodger (**rodgergk@marlab.ac.uk**). The text may be downloaded from: **http://www.marlab.ac.uk/greenbook/GREEN.htm**

These schemes provide a potential model for establishing quality assurance measures in SAC monitoring.

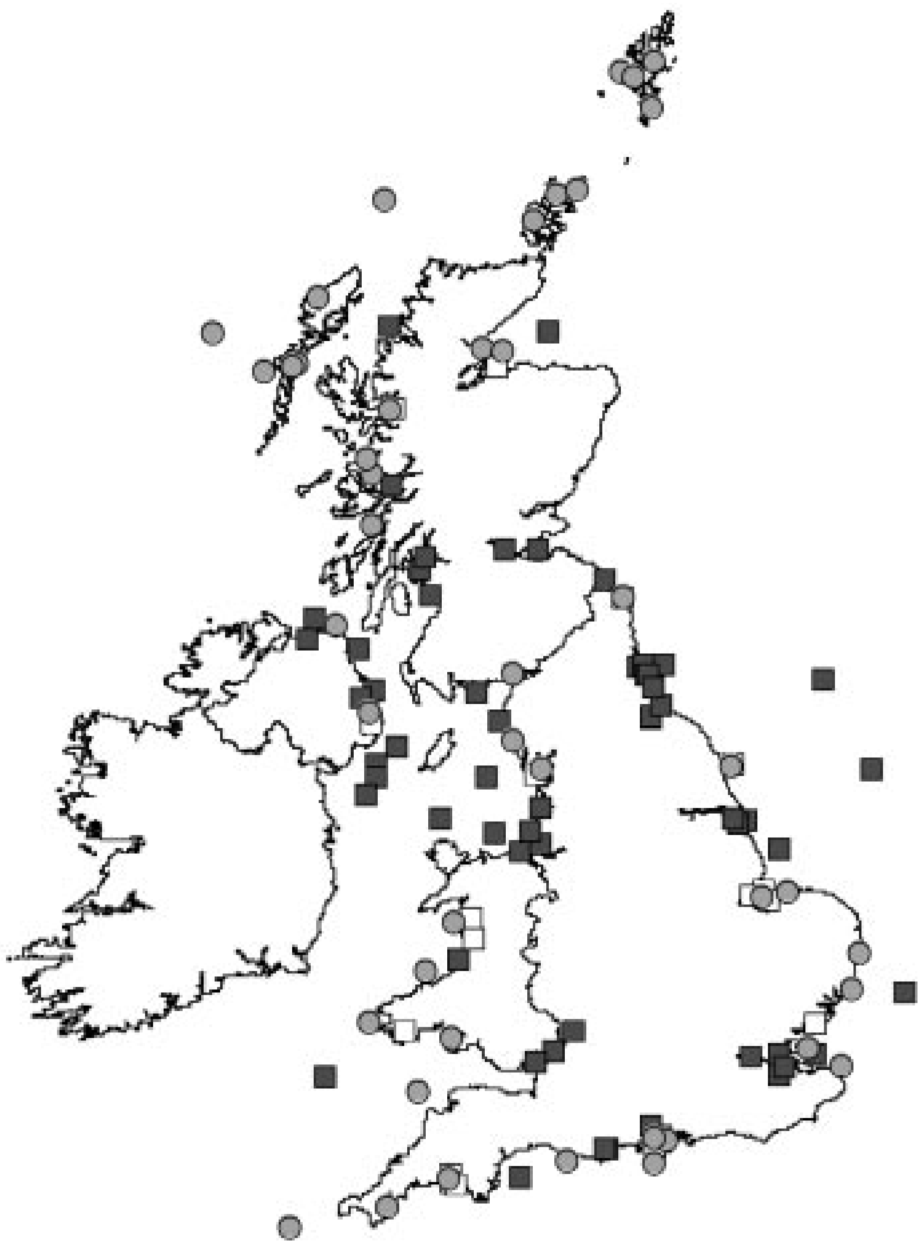


**Figure 1-4** Location of the National Marine Monitoring Programme (NMMP) sample sites in the UK. Key: ● - cSAC (pre moderation[7]); ❑ - NMMP sites within cSACs; ■ - NMMP sites (see **http://www.environment-agency.gov.uk/s-enviro/viewpoints/5change-ltrs/3nmmp/5-3a.html**).

Biological survey in the NMMP is based on macrobenthic sampling using grab and core sampling of subtidal sediment biotopes. Being quantitative counts of individual organisms, the results lend themselves to the use of diversity indices and multivariate analysis to indicate 'health' and extent of change. Analyses of the entire data set provide an indication of any national trends in the 'health' of these biological communities. The first holistic NMMP report on this spatial survey, ***National Monitoring Programme Survey of the Quality of UK Coastal Waters***,[j] was published in November 1998.

7 The original UK list of cSACs was reviewed at the EC Atlantic Biogeographic Region meeting at Kilkee, Ireland in October 1999; the UK is currently revising its list following this meeting.

These national results will provide an important context for assessing the significance of any localised change recorded during a SAC monitoring study.

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d European Commission (2000) *Managing Natura 2000 sites – the provisions of Article 6 of the 'Habitats' Directive 92/43/EEC*. European Commission, Brussels.

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i Marine Pollution Monitoring Management Group (2000) *UK National Marine Monitoring Programme: Green Book.* Marine Pollution Monitoring Management Group, Aberdeen.

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# 2 Establishing monitoring programmes for marine features

Jon Davies

## Introduction

There are four stages in a monitoring programme to assess the condition of the interest features of marine SACs:

(1) establish what to monitor

(2) determine the most appropriate technique to use

(3) organise the deployment of the technique in the field

(4) assess the condition of the feature

The process is summarised in Figure 2-1.

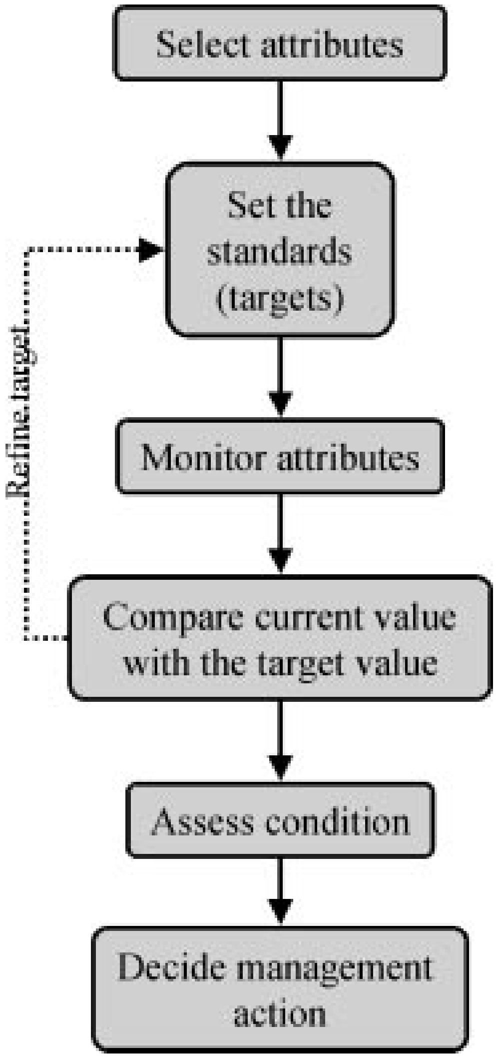


**Figure 2-1** Summary of the SAC monitoring process

## What do I need to measure?

As explained in Section 1 of the Handbook, the aspiration for the features on UK marine SACs is *favourable condition* as defined by the targets set for a range of selected attributes. The targets provide the framework to be tested in a monitoring programme. The process of developing conservation objectives for marine SACs is described in a separate report[a] and will not be repeated here; the process is illustrated in Figure 2-2. The monitoring programme is analogous to a scientific investigation where the hypothesis under test is whether the targets have been achieved; the feature is then considered to be in *favourable condition.*[1] A monitoring programme must therefore make a series of measurements to test the hypothesis that each attribute is in favourable condition and therefore enable a judgement to be made on the status of the whole feature. Common Standards Monitoring[b] requires a discrete data gathering exercise (that may nevertheless require several field visits) during the reporting cycle to evaluate the condition of the feature.

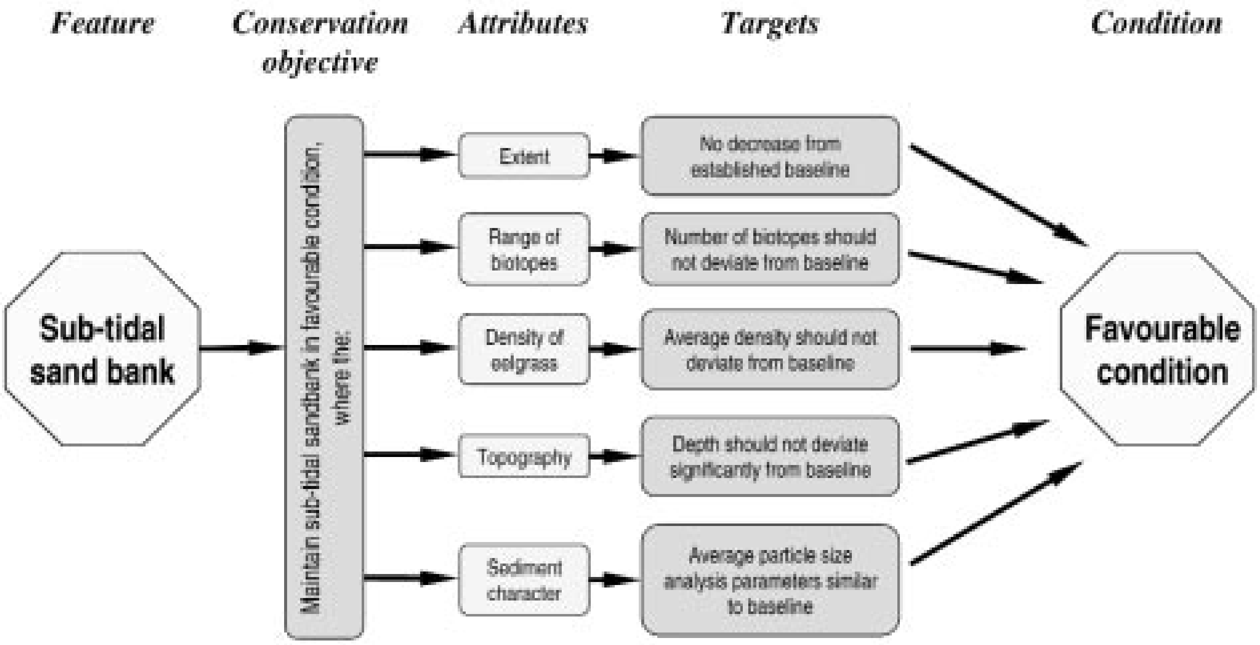


**Figure 2-2** A hypothetical example of a feature and its conservation objective, showing the attributes and targets (adapted from Ecoscope 2000a).[c] This diagram will also apply to a sub-feature (see Section 1).

In practice, information on *targets*[2] is often presented in the form of a table, which shows the relationship between feature, sub-feature, attribute and target, together with any site/attribute specific comments. An example is shown below in Box 2-1.

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1 Brown (2000)[s] provides an excellent and comprehensive explanation of how the Common Standards Model is used for condition monitoring, including a detailed account of methods and appropriate statistical procedures to evaluate a feature's condition.

2 All features are subject to some change and so the targets may express how much change we would accept whilst still considering the feature to be in favourable condition. These will serve as a trigger mechanism so that when changes that fall outside the thresholds expressed are observed or measured some further investigation or remedial action is taken.

**Box 2-1**

An example of part of the Favourable Condition Table[3] for the subtidal sandbank feature in Plymouth Sound cSAC[4]. The first three attributes apply to the whole feature in the SAC; the remaining attributes only apply to the *eelgrass bed community* sub-feature.

| *Feature or Sub-Feature* | *Attribute* | *Measure* | *Target* | *Comments* |
|---|---|---|---|---|
| Feature: Subtidal sandbanks | Extent | Area (ha) of subtidal sandbank communities measured periodically (frequency to be determined). | No decrease in extent from an established baseline, subject to natural change. | Extent of the feature is a reporting requirement of the Habitats Directive. Monitoring will need to take account of the dynamic nature of the feature but reduction in extent may indicate long-term changes in the physical conditions influencing the feature. |
| | Sediment character | Particle size analysis (PSA). Parameters include percentage sand/silt/gravel, mean and median grain size, and sorting coefficient, used to characterise sediment type. Sediment character to be measured during summer, once during reporting cycle. | Average PSA parameters should not deviate significantly from an established baseline, subject to natural change. | Sediment character defined by particle size analysis is key to the structure of the feature, and reflects all of the physical processes acting on it. Particle size composition varies across the feature and can be used to indicate spatial distribution of sediment types thus reflecting the stability of the feature and the processes supporting it. |
| | Topography | Depth distribution of sandbanks from selected sites, measured periodically (frequency to be determined). | Depth should not deviate significantly from an established baseline, subject to natural change. | Depth and distribution of the sandbanks reflects the energy conditions and stability of the sediment, which is key to the structure of the feature. Depth of the feature is a major influence on the distribution of communities throughout. |
| Sub feature: Eelgrass bed communities | Extent | Area (ha) of eelgrass bed communities measured during peak growth period twice during reporting cycle. | No decrease in extent from an established baseline, subject to natural change. | The extent and distribution of seagrass beds provides a long-term integrated measure of environmental conditions. |
| | Water clarity | Average light attenuation measured periodically throughout the reporting cycle (frequency to be determined). | Average light attenuation should not decrease significantly from an established baseline, subject to natural change. | Water clarity is important for maintaining the eelgrass beds, and thus the structure of the feature. Clarity decreases through increases in amounts of suspended organic/inorganic matter. Water clarity is already being measured in the shallow inlets and bays feature, but has to be measured on all eelgrass beds. |
| | Characteristic species-density of *Zostera marina* | Average density, measured during peak growth period twice during reporting cycle. | Average density should not deviate significantly from an established baseline, subject to natural change. | An early indicator of seagrass under stress is a reduction in biomass, i.e. the number and length of leaves. Density is preferred as a surrogate for biomass, being less destructive, based on baseline survey to establish the relationship between density and biomass at a site. |

3 Scottish Natural Heritage use the expression *Site Attribute Table*

4 The full table is published in: Anon (2000) *Plymouth Sound and Estuaries European Marine Site. English Nature's advice given under Regulation 33(2) of the Conservation (Natural Habitats & c.) Regulations 1994.* English Nature, Peterborough.

## What attributes should I select?

As explained in Section 1, the UK considers *favourable condition* to be *favourable conservation status* at the level of the individual SAC. Why is this important and how does it relate to the choice of attributes for monitoring? Part of the answer lies in the requirements of the Habitats Directive, which defines what is meant by *favourable conservation status*, and is set out in Box 2-2.

> **Box 2-2** Definitions of favourable conservation status for Annex I habitats (Article 1e) and Annex II species (Article 1i)
>
> For a natural habitat, *favourable conservation status* occurs when:
>
> - its natural range and area it covers within that range are stable or increasing; and
> - the specific structure and functions, which are necessary for its long-term maintenance, exist and are likely to continue to exist for the foreseeable future; and
> - the conservation status of its typical species is favourable.
>
> For a species, *favourable conservation status* occurs when:
>
> - the population dynamics data on the species concerned indicate that it is maintaining itself on a long-term basis as a viable component of its natural habitats; and
> - the natural range of the species is neither being reduced nor is likely to be reduced for the foreseeable future; and
> - there is, and will probably continue to be, a sufficiently large habitat to maintain its populations on a long-term basis.

Taking habitat features only, these definitions clearly suggest that an assessment of FCS must consider attributes relating to extent, structure, function and typical species. The Joint Nature Conservation Committee commissioned a study[d] to identify generic parameters for defining *favourable condition* of each feature that equate to the broad definitions in Box 2-2. It provided useful guidance on the type of *generic attribute*[5] to consider in relation to the definitions of FCS. Adopting generic attributes will make a valuable contribution to the implementation of the UK's Common Standards for Monitoring programme[b] across the site series. These ideas were explored at the UK Marine SACs Project European workshop held at Gatwick[e] and further developed as guidance by English Nature,[6] who concluded that generic attributes would:

- ensure consistency of condition assessments;
- facilitate aggregation of condition assessments;
- assist in the identification of large scale change, for example across the Natura 2000 series.

Scottish Natural Heritage's handbook on site condition monitoring[f] suggests the habitat attributes should consider the quantity and quality, where quality is further sub-divided into *physical attributes, composition, structure, dynamics* and *function*. For species, the attributes should be *quantity, population dynamics, population structure, genetic diversity* and *habitat requirements*. To provide a structured approach in the present Handbook, the following generic attributes are used: *extent, biotic composition, biological structure* and *physical structure* for Annex I habitats, and *quantity, population dynamics, population structure* and *habitat requirements* for Annex II species. Table 2-1 and Table 2-2 give examples of how these generic attributes have been interpreted and then applied to candidate SACs in UK. In the UK, all reference to biological communities must use the terms in the national *marine*

5 A *generic attribute* is a summary term describing the broad theme from which site-specific attributes may be derived. For example, *biotic composition* (of a feature) is the generic attribute whereas, the *species composition of biotope x* and *the presence of species y* would be site-specific representations.

6 *Selecting attributes for Annex I habitats and Annex II species of marine SACs*, paper by Paul Gilliland, Maritime Team, English Nature; Paul.Gilliland@english-nature.org.uk

*biotope classification*,[g] and for species, all taxonomic nomenclature must follow the *Species Directory*[h] to ensure a consistent approach across the site series.

### *Summary*

A monitoring strategy must measure at least one attribute of the *extent,* the *biotic composition,* the *biological structure* and the *physical structure* of an Annex I habitat feature, and the *quantity*, the *population dynamics*, the *population structure* and the *habitat requirements* of an Annex II species.

**Table 2-1** A selection of attributes for marine Annex I features, together with examples of how they have been applied to a range of candidate SACs in the UK

| *Generic attribute* | *Conceptual attribute* | *Example attribute* | *Example target* | *Example measure* |
|---|---|---|---|---|
| Extent of feature | Area of habitat | Extent | No decrease in extent from an established baseline, subject to natural change | Area (ha) of the reefs, measured periodically |
| Biotic composition | Presence and distribution of biotopes | Range and distribution of rock communities (SLR, MLR, MCR biotopes) | Range and distribution should not deviate significantly from an established baseline, subject to natural change | Variety (range) and distribution (approximate location) of biotopes measured during late summer/early autumn, once during reporting cycle. |
| | Species composition of biotopes | Species composition of characteristic rocky scar biotopes: mussel beds and tideswept boulders with *Fucus ceranoides* | Presence and abundance of composite species should not deviate significantly from the established baseline, subject to natural change | Presence and abundance of characterising species, measured once during reporting cycle. |
| | Diversity of biotopes | Presence and distribution of a selection of biotopes representative of the Pen Llyn reefs | These biotopes should always be present. The suite of representative biotopes for the Pen Llyn reefs is to be determined. The lower limit for this attribute will be the presence of all the representative biotopes | |
| | Population size/density of characteristic species | Characteristic species – the sponges *Haliclona oculata*, *Halichondria panicea* and *Hymeniacidon perleve* | Average abundance should not deviate significantly from an established baseline, subject to natural change | Abundance (% cover) of characteristic sponge species in $m^2$ quadrats along two transects: measured twice during reporting cycle |
| Biological structure | Extent of specific biotopes | Extent of brittlestar beds | No decrease in extent from the established baseline (reference), subject to natural change | Area (ha) measured at same time during the year, once during the reporting cycle |
| | Structural integrity of selected biotopes | Structural integrity of the horse mussel *(Modiolus modiolus)* biogenic reef | Target and limits for this attribute to be determined: these will depend on the specific aspects of structural integrity chosen for each selected biotope | Three aspects of structural integrity have been identified for the *Modiolus modiolus* reef: 1) continuity to include the area, the periphery ratio of the reef and/or the incidence of scaring; 2) density/area covered by live *M. modiolus*; and 3) age structure of the *M. modiolus* |
| | Spatial pattern of biotopes | Distribution of major communities within the estuaries | The target value for the broadscale distribution of the sandy and muddy biotopes may be represented in the form of a map of the biotope distribution or as indicated from a broadscale sampling grid or transect series | Proportions of the major communities present in described 'zones' of each estuary may provide an appropriate measure for target/limit setting |

| *Generic attribute* | *Conceptual attribute* | *Example attribute* | *Example target* | *Example measure* |
| --- | --- | --- | --- | --- |
| Physical structure | Topography | Bathymetry | Depth distribution should not deviate significantly from an established baseline, subject to natural change | Depth distribution of sandbanks from selected sites, measured periodically |
| | Morphological equilibrium (estuaries only) | Morphological equilibrium | No significant deviation from the intra- and inter-estuarine TP/CS relationship, subject to natural change | Tidal Prism/Cross-section ratio (TP/CS ratio), measured periodically |
| | Sediment type and sediment structure | Sediment character – grain size | Average sediment parameters should not deviate significantly from an established baseline, subject to natural change | Particle size analysis: parameters include % sand/silt/gravel, mean and median grain size and sorting co-efficient, used to characterise sediment type, measured periodically |
| | Water quality (temperature, salinity, nutrient status) | Water density (salinity and temperature) | Average density should not deviate significantly from an established baseline, subject to natural change | Average temperature and salinity measured periodically in the subtidal, throughout the reporting cycle |
| | | Nutrient status | No significant deviation from the established baseline, subject to natural change | Average phytoplankton concentration in summer, measured annually |
| | Water clarity | Water clarity | Average light attenuation should not deviate significantly from an established baseline, subject to natural change | Average light attenuation measured periodically throughout the reporting cycle |

**Table 2-2** A selection of attributes for marine Annex II species, together with examples of how they have been applied to a range of candidate SACs in the UK. Note, there are no examples of the generic attribute 'population structure' mentioned in the previous section.

| *Generic attribute* | *Conceptual attribute* | *Example attribute* | *Example target* | *Example measure* |
|---|---|---|---|---|
| Quantity | Population size | Number of individuals | No significant reduction in numbers from an established baseline, subject to natural change | Count number of seals using aerial photographic techniques |
| Population dynamics | Recruitment | Numbers of young | No significant reduction in numbers of young produced from an established baseline, subject to natural change | Count pups produced on annual basis or on average per reporting cycle |
| | Population viability[7] | Adult numbers | Maintain adult population | Count adults and sex ratios to gain an average per reporting cycle |
| | | Adult sex ratios | Maintain adult sex ratios | |
| | Genetic diversity | Genetic diversity | Maintain genetic diversity of breeding population | Periodic sampling of genetic material and use of DNA to measure genetic variability[8] |
| Habitat requirements | Area for breeding | Extent of rocky and coarse sediment shores | No decrease in extent from an established baseline, subject to natural change | Total area (ha), measured once during the reporting cycle |
| | Availability of haulout sites | Disturbance | No increase in activities likely to cause disturbance | |
| | Area for feeding | Availability of food (fish populations) | Ensure food availability is not a limiting factor on the population viability of dolphins | Monitor commercial fish catches within and adjacent to SAC |
| | Environmental processes | Water quality: levels of nutrients, pollutants and pathogens | Attain and maintain a high water quality standard for the SAC | Measure known nutrients, pollutants and pathogens within the SAC |

7 A *viable population* is considered a secure and enduring population that is able to sustain itself in the long term. This is dictated by minimum and maximum breeding age, adult and young survival rate, and annual birth rate – annotated from Annex 1 of Scottish Natural Heritage's Draft Regulation 33(2) advice for the Moray Firth marine candidate SAC bottlenose dolphin population.

8 See http://smub.st-and.ac.uk/ch2_3.html

## What is the target condition?

Section 2.2 explained how a monitoring study compares the current situation to an established standard to determine the condition of a feature. This standard is expressed as the *target condition*[9] in the *conservation objective* and therefore it is essential that the target be clearly defined. In practice, identifying the target condition has proved very difficult and only broad generic values have been specified for many attributes. It is important to remember that establishing that one condition (*favourable condition*) is preferable to all others will ultimately always be a subjective process and as such requires a value judgement (or 'expert opinion'). In other words, defining a condition we *prefer* to have cannot be a decision based solely on science.[a]

Sites were selected as candidate SACs using all available information at that time, and for marine SACs, the features were assumed to be in favourable condition unless information became available to the contrary. The criteria used for selection are different to many of the attributes now used to define and hence monitor favourable condition. However, previous data might not be appropriate to establish a definitive target value. Moreover, many of the data available at the time of designation were derived from a single field survey and, therefore, do not provide any indication of variability over time. For instance, a mapping exercise designed to give an indicative distribution of the biological communities of a site may not have recorded data at sufficient scale to establish the boundary of particular habitats sufficiently accurately for any future assessment of a change in extent to be made.

For some attributes, it may be possible to use data from existing long-term studies (such as the National Marine Monitoring Programme) to establish a target condition. Such data may require re-analysis and interpretation because the objective of the original monitoring project is unlikely to match those of condition monitoring.

For some attributes, however, such data may not exist and establishing a target condition will require a dedicated data collection programme that, where possible, extends over a sufficient time period to indicate any temporal variability.[10] Generally, the target condition will be the current condition at the time of selection (or at the time of the baseline monitoring if different), until sufficient data are available to provide a more refined target that takes account of inherent variability – natural or anthropogenic. Where possible, it would be prudent to establish a *surveillance* programme to measure the temporal variability of an attribute. These surveillance data would help refine the target condition in terms of decreasing its confidence limits (Figure 2-3).

9 The target condition will, in general, represent the minimum threshold value for the attribute, although in some instances, it may also be necessary to set a maximum value.

10 This issue is more fully explained by Cole-King *et al.* (In prep).[a]

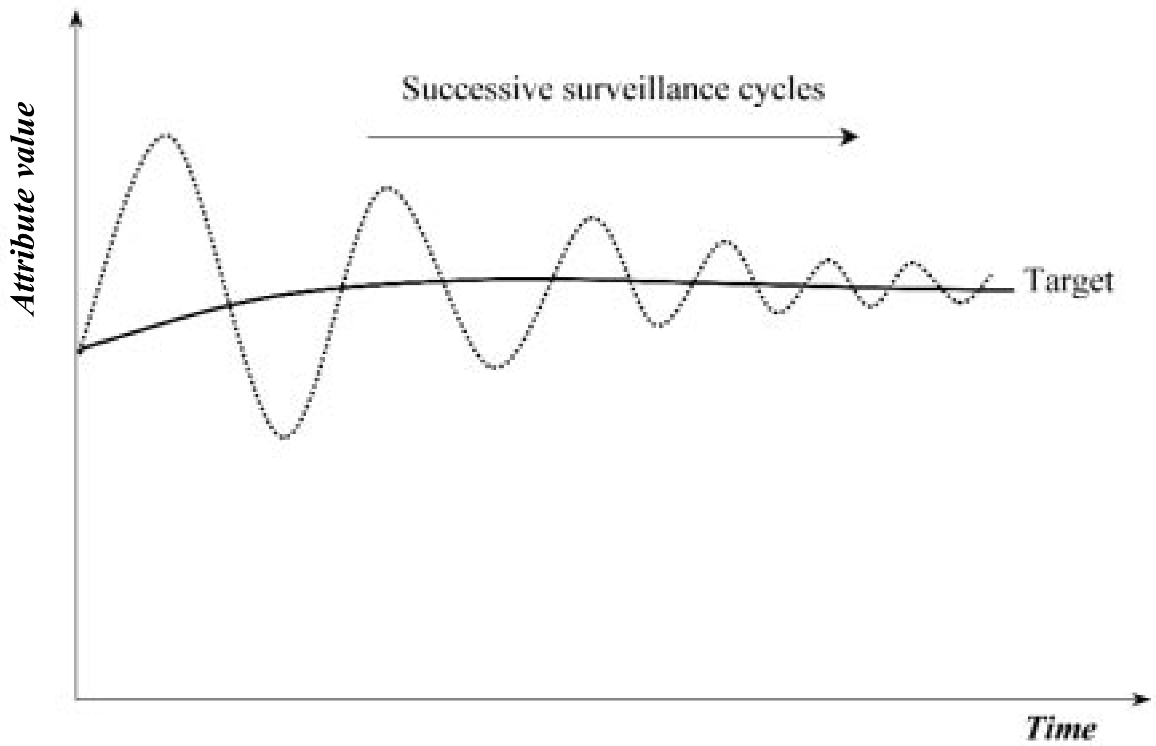



**Figure 2-3** Hypothetical example of how an attribute's target value may be refined over time. If the value fluctuates, successive surveillance (or possibly monitoring) cycles enable a more accurate determination of the confidence limits (dashed line) and hence the target value (solid line). Clearly, it is possible that the intial target value may actually be located at the upper confidence limit and subsequent data collection would result in a substantial decrease in its final value.

*Recommendation*
To set a target condition:

- Re-analyse data from an existing monitoring programme if possible; or
- Commission a data gathering exercise; or
- Use a value judgement based on the situation at the time of selection (or other contemporary baseline); and then
- Establish a *surveillance* programme during the first reporting period to evaluate whether the *proposed target condition* equates to the feature's desired condition.

## What is the most appropriate method?

The ability of a monitoring programme to meet its aims successfully hinges on the selection of an appropriate method, together with its deployment strategy, to measure each attribute. It is vital that the technique used for measurement is sufficiently sensitive (i.e. accurate and precise) to record information to compare with the target value. It is prudent to ask a series of questions to review critically the capability of different techniques prior to establishing the monitoring programme as set out in Figure 2-4. In reality, the available budget is likely to be the predominant factor in the decision process. Nevertheless, budget should not be the final arbiter because a technique should only be used if it is sufficiently sensitive to detect any deviation from the *target value*. For further information on how to use the decision tree set out in Figure 2-4, see Ecoscope (2000a).[c]

An important issue in the selection of an appropriate technique is whether that same method (and strategy of deployment) should be used for the entire duration of the monitoring programme. It is likely that technological developments over time will expand the range of techniques available to measure an attribute, potentially with greater precision and at lower cost. For strict *condition monitoring* activities, there is no requirement to adhere to a single method over time if each different method can measure the attribute with sufficient precision and accuracy.

For *surveillance*, or where there is an element of surveillance in a monitoring programme,[11] it is necessary to adhere to a single method (and method of deployment) to ensure the data are comparable between recording events. If prevailing circumstances dictate that change of method is necessary, a comprehensive calibration exercise will be required to ensure data can be corrected to maintain their comparability. For example, if a satellite remote sensing system will be decommissioned during a monitoring programme, it will be necessary to record contemporary images from the old and a new sensor for calibration purposes.

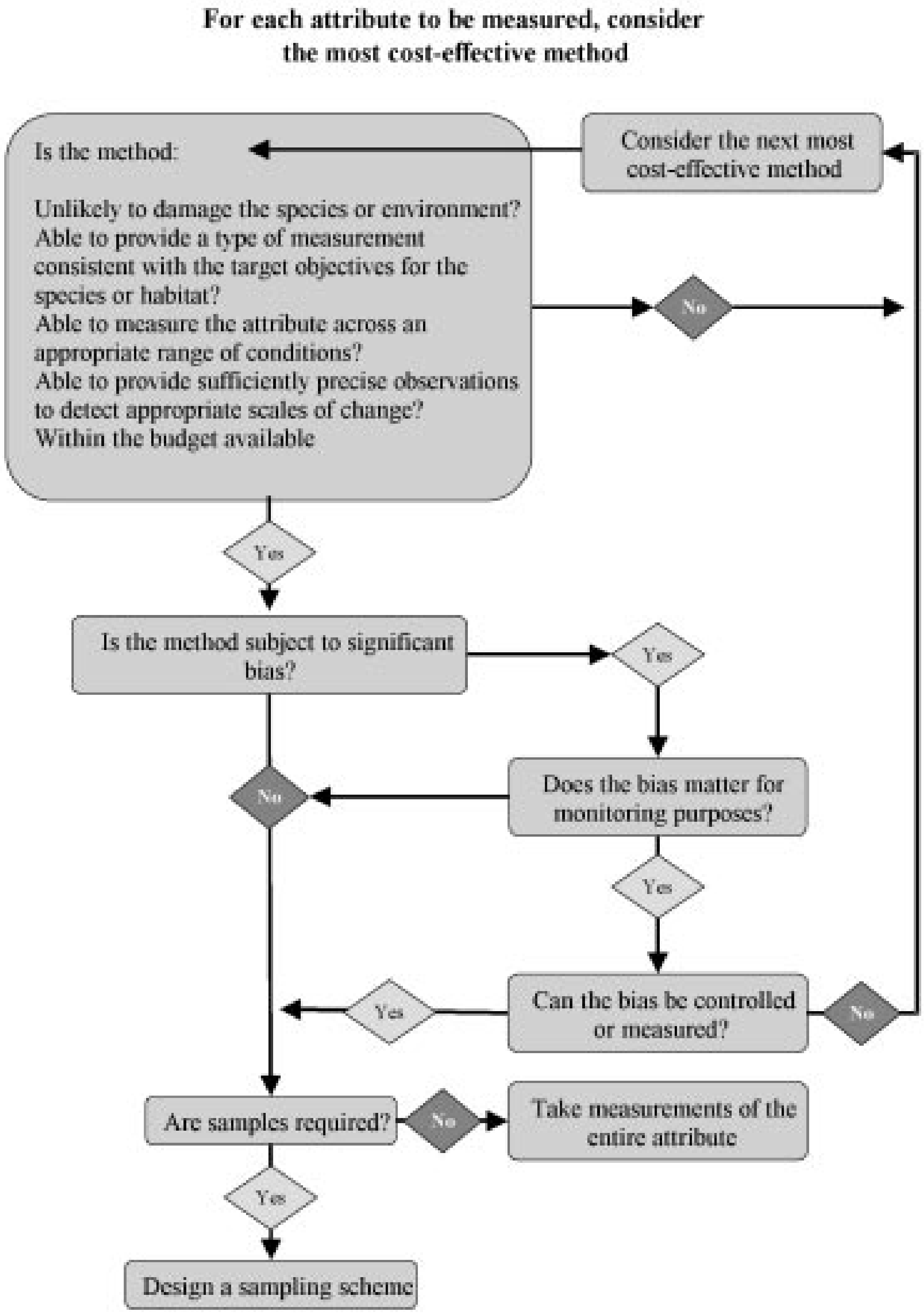



**Figure 2-4** Suggested decision tree for the selection of methods for monitoring each attribute (from Ecoscope 2000a)

11 Generally for those attributes where additional data are required to refine target values during the early monitoring cycles.

A further consideration when selecting a technique is the need to conform to the requirements of common standards monitoring to contribute to the assessment of favourable conservation status (FCS). Shaw and Wind (1997)[i] considered there are two aspects to the form of the data to facilitate this assessment:

– the data are capable of being added together, or of being aggregated at a national level; and

– the data are recorded with comparable levels of precision and accuracy, and within a similar time-frame.

While a uniform approach to assigning a single technique to each attribute across the entire site series would standardise data collection, this approach may not be practicable for a range of operational and economic reasons. Shaw and Wind (1997) concluded that a degree of flexibility in the selection of methods can be retained provided that the techniques use the same form of measurement, have comparable levels of precision and accuracy, and are applied within a similar time-frame.

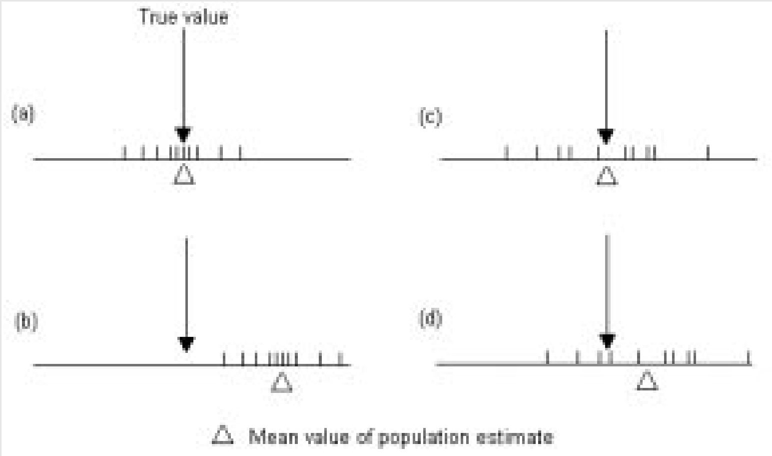
Sections 3 and 4 of the present manual provide advice on a limited range of appropriate techniques for each generic attribute for each feature, together with procedural guidelines on their field deployment (Section 6). It is vital to the success of the Common Standards for Monitoring programme that SAC monitoring programmes follow these guidelines in a quality-assured manner. Any modification to a standard technique deemed necessary to meet local operating conditions must be fully approved prior to its field deployment.[12]

## Precision and Accuracy

A critical consideration in the selection and deployment of a monitoring technique is its reliability in reflecting the actual condition of the attribute it is monitoring. Two factors are crucial in this and these are *precision* and *accuracy.* It is important that these factors are fully understood when selecting a technique and its deployment strategy (Box 2-3). Precision is a measure of the closeness of multiple sample measurements to each other or, in other words, how tightly grouped they are around a mean point. Accuracy determines how close a sample measurement is to the actual (true) value.

12 In the UK, approval should be given by the appropriate Country Agency specialist in consultation with JNCC.

**Box 2-3** Precision and Accuracy (taken from Ecoscope 2000a[c])




Precision and accuracy vary independently so can be either high or low in a particular study. The results for 10 different samples are shown in relation to the unknown true density.

(a) *Precise and accurate*. The estimates are closely spaced about the true value. This is the ideal situation, but is difficult to achieve.

(b) *Precise and inaccurate*. The estimates are closely spaced but their mean deviates from the true value. Since the true value is unknown to the observer, this result cannot readily be recognised as different from that in (a). A bias makes the estimates inaccurate (i.e. wide of the true mean).

(c) *Imprecise and accurate*. The estimates are spread rather widely about the true value.

(d) *Imprecise and inaccurate*. The estimates are spread widely and their average deviates from the true value. Again, since the true value is unknown to the observer, this result cannot readily be distinguished from that in (c).

Source: adapted from Bibby, Burgess and Hill (1992) *Bird Census Techniques*, Academic Press, London

The magnitude of change that may be detected by any technique is directly related to its precision. Therefore, careful consideration of the degree of change permitted for an attribute's target value is necessary prior to specifying the level of precision that any technique must achieve. In general, the level of sampling effort usually determines the level of precision, where typically for a given monitoring technique, the accuracy increases in proportion to the square root of the sample size; for example, to double the accuracy obtained from 10 samples requires a further 30 samples. Sampling effort is discussed below.

# How do I ensure my monitoring programme will measure any change accurately?

After identifying the most appropriate technique, the next step is the design of its field deployment to ensure the results can accurately and precisely measure the attribute. It may be possible to measure an attribute for the entire feature (or sub-feature) – for example the extent of a mudflat using airborne remote sensing. For most attributes, this will be impossible: only a proportion of the feature can be measured, and the results must be extrapolated to represent the entire feature. This is termed *sampling* and the procedure for organising the field deployment of samples is known as the *sampling strategy*. Arguably, the most important issue in relation to a sampling strategy is ensuring that the samples recorded are representative of the entire feature, and in particular, that the results account for the inherent variability within a feature. Such variability is strongly influenced by both *natural change* and *spatial pattern*, and must be considered when planning a sampling strategy.

## Natural change

Traditional theories of community ecology considered systems to be in equilibrium. These theories have been challenged by some ecological studies that demonstrated a high frequency of natural disturbance, and noted that environmental change can occur more rapidly than the system can return to an equilibrium.[j] Current ecological thinking suggests that marine ecosystems are constantly changing and the sampling strategy behind any monitoring programme must be sufficiently robust to take account of both the magnitude of change and the processes behind such change. Studies undertaken in the Loch Maddy cSAC and Plymouth Sound cSAC by the UK Marine SACs project clearly demonstrated a high degree of change in the species composition of an individual biotope; nevertheless, the actual biotope present at the site remained the same. For Plymouth, there were large changes in the most common species – often greater than x2 – and the total species list changed by more than 40% between the 1998 and 1999 samples at all three study sites.[k] For Loch Maddy, there were significant changes in the composition of the biotopes investigated, although some of these changes were attributed to seasonal effects due to the timing of the sampling. There were however, significant changes in the species assemblage associated with maerl beds in shallow rapids that were not attributed to seasonal change.[l] In both studies, many of the component species within the biotopes studied had an annual life cycle and therefore a large turnover of species would be expected. Such inherent changes have clear implications for the choice of attribute in a monitoring strategy. Where an attribute refers to the composition of a biotope, the biotope definition must be sufficiently robust to encompass this natural change at a local level. Unfortunately, there are few examples where the level of species turnover is sufficiently well understood to set realistic targets, and local *surveillance* programmes will be necessary to provide such information.

Often a surveillance or monitoring programme will fix the timing of data collection in an attempt to minimise seasonal effects. Such regular sampling may be inappropriate because it may not provide any estimate of temporal variance, which in turn may lead to the over- or under-estimation of an impact/effect.[m] The timing of sample collection should be carefully chosen in relation to the known biology of the organism or community, natural rates of change and any temporal variation. Where there is little information about natural rates of change a series of nested time-scales is recommended during the early phase of a monitoring/surveillance programme to quantify the variance associated with temporal effects.[n] In other words, it is necessary to test the assumption that a change from one season to the next is actually a seasonal effect by sampling regularly within a season and between seasons.

## Spatial pattern

Marine communities often have a patchy distribution which, combined with natural fluctuations, results in considerable inherent variability in marine ecosystems. If the design of a sampling programme does not account for a significant proportion of this natural variability, it will be unlikely to provide any meaningful results for assessing the status of a feature.[o] In particular, an area may support a range of biotopes although the actual biotope(s) present will depend on the timing of recent disturbance events. For example, the cycle between fucoid algae, mussel or barnacle dominated shores is well documented. It will be necessary to exercise careful judgement in the choice of attribute for a monitoring strategy where the actual biotope present is related to stochastic events. A local *surveillance* programme may be necessary prior to establishing targets for an attribute.

Spatial patterns occur at scales ranging from centimetres – for instance, the precise location of individuals or colonies – to thousands of kilometres – biogeographical patterns in species distribution. Inappropriate choice of scale will have a profound influence on the accuracy of a sampling programme to fully address the hypothesis. For example, data recorded from a kelp forest at a single location will not provide sufficient information to consider any change in the status of the kelp forest in the whole SAC. Similarly, data from the kelp forest throughout an SAC will not enable an assessment of the status of all kelp forests in the whole SAC series. Furthermore, monitoring trials on a horse mussel reef as part of the UK Marine SACs project found that spatial variation in community composition could be halved (with a corresponding increase in monitoring sensitivity) if sampling was stratified to the wave 'crests' of the reef.[p]

A sampling strategy must account for the type of attribute being measured, the method and its deployment, the inherent variability of the attribute (if known), the required accuracy and precision of measurement, and the time/budget available for sampling. It is beyond the scope of the present handbook to present a detailed review of the issues associated with the design of a sampling strategy; there are a number of comprehensive texts on this topic.[13]

Inherent variability in marine ecosystems requires more than one sample to explain any change. Additional samples are known as replicates, and the use of replicate samples is required across all levels of sampling design. There is a positive correlation between the degree of variability of an attribute and the number of replicate samples required for enumerating an accurate estimate of its true value. The location of each replicate must relate to the main question – if you are considering an individual sandbank, the replicates must be located on that sandbank, not scattered across sandbanks throughout the SAC. If you are monitoring sandbanks in the SAC, you must sample multiple sandbanks throughout the site. Replication, and in particular the concept of pseudoreplication, and its associated problems in sampling programmes were comprehensively described by Hurlbert (1984).[q]

For any SAC sampling programme to draw conclusions about the whole feature, its principal requirements are that:

- Samples must be representative of the whole feature; and
- More than one sampling unit per feature (or sub-feature) is required (replication).

Figure 2-5 sets out a series of questions to consider when designing a sampling strategy; the main issues for each topic are described by Ecoscope (2000a).[c]

13 See: Brown (2000)[s]; Krebs, C J (1999) *Ecological Methodology*, Addison Wesley Longman, Menlo Park, California; Sutherland, W J (1996) *Ecological Census Techniques*, Cambridge University Press, Cambridge; Underwood, A J (1997) *Experiments in Ecology*, Cambridge University Press, Cambridge.

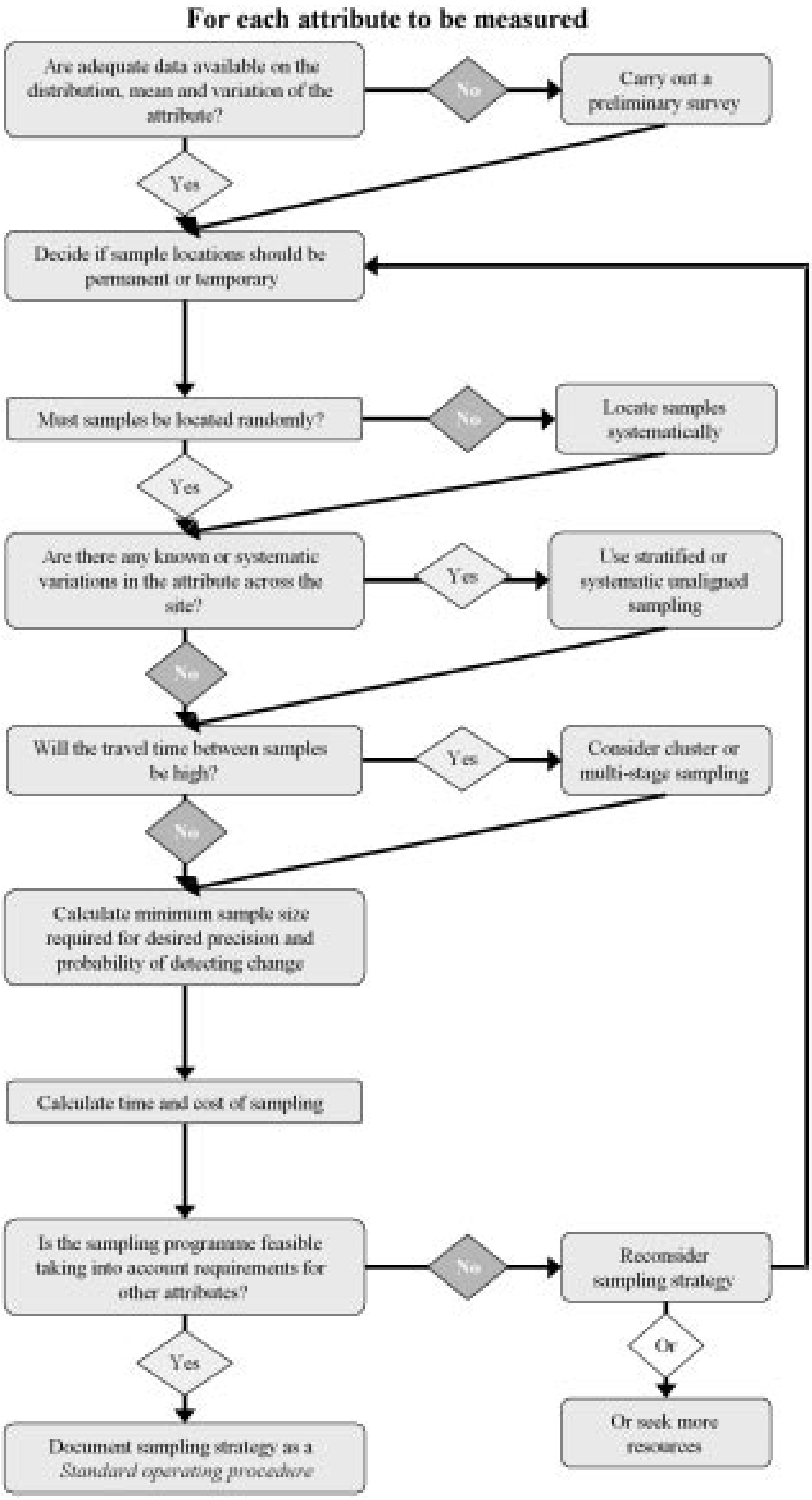



**Figure 2-5** Issues to consider when designing a sampling strategy (after Ecoscope 2000a)

## Permanent sample stations

Permanent sample stations can provide an effective approach to reducing random variability when temporal changes are to be monitored. Permanent plots provide a very precise measure of change and are useful for monitoring rare sessile species that are only known from specific locations. There are, however, a number of significant disadvantages to using permanent plots: they may be unrepresentative of the feature as a whole; repeated monitoring may damage the site; and there are financial overheads associated with marking and maintenance.

Ecoscope (2000a) concluded that permanent plots should only be used if:

- Minimising sampling variation is of prime importance (e.g. where subtle changes must be detected at sites which are highly heterogeneous) or information is needed on turnover and species dynamics.
- There is sufficient fieldwork time available for marking and relocating permanent sampling locations, and this time cannot be more efficiently used for collecting data from temporary sample locations.
- Sample locations are representative of the site and sufficient samples are taken to minimise the risk of chance events reducing their representativeness.
- Provision is made for the unexpected loss of sample locations.
- The feature and the surrounding environment will not be significantly altered or damaged by repeat field visits.

## Locating samples – random or not?

If permanent stations are not appropriate, the method used to establish the precise location of each sample on the ground does itself influence the reliability of determining change and, understandably, has been extensively investigated.[r] There are four commonly used strategies for locating samples (Figure 2-6 and Table 2-3): *judgement* or *selective* location by the field operative; *random*; *stratified random* based on an *a priori* sub-division of the study area; and *systematic sampling* based on a user-defined grid. These strategies are fully explained in many texts.[r]

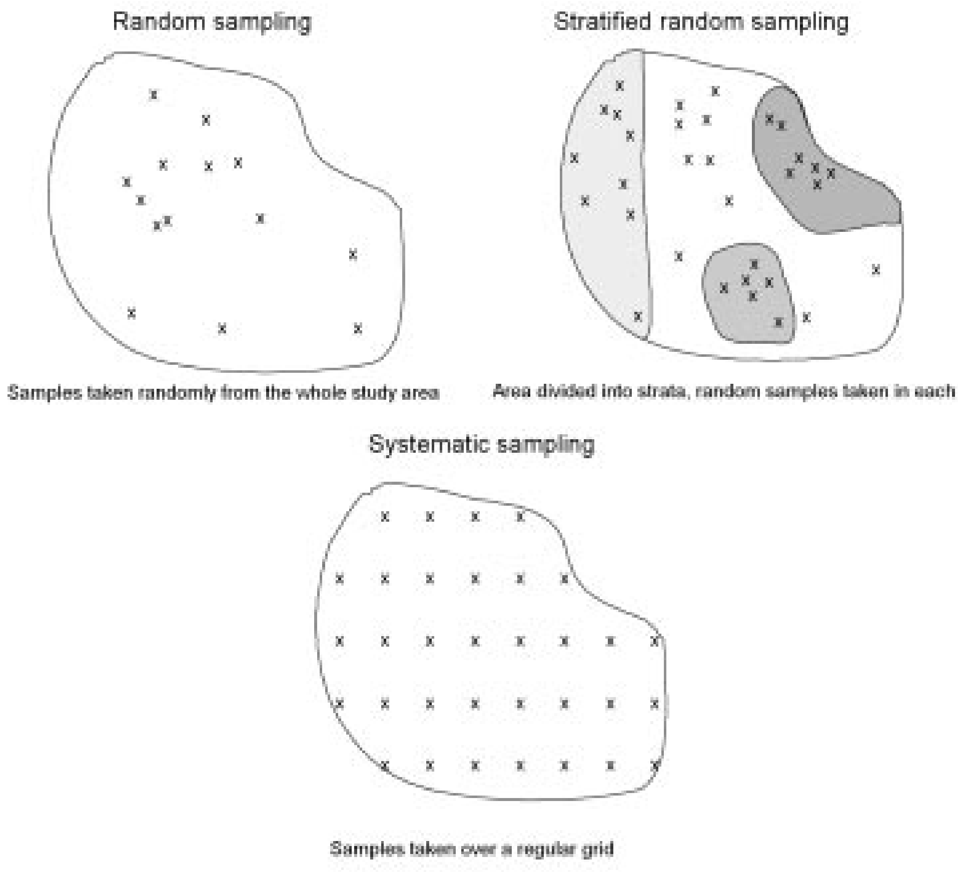



**Figure 2-6** Three common types of sampling strategy (after Ecoscope 2000a). Note: *judgement or selective sampling is not shown.*

**Table 2-3** Summary of the advantages and disadvantages of different types of sample selection (from Ecoscope 2000a)

| *Sampling location* | *Advantages* | *Disadvantages* | *Comment* |
|---|---|---|---|
| Judgement | Can be quick and simple if knowledge of habitat/species is sufficient.<br><br>Samples can be deliberately taken around e.g. a rare species or feature of particular importance. Useful when the locations of a rare habitat or species are known.<br><br>Samples can be placed in areas subjectively considered homogeneous or representative. | Extrapolation of results to the whole feature or site is not valid without strong justification. Comprehensive knowledge of the site is required.<br><br>Statistical analysis is not valid and errors are unknown. | Efficient but dependent on quality of prior knowledge.<br><br>Should not be used if there are any concerns over the quality/reliability of this prior knowledge |
| Random | Requires minimum knowledge of a population in advance.<br><br>Free of possible classification errors.<br><br>Easy to analyse data and compute errors. | Locating sample observations can be time-consuming.<br><br>Often larger errors for a given sample size than with systematic sampling.<br><br>May not monitor what is required | Only useful when a feature is spatially homogeneous throughout the SAC<br><br>Any restrictions on access will compromise the process |
| Stratified random | Ensures that all the main habitat types present on a site will be sampled (if defined as strata).<br><br>Characteristics of each stratum can be measured and comparisons between them can be made.<br><br>Greater precision is obtained for each stratum and for overall mean estimates if strata are homogeneous. | If strata have not been identified prior to monitoring, preparation can be time-consuming.<br><br>The most appropriate stratification for a site at one time may have changed when repeat surveys are carried out. Monitoring efficiency may therefore also change. | The optimum approach for most SAC monitoring requiring a degree of randomness |
| Systematic or grid | If the population or attribute is ordered with respect to some pertinent variable, a stratification effect reduces variability compared with random sampling.<br><br>Provides an efficient means of mapping distribution and calculating abundance at the same time. | If sampling interval is correlated with a periodic feature in the habitat, bias may be introduced.<br>Strictly speaking, statistical tests are not valid, though in practice, conclusions are unlikely to be affected. | This has the advantage of providing an estimate of extent and a random sub-sample can be taken for other analyses |

Brown (2000)[s] presents a detailed discussion of the use of these different sampling approaches in the context of condition monitoring of protected sites. He concludes that the 'selective' (= *judgement*) approach is likely to be the most efficient because it is based on prior knowledge, but warns that '... we [Brown] can only really recommend this approach in the hands of the expert'. It must be emphasised that the quality of the results is dependent on the reliability of this prior knowledge. He also concluded that the 'classical' (= *random*) approach is '... rarely suitable for monitoring but very suitable for surveillance and environmental effects monitoring'.

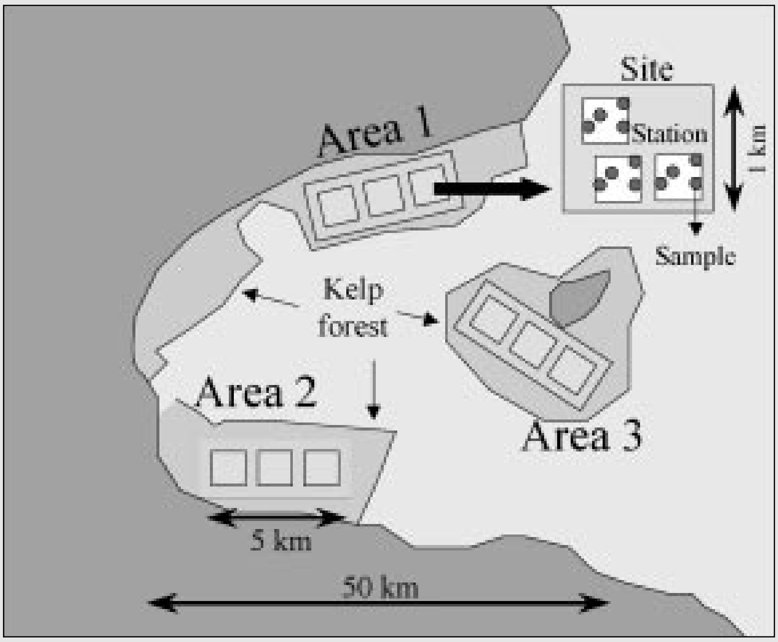
**Recommendation.** Monitoring Annex I features of a SAC should use a stratified random sampling strategy for locating sampling stations, except where an estimation of spatial pattern/extent is required when a systematic/grid sampling strategy should be adopted.

At the time of publication, it is not possible to provide similar advice for marine Annex II species and further research is required to determine the most appropriate sampling regime.[14]

## Nested sampling

It is of course vital that sampling programmes are designed to provide clear and unambiguous data for each attribute to assess the condition of the feature against its target values. In reality, there are unlikely to be sufficient funds available for a plethora of investigations considering a single attribute of a feature. Careful design of a sampling strategy can provide data to address a number of attributes at the same time. Specifically, with a nested (hierarchical) sampling design that has successively finer spatial (or temporal) scales, data can be sequentially aggregated at broader and broader scales to answer questions at each scale (see Box 2-4 for an example).

**Box 2-4** Nested (hierarchical) sampling design (modified from Oxley 1996[t])

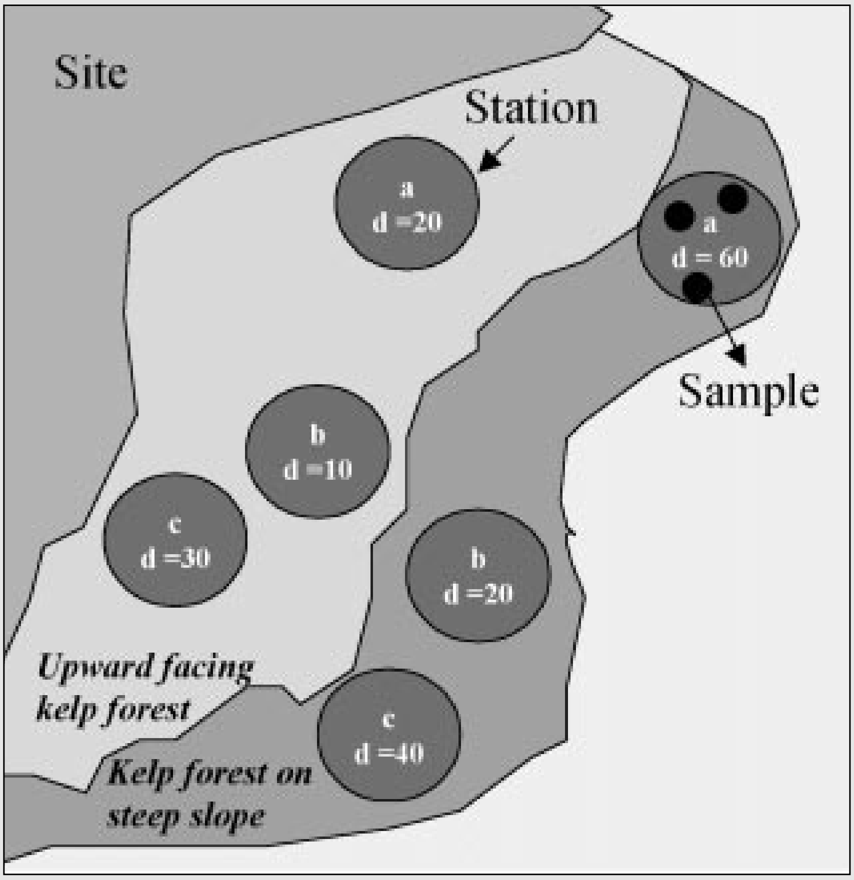



An example of a nested sampling design showing three areas at the whole SAC level. Sites are allocated in each area, stations are located randomly within the site, and samples are randomly positioned in each station. This sampling design can evaluate the difference in kelp cover between three areas, within each area, and between the stations at each site.

Box 2-5 illustrates a situation where there are two main zones present at a site, with three replicate stations in each zone. Extending the sample design in this manner can provide information on the relative density of kelp (d) between the two zones. The importance of replication is highlighted through four scenarios taking different combinations of stations from the two zones. Selecting a single station from each zone and taking replicate samples at each station would give three possible measures of kelp density leading to contradictory conclusions. It could show differences in the density between the zones, but this could be attributable to inter-station differences rather than an actual difference between zones. Replicating the number of stations gives a more reliable measure of kelp density but at the expense of increased sampling effort. Generally the greater the number of stations sampled in each zone, the higher the confidence in the conclusion.

14 For example, *Distance sampling* techniques may be appropriate, which are the focus of much current research (see: **http://www.ruwpa.st-and.ac.uk/distance/**)

**Box 2-5** Schematic representation of a study site with two zones. The density of kelp was estimated by taking samples at each station (identified by letters). Scenario 4 is the most reliable estimate of the density of kelp in this area. (Modified from Oxley 1996[t])




| *Scenario* | *Comparison* | | *Conclusion* |
|---|---|---|---|
| | Upward facing rock | Steep rock slope | |
| 1 | a (d = 20) | b (d = 20) | *No difference in density between zones* |
| 2 | b (d = 10) | a (d = 60) | *Density higher on slope* |
| 3 | c (d = 30) | b (d = 20) | *Density higher on upward facing surface* |
| 4 (actual) | a, b, c (mean = 20) | a, b, c (mean = 40) | *Density higher on sloping rock* |

In reality, however, funds will be finite and the number of samples recorded will be restricted to the absolute minimum necessary to provide an acceptable level of confidence in the conclusion. Alternatively, it may be possible to select a less costly sampling technique if any are available, although this may be at the expense of precision/accuracy.

## How many samples do I need to take?

There is no simple or straightforward answer to this question. Perhaps the most important issue here pertains to the accuracy of the results and the confidence with which someone can make a decision on the condition of the feature and/or any management action on the site. If there was no spatial or temporal variability in the attribute under investigation, and the measurement technique itself was free from error, it would be possible to make a single measurement to assess the condition of the attribute. Once any variability is introduced into the system, there is a clear risk that a single measurement may not be correct. To reduce the *risk* of making an inaccurate measurement, we make multiple measurements or samples. For a monitoring study, selecting the actual number of samples to record is an exercise in *risk management*. In general, the less risk that we are prepared to accept the greater the number of samples required to avoid reaching an inaccurate conclusion. There are two aspects to determining the number of samples to collect:

- Sampling a sufficient area of seabed to make a representative measurement of an attribute at a station. Guidance is provided with the relevant procedural guideline (see Section 6).
- Sampling sufficient stations to make a representative measurement of an attribute for the feature in an SAC (see below).

Marine sampling, and subtidal sampling in particular, is an expensive exercise due to the very nature of the environment. Where funds are restricted, a rigorous experimental design is essential to ensure the sampling programme will answer the main question with sufficient confidence to justify any remedial management action, since such actions are likely to be costly. Arguably the most important decision in any monitoring programme is setting the acceptable level of confidence because, ultimately, this will dictate the number of samples required and hence set the total cost of the study.

The greatest care has to be taken in accepting established techniques. For instance, diversity indices or the results of multivariate analysis are useful for nature conservation management only if they are interpreted properly. Even if the score or plot stays within the range considered to reflect normal variability, inspection of the data will be required to show whether species considered to be of marine natural heritage importance have been lost or whether species considered to be indicators of stress or pollution are driving any change in numerical scores.

'Traditional' macrobenthic sampling methods, based on sampling small areas of seabed and identifying and counting all of the species which occur as individuals, should not go unchallenged in monitoring for environmental protection and management. Usually, the number of samples required to characterise the communities present is based on taking a large number of samples, identifying all of the species present and plotting a cumulative distribution or *species/area curve* (Figure 2-7). The number of samples above which obtaining a 10% increase in the number of species would require a 100% increase in sample area is often considered about the 'right' sampling frequency for monitoring studies. Whilst such species area curves produce very useful indications of species richness in different locations, or over time at the same location, it is often only possible to identify real change in the quantity of the most abundant species. In conclusion, it seems that, although comparative species richness can be assessed using a reasonable number of quantitative samples, trying to establish meaningful information about changes in abundance of 'all' of the species in a community would require an almost impossibly large (and certainly financially impractical) number of samples.

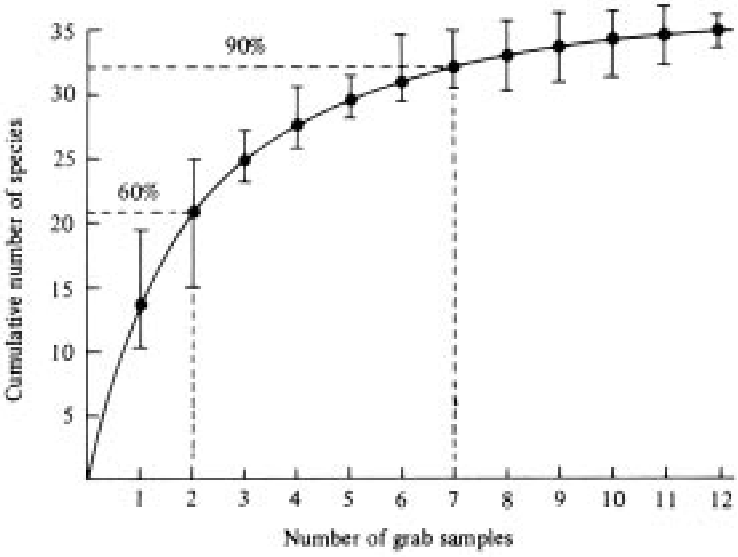



**Figure 2-7** Species/area curve used to indicate the proportion of the fauna being collected with increasing numbers of grab samples and traditionally used to identify a minimum sampling area (from Gray 1981[u]).

Studies which sample only small areas are also unlikely to include large, widely dispersed species which may be very good indicators or which, because they are scarce, have an importance for conservation. 'Traditional' methods of grab or core sampling for such species are inappropriate and in situ observation (whether by diver or remote operated video) or digging-over an area of sediment (for infauna) will be required.

It is possible to use empirical methods to calculate the number of samples necessary to achieve a desired level of precision.[15] As a rule of thumb, measurements should be taken from at least five stations before any generalisations can be made about an attribute of a feature within an SAC, although such a low level of replication is likely to have very low power. For frequency data[16] only very large changes can be detected with fewer than 50 samples and 100 samples are considered the minimum.[v]

A pilot study is one method of gaining an improved understanding of the variability of marine ecosystems, and helps identify some of the problems with sampling the feature. It can investigate some of the potential questions at a small scale, quantify many of the sources of variation, and help determine the optimum sampling design within the resources available. In particular, a pilot study should consider the optimum time to sample, where to sample and the size of sampling units in relation to the attribute/community/species of interest.[w] It should also investigate potential sources of variability in the deployment of a technique. Such data will contribute to both the setting of the number of samples required to improve the confidence in the data, and developing local adaptations to the mode of deployment to mitigate this variability. Data from a pilot study will facilitate the statistical technique termed *power analysis* to enumerate the number of samples required to achieve a requisite level of confidence.

**Recommendation**. A pilot study should be undertaken to help identify and quantify sources of variability within a feature on a SAC. Data from this pilot study should be used to determine the number of samples required, ideally using power analysis, to reliably detect whether an attribute achieves its target value.

### Power analysis

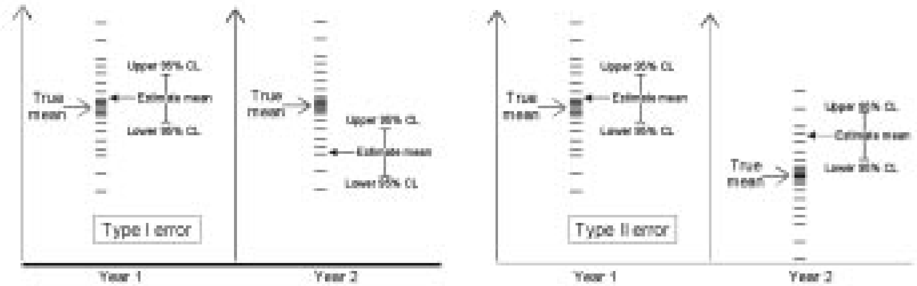
Statistical *power* is the probability of getting a statistically significant result given that there is a real biological effect in the population under investigation. In statistical terms, *power* is defined as 1 – ß, where ß is the probability of wrongly accepting a null hypothesis when it is actually false, known as a type II error. When a statistical test returns a non-significant result, it is important to distinguish whether there is no biological effect, or whether it is because the sample design is insensitive to a real biological effect. Power analysis can distinguish between these alternatives and therefore is an important component of experimental design. In monitoring terms, careful consideration of the power of a sampling programme can make the difference between insufficient sampling for conclusive decision-making and wasting resources by over-sampling beyond that necessary to achieve significant results. For condition monitoring, a type II error results in a feature being considered *favourable* when it is actually *unfavourable* (see Box 2-6).

15 See Appendix 1.5 in Ecoscope (2000a).[c]

16 *Frequency data* are normally recorded using a quadrat sub-divided into cells by cross wires. The number of cells containing a species is recorded, rather than a direct count of the number of individual or an evaluation the percentage cover. See Brown (2000)[s] for a detailed explanation.

**Box 2-6** Type I and type II errors in relation to monitoring (from Ecoscope 2000a)

If we use a significance level of 5% it follows that there is a 5% chance that the null hypothesis will be rejected when there is in fact no difference between the populations being analysed. The rejection of a null hypothesis when it is true is known as a type I error. Setting a lower significance level (e.g. 1%) reduces the risk of committing this type of error. However, this increases the risk of committing a type II error, which is the acceptance of a null hypothesis when it is false. In monitoring terms, this would be concluding that no change is taking place when in fact it is. In many situations it is preferable to err on the side of caution and try to limit type I errors. However, type II errors may have profound consequences in monitoring studies because real changes in the condition of a feature may not be detected. For monitoring studies, it may therefore be prudent to follow the precautionary principle and adopt significance levels above 5% at least as a trigger for further studies.




The lines on the diagram represent means from different potential samples of a variable. The estimate mean and confidence limits represent one sample taken by an observer.
Type I error: In year 2, the values of the variable and hence potential sample means have remained the same. However, the random sample taken by the observer happens by chance to contain lower values. The mean of the year 2 sample is significantly lower than that of year 1, and it is wrongly concluded that a change has occurred.
Type II error: In year 2 the values of the variable have declined. However, the random sample taken by the observer happens by chance to contain high values. The mean of the year 2 estimate is not significantly different from that of year 1, and it is wrongly concluded that no change has occurred.

*Monitoring in relation to an absolute standard*

The explanation of hypothesis testing given above is based upon the comparison of the means of two (or more) statistical populations. In monitoring terms, this is analogous to comparing two data sets from two different years to look for changes. However, monitoring may also need to detect whether a feature is above or below predetermined absolute target value. For example, it might be decided that unacceptable change has taken place if the mean density of a particular species falls below 10 plants per $m^2$. Estimates of density obtained from samples will therefore be compared to this value. The principles of hypothesis testing remain exactly the same for this method: one is testing whether the target value (e.g. 10 limpets per $m^2$) falls in either tail of the sample distribution; if this occurs it is more likely that the sample mean is different and that change has occurred. Alternatively, if 95% confidence limits for the sample density are calculated, and the target value is outside these limits, then one can also conclude that the current density is above or below the change limit.

It is beyond the scope of the present handbook to present a detailed description of power analysis. Brown (2000)[s] provides a comprehensive explanation of power analysis in condition monitoring, including step-by-step worked examples using the spreadsheet *Microsoft Excel*™. Sheppard (1999)[x] provides a simple explanation of how power analysis is used to determine sample size in marine environmental science, which includes a quick guide to its use in relation to basic statistical tests (t-test, $\chi 2$ test and analysis of variance).

An internet search for the text 'power analysis' revealed more than one and a half million hits![17] Box 2-7 gives some useful URLs, and the subject is comprehensively covered in many statistical textbooks.[18]

17 Using the search engine Google - http://www.google.com/

18 See the bibliography at http://www.mp2-pwrc.usgs.gov/ampCV/powcase/powrefs.cfm

**Box 2-7** Some internet sites providing sources of information on power analysis

The United States Geological Service hosts an internet site dedicated to the use of power analysis in monitoring programmes:
**http://www.mp1-pwrc.usgs.gov/powcase/index.html**

A small DOS program (Monitor) for calculating the number of samples required for a monitoring programme may be downloaded from:
**http://www.mp1-pwrc.usgs.gov/powcase/monitor.html**

A comprehensive review of software for power analysis is available at:
**http://sustain.forestry.ubc.ca/cacb/power/review/review.html**

**http://sustain.forestry.ubc.ca/cacb/power/** lists power analysis software including hyperlinks to appropriate sites.

Power analysis requires actual sample data to evaluate the number of samples required to achieve the desired level of confidence. Ideally, such data would be recorded by a pilot study.

An important alternative use of power analysis is for *post hoc* evaluation of a sampling programme: in other words, to determine the certainty or confidence that can be placed in the results from an existing sampling programme. For example, where there was a long-term sampling programme already in existence on a SAC, it would be possible to use power analysis to evaluate the potential for using its results for monitoring the condition of an attribute. A similar *post hoc* use is the analysis of the data from a pilot study to determine the number of samples to record in subsequent monitoring events (Box 2-8).

**Box 2-8** An example of the practical use of post hoc power analysis from the UK Marine SACs project study in Loch Maddy[1]

A power analysis carried out on the 1998 and 1999 data for circalittoral rock, showed that 10 quadrats would detect a change of between 13% and 18% in the species composition of a biotope, whereas 20 quadrats would detect 10–12 % change. These calculations use a type I probability of 0.05, and a type II probability of 0.2. Each quadrat at this site required between 10 and 15 minutes to record, so that a diver could complete two or three quadrats per dive. 12 quadrats would represent one day's work for a pair of divers or half a day for two pairs and would seem a sensible target for future monitoring events in light of the information gathered in 1999.

**Recommendation:** *post hoc* power analysis should be undertaken on the results of a monitoring exercise to determine the their reliability for determining management actions.

## Assessing the condition of a feature

The monitoring data for a range of attributes has to be considered together in order to assess the condition of a feature on a marine SAC, as illustrated diagrammatically in Figure 2-8. All attributes must attain their target value for the condition of the feature (habitat or species) to be considered *favourable*.

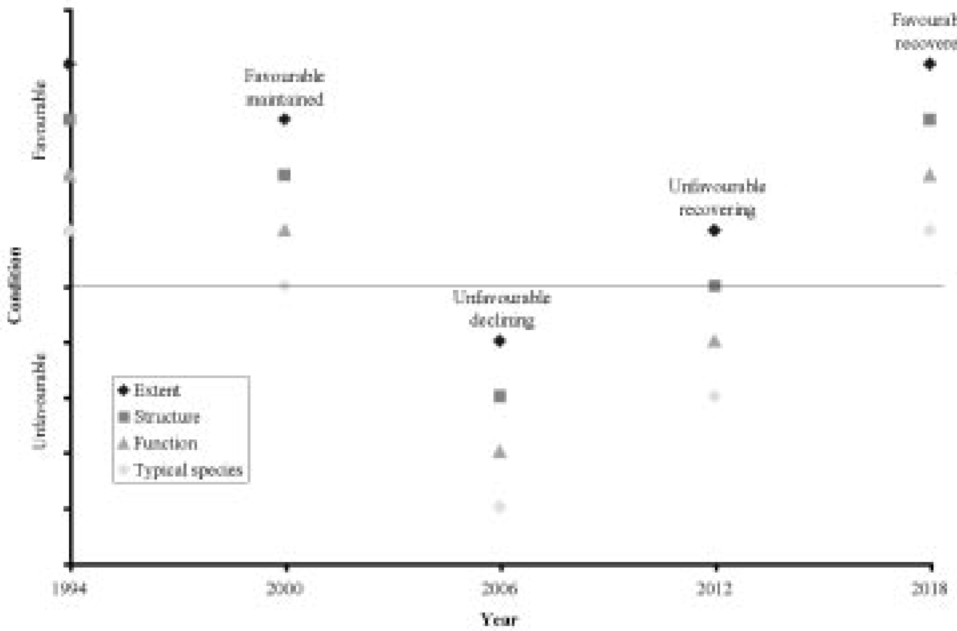



**Figure 2-8** A modified version of the original common standards model (Rowell 1993)[y] proposed by Brown (2000).[s] The vertical axis shows the condition or state of the feature over the period shown on the horizontal axis. The horizontal line defines favourable condition (= the formulated standard) of the feature. The symbols represent the conclusions from the monitoring activities for each attribute and, when aggregrated, represent either favourable or unfavourable condition.

Figure 2-9 summarises the process of forming a judgement on the condition of a feature based on monitoring results. At the time of publication, practical testing of the monitoring system described in Sections 1 and 2 of this handbook has not yet been carried through to the point where an assessment of feature's condition has been possible. This is because, while baseline data for some of the attributes on the trial marine SACs are available, this is not true for all the selected attributes. Nor has repeat monitoring been carried out to compare with the baseline. Consequently, a number of issues require further investigation, discussion and practical field-testing. In particular, more experience must be gained on how to form judgements both in relation to the condition of individual attributes, and when aggregating the results of a range of attributes for a particular feature (habitat or species).

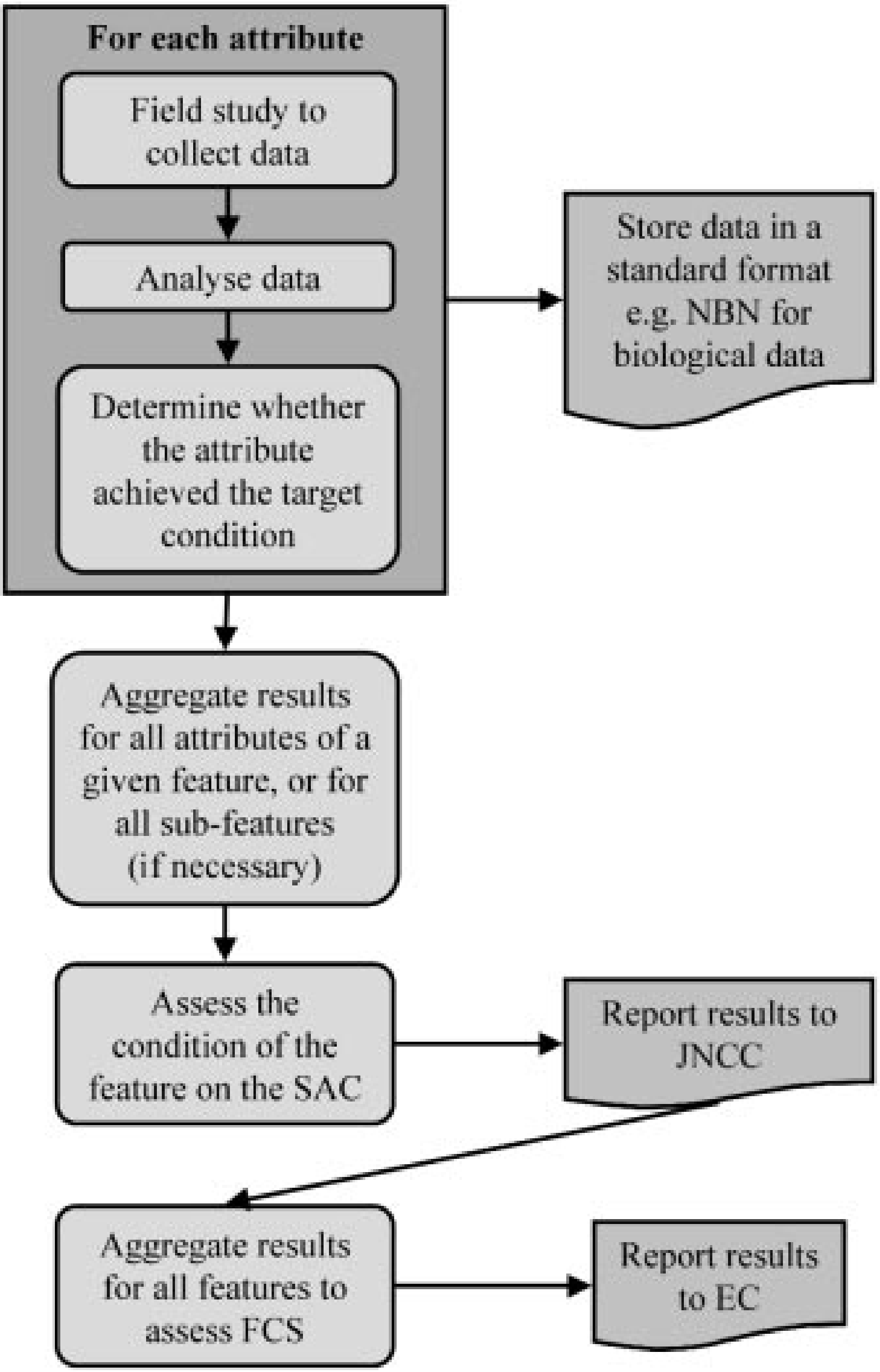



**Figure 2-9** A summary of the anticipated process of assessing the condition of SAC features. The National Biodiversity Network (NBN)[19] has developed a data model that provides a *standard format* for biological data.

## A Checklist of basic errors

After the design phase of a monitoring programme is complete, it is worth reviewing the '*Twenty commonest censusing sins*' [z] (Box 2-9) to check whether the proposed programme has made, or is likely to make, any basic errors.

19 See: **http://www.nbn.org.uk/**

**Box 2-9** Sutherland's twenty commonest sins in censusing[z]

1. Not sampling randomly.
2. Collecting far more samples than can possibly be analysed.
3. Changing the methodology in monitoring.
4. Counting the same individual in two locations as two individuals.
5. Not knowing your species.
6. Not having controls in management experiments.
7. Not storing information where it can be retrieved in the future.
8. Not giving precise information as to where sampling occurred.
9. Counting in one or a few large areas rather than a large number of small ones.
10. Not being honest about the methods used.
11. Believing the results.
12. Believing that the density of trapped (or counted) individuals is the same as absolute density.
13. Not thinking about how you will analyse your data before collecting it.
14. Assuming you know where you are.
15. Assuming sampling efficiency is similar in different habitats.
16. Thinking that someone else will identify your samples for you.
17. Not knowing why you are censusing.
18. Deviating from transect routes.
19. Not having a large enough area for numbers to be meaningful.
20. Assuming others will collect data in exactly the same manner and with the same enthusiasm.

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# 3 Advice on establishing monitoring programmes for Annex I habitats

Jon Davies

# Introduction

**Aim**

To provide advice on marine Annex I features to assist the selection of attributes, appropriate monitoring techniques and their field deployment

Marine Annex I features may be divided into two broad categories: broad habitat types (reefs, intertidal sediment flats, subtidal sandbanks) and physiographic features (estuaries, large shallow inlet and bays, lagoons and sea caves). Broad habitat types from the first group may be found in the physiographic features. Such complex features pose a number of theoretical and operational problems to the definition and implementation of a monitoring programme.

This section provides advice on monitoring each Annex I feature. It also:

- provides a summary of the ecological requirements (form and function) of the marine Annex I feature, to emphasise its typical biological and physical characteristics;
- establishes the generic characteristics to be considered when assessing the condition of a feature - outlining a range of attributes that it could be appropriate to monitor and measure for each feature;
- provides broad feature specific guidance on how to take account of environmental changes and/or human influences/threats and resources when planning the actual monitoring programme;
- lists options for techniques to use to monitor the attributes for each feature in a matrix format;
- where current knowledge is sufficient, indicates a possible sampling strategy; and
- advises on quality control and quality assurance procedures to achieve consistent and comparable results between monitoring events on a site and between sites if necessary.

Each section starts with a definition of the feature extracted from the EC interpretation manual,[1] followed by a UK description of the feature adapted from Brown et al. (1997),[2] also available on the Joint Nature Conservation Committee (JNCC) Internet site.[3] A map of the sites selected for each feature is also available on the JNCC Internet site.

*Please note that the advice provided in this section is based on our present understanding (winter 2000) and is likely to change as our practical experience of SAC monitoring increases. In particular, the Joint Nature Conservation Committee is developing detailed guidance during 2001 to implement the UK's Common Standards for Monitoring programme that will probably result in a significant revision of this section.*

*The listing of an attribute in the tables in this section does not imply that it should form part of a monitoring programme for the feature, but it may need to be considered*

1 European Commission. (1996). *Interpretation manual of European Union Habitats:. Version EUR 15*. Brussels, European Commission (DG XI – Environment, nuclear safety and civil protection).

2 Brown, A E, Burn, A J, Hopkins, J J and Way, S F (1997) . *The Habitats Directive: selection of Special Areas of Conservation in the UK*. JNCC Report 270. Joint Nature Conservation Committee, Peterborough.

3 See: **http://www.jncc.gov.uk/idt/default.htm**.

# Reefs

**Definition**

Submarine, or exposed at low tide, rocky substrates and biogenic concretions, which arise from the seafloor in the sublittoral zone but may extend into the littoral zone where there is an uninterrupted zonation of plant and animal communities. These reefs generally support a zonation of benthic communities of algae and animal species including concretions, encrustations and corallogenic concretions.

## Introduction to the feature's interest

Reefs are widespread in northern and southern Europe and occur widely around the UK coast. They are very variable in form and in the communities that they support. Sites have been chosen to represent the main geographical and ecological range in the UK of this extremely variable habitat type. Selection has favoured extensive examples with diverse community structure. The selection process has taken account of the UK's special EC responsibility for reef types in conditions of extreme wave and tidal stream exposure. A large proportion of the chalk reefs of Europe occurs in the UK and selection of this type of reef was emphasised in recognition of the UK's special responsibility.

Reefs are rocky marine habitats or biological concretions that rise from the seabed. They are generally subtidal but may extend as an unbroken transition to the intertidal zone, where they are exposed to the air at low tide. Two main types of reef can be recognised, those where structure is created by the animals themselves (biogenic reefs) and those where animal and plant communities grow on raised or protruding rock. Only a few invertebrate species are able to develop biogenic reefs, which are therefore restricted in distribution and extent.

There is a far greater range and extent of rocky reefs than biogenic concretions in the UK. Rocky reef types are extremely variable, both in structure and in the communities they support. A wide range of topological reef forms meet the EC definition of this habitat type. These range from vertical rock walls to horizontal ledges, broken rock and boulder fields. The common feature between these different forms is the type of animal and plant community that grows on the rock. The species assemblage is characterised by attached algae and invertebrates, usually associated with a range of mobile animals, including invertebrates and fish. The specific communities that occur vary according to a number of factors. For example, rock type is important, with particularly distinct communities associated with chalk and limestone rock. These have a restricted distribution in accordance with the distribution of the rock type on which they grow. There may be further variety associated with topographical features such as vertical rock walls, gully and canyon systems, outcrops from sediment and rock pools on the shore. The greatest variety of communities is typically found where coastal topography is highly varied, with a wide range of exposures to wave action and tidal streams.

Exposure to wave action has a major effect on community structure, with extremely exposed habitats dominated by a robust turf of sponges, anemones and foliose red seaweeds, while reefs in the most sheltered sea lochs and rias[1] support delicate or silt-tolerant filamentous algae, fan worms, ascidians and brachiopods. The presence of enhanced tidal streams often significantly increases species diversity, although some communities require very still conditions. The strength of tidal streams varies considerably, from negligible currents in many sea loch basins to very strong tidal currents of 8–10 knots (4–5 m/s) or more through tidal rapids or in sounds. In strong currents there are communities of barnacles, the soft coral *Alcyonium digitatum*, massive sponges and hydroids.

In addition, in the UK there is a marked biogeographical trend in species composition related to temperature, with warm, temperate species such as the sea fan *Eunicella verrucosa* and the corals *Leptopsammia pruvoti* and *Balanophyllia regia* occurring in the south, and cold-water species such as the anemone *Bolocera tuediae* and the red seaweed *Ptilota plumosa* in the north. A major factor affecting reef communities is the turbidity of the water. In turbid waters, light penetration is low and algae can occur only in shallow depths or in the intertidal zone. However, in such conditions animals have a plentiful supply of suspended food and filter-feeding species may be abundant. Salinity is also impor-

1 A ria is a drowned river valley.

tant. Although most reefs are fully marine, rocky habitats in certain marine inlets are subject to variable or permanently reduced salinity and have their own distinctive communities.

Where reefs extend from the seabed into the intertidal zone, a strong vertical zonation of communities is apparent. Lichens occur at the top of the shore, with communities characterised by barnacles, mussels or species of fucoid (wrack) seaweeds in the intertidal zone.

## Typical attributes to define the feature's condition

### *Generic attributes*

Table 3.2-1 lists the generic attributes for reef features and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge of the factors that determine the condition of reef ecosystems improves.

**Table 3.2-1** A summary of attributes that may define favourable condition of reefs

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Extent* | | |
| Extent of the feature | Area (ha) measured periodically | Extent of the feature is a reporting requirement of the Habitats Directive. The extent of (non-biogenic) reef is unlikely to change significantly over time unless due to some human activity but nevertheless needs to be measured periodically. The extent of a biogenic reef is an important attribute in relation to the viability of the reef. |
| Extent of a specific biotope | Area and distribution of a typical or notable biotope from the site | The extent of a biotope that is a key structural component of the reef, and is particularly important due to it being: *a typical biotope for the biological zone; notable for its nature conservation importance due to its rarity/scarcity, regional importance, species richness; and/or an extensive example; sensitive to non-native species or changes in supporting processes* |
| Extent of a biogenic reef | Extent of the horse mussel *Modiolus modiolus* biogenic reef | |
| *Physical properties* | | |
| Water clarity | Average light attenuation measured periodically throughout the reporting cycle | Water clarity is a key process influencing algal/plant growth, density and extent and thereby algal/plant dominated biotopes. Changes in water clarity could be caused, for example, by an increase in suspended material due to organic enrichment.<br><br>Siltation causes smothering of substrata and organisms affecting feeding efficiency or feeding mechanisms, and colonisation. |
| Water density<br><br>Water temperature<br><br>Salinity | Regular measurement of water temperature and/or salinity periodically throughout the reporting cycle | Temperature and salinity are characteristic of the overall hydrography of the area. Changes in temperature and salinity may influence the presence and distribution of species (along with recruitment processes and spawning behaviour), particularly those species at the edge of their geographic ranges. |

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Biotic composition* | | |
| Biotope composition | Number and occurrence/ frequency of all biotopes or a range of specified biotopes | The number and occurrence/frequency of specified biotopes is an important structural aspect of the site. It is important to establish the finest level in the national classification to which the biotopes will be discriminated.<br><br>The biotopes specified should reflect both the biological and regional/local character of site |
| | Overall biotope richness (number of biotopes) | The target value is likely to be the total number of biotopes known from the SAC. The lower limit for a single monitoring cycle may be less than 100% of the biotopes to take account of the likelihood of not recording a biotope with a given level of effort. It may be necessary to ensure that 100% of the biotopes present are recorded over, for example, three monitoring cycles. |
| Species composition of a specific biotope | Frequency and occurrence of composite species (total or sub-set) from a biotope | Species composition is an important contributor to the structure of a biotope and therefore the reef as a whole.<br><br>The presence and relative abundance of all characterising species gives an indication of the quality of a biotope and any change in composition may indicate a cyclic change or trend in reef communities. |
| Characteristic species | Estimate population size from a measure of the abundance/occurrence/ frequency/biomass of a specified species<br><br>Record a relevant population structure measure such as age structure of a specified species | The species selected should be an important structural element of the biotope, and is indicative of the structure of the particular biotope; for example kelp, *Modiolus modiolus* in biogenic reef.<br><br>Change in the species may indicate cyclic change/trend in host biotope and/or reef communities as a whole. |
| Notable species | Occurrence and frequency of a species | A notable species may:<br>have nature conservation importance due to such factors such as its rarity/scarcity;<br>contribute to reef structure;<br>be used as an indicator of environmental stress (e.g. green algae), or changes in water circulation patterns (e.g. edge of range species) or sensitivity to pollutants (e.g. molluscan sensitivity to TBT). |
| *Biological structure* | | |
| Productivity – algal biomass | Algal biomass measured in late summer through the depth zone | Algal productivity, such as in a kelp forest, plays an important functional role within the food chain both directly and through detrital supply. |
| Distribution of all or a range of biotopes | Relative distribution of important communities throughout the feature | The relative distribution of biotopes, for instance kelp biotopes, is an important structural aspect of the site. Changes in the extent and distribution may indicate long-term changes in the prevailing physical conditions at the site. |
| Structural integrity of selected biotopes | Actual measures will depend on the specific aspects of structural integrity chosen for each selected biotope | For example, in Pen Llyn a'r Sarnau cSAC, three aspects of structural integrity were identified for the horse mussel *Modiolus modiolus* reef:<br>continuity and area to periphery ratio of the reef/incidence of scaring;<br>density/area covered by live *M. modiolus;*<br>age structure of the *M. modiolus* |

### *Suggested techniques for monitoring reef attributes*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.2-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

**Table 3.2-2** Suggested techniques for measuring reef attributes. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic Attribute* | *Feature-specific attribute* | *Technique* |
|---|---|---|
| Extent | Intertidal | *Air photo interpretation; Remote imaging*; Intertidal resource mapping |
| | Subtidal | AGDS; Side scan sonar; Point sample mapping; (for shallow areas: *Air photo interpretation; Remote imaging)* |
| | Subtidal biogenic reefs | AGDS; Side scan sonar; Mosaicing sonar images; Point sample mapping |
| Physical properties | Water clarity | Measuring water quality; *Water chemistry data loggers; Secchi disk* |
| | Water chemistry (including salinity, temperature) | Measuring water quality; *Water chemistry data loggers* |
| | Substratum | Drop-down video; ROV; AGDS; Side scan sonar |
| Biotic composition | Intertidal biotope richness | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; Viewpoint photography |
| | Subtidal biotope richness | Subtidal biotope ID; Drop-down video; ROV; Diver-operated video; Towed video (limited by topography and/or risk of damage) |
| | Intertidal species composition/richness | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Fish in rockpools; |
| | Subtidal species composition/richness | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal photography; Suction sampling; Fish in subtidal rock habitats; ROV; Drop-down video; Diver-operated video |
| | Intertidal characteristic species | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Fish in rockpools |
| | Subtidal characteristic species | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal photography; Suction sampling (small epibiota); Fish in subtidal rock habitats; Fish in vegetative cover; ROV ('large' conspicuous species only); Drop-down video ('large' conspicuous species only); Diver-operated video |

| *Generic Attribute* | *Feature-specific attribute* | *Technique* |
|---|---|---|
| Biological structure | Intertidal zonation | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; *Transect survey; Shore profiling* |
| | Subtidal zonation | Subtidal biotope ID; Diver-operated video; Subtidal quadrat sampling; ROV; Towed video (limited by topography and/or risk of damage) |
| | Spatial pattern of intertidal biotopes | Intertidal resource mapping; Intertidal biotope ID; Viewpoint photography; *Air photo interpretation; Remote imaging* |
| | Spatial pattern of subtidal biotopes | AGDS; Side scan sonar (with mosaicing); Point sample mapping (from ROV or Drop-down video data) |

## Specific issues affecting the monitoring of reefs

All attributes will have their own inherent sources of variability that must be addressed during data collection and subsequent interpretation of the results. There are, however, some generic issues that should be considered when planning the whole monitoring study.

### *Seasonal effects*

Marine communities exhibit seasonal change, although the precise effects are poorly understood for many communities. Some of the more obvious visual changes occur in algal assemblages, and following massive settlements of juvenile animals such as mussels and barnacles. In Loch Maddy cSAC, a recent study concluded that the largest changes observed in shallow communities between autumn 1998 and summer 1999 were due to an increase in diversity and abundance of algae.[a] Similarly, in Plymouth Sound cSAC, most of the changes observed between 1998 and 1999 were attributed to real changes in populations, rather than variability in recording methods or behavioural factors.[b] The degree to which seasonal change will influence the monitoring of a reef attribute will depend on the community under investigation. Where possible, a community should be investigated either directly or via a literature review to gather information on the likelihood of seasonal change affecting an attribute. In general, algal assemblages should be studied during the summer months. Where seasonal effects are not fully understood, it is vital that a monitoring strategy explicitly states that data collection must always be undertaken at the same time of year.[2]

Whilst seasonal variation strictly relates to changes within a year, reef communities may change over a longer time period (many years) as a consequence of ecological processes affecting community dynamics. Physical and biotic processes can cause wholescale changes in community composition on a reef. Community dynamics of rock shores have been extensively investigated and many authors report cyclical changes in the community composition over time.[c,d] Clearly, not considering such changes when interpreting the results of a monitoring exercise would lead to incorrect conclusions. Similarly, and perhaps more importantly, over-specificity when setting an attribute – such as the presence of biotope x – would be a recipe for disaster if 'biotope x' was only one of a suite of possible biotopes in a natural cycle.

### *Meteorological changes*

Prevailing weather conditions and tidal state will affect any monitoring study. Sites open to the prevailing wind and swell will require calm conditions for effective field survey. Where a reef is adjacent to sediment habitats, excessive water movement (from strong winds or spring tides) will mobilise fine sediment into the water column, thereby reducing underwater visibility. Conversely, calm conditions will cause suspended sediment to deposit out of the water column, visibility will improve but reef assemblages may then become smothered with sediment obscuring some species from view.

Periods of extreme cold coinciding with low water can result in mass mortality of kelp plants.[e]

When establishing a monitoring strategy, meteorological effects must be integrated with seasonal effects to ensure that sites can be monitored reliably through time.

2 See comments in Section 2: What is the most appropriate method?

### *Access*

To gain access to the site, the surveyor must consider the issues of permission (intertidal sites), tidal state (high or low water/slack water), prevailing wind/wave/swell conditions and underwater visibility. Access to intertidal habitats would be gained from the land, except for islands and offshore banks or remote sites where boat access will be necessary. It will be necessary to use a boat to gain access to many subtidal reefs and therefore it will be necessary to consider the availability of harbours and/or launching facilities. Land access would be possible for those subtidal habitats immediately adjacent to the shore.

### *Sampling issues*

Reefs are topographically complex features, and may comprise a wide range of biotopes, particularly where a reef extends from the top of the intertidal zone through to the deep circalittoral zone. Such complexity within a single reef, and between reefs, poses considerable obstacles to achieving a consistent monitoring strategy within an SAC. Consequently, it is not possible to consider all aspects of reef sampling in the current report and what follows will consist of some basic advice in relation to common standards monitoring.

It should be emphasised that the aim of monitoring is to assess the condition of the *whole* feature within an SAC, and therefore the sampling programme must ensure samples are recorded throughout the entire site. A stratified approach may be adopted for extensive sites where the available resources only permit a few locations to be investigated in detail, and the results must be extrapolated to the whole site. Nevertheless, the sampling strategy should include a series of 'spot checks' throughout the site to ensure that the extrapolated results are in fact representative of the condition of the entire site. Using a 'top-down' approach to stratify sampling can result in significant cost-savings by linking techniques to address multiple attributes in a single monitoring exercise. For example, a remote sensing campaign could map the extent of a feature (or more likely sub-features). The imagery could then stratify a detailed ground validation campaign, and the results could be used to measure *biotope richness*. If an ROV was used for the sampling, it would be possible to record additional information, such as counts of a conspicuous *characteristic species*.

It is vital that a standardised approach is adopted when measuring attributes of the number of species (species richness) or biotopes (biotope richness) because the number recorded is directly linked to the sampling effort. All techniques must be 'effort limited' – for example by restricting the search area or search time.[3]

The characterising species of many reef biotopes have a huge range in body size: for example in kelp biotopes, body size will range from metres (kelp plants) to millimetres (fine hydroids, small bivalves). The dimensions and scale of occurrence of the target organism is an important factor when selecting the size of the sampling unit such as a quadrat, and the enumeration technique – counts, frequency or percentage cover. The choice has a significant effect on the time required for field survey and, more importantly, the reliability (accuracy and precision) of the results. It may be possible to improve sampling efficiency through a nested approach where a large quadrat is sub-divided into smaller units[4] (Figure 3-1). Large organisms are enumerated in the entire quadrat, but small organisms are only enumerated for a proportion of the smaller units (quadrats in their own right). For monitoring of an individual species, a scale of variance analysis can help to determine the appropriate sampling unit.

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3 Effort limitation was addressed by Sanderson, W G, Holt, R H F, Kay, L (2000) Efficacy of deployment of divers. In: Sanderson, W G, Holt, R H F, Kay, L, Wyn, G and McMath, A J (eds.) (2000) *The establishment of an appropriate programme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998–-1999 trials*, pp. 29–36. Contract Science Report No: 380, pp. 29-36. Countryside Council for Wales, Bangor.

4 For a description of this approach see Chapter 3.4 and Appendix 2 in: Ecoscope (2000) *A species and habitats monitoring handbook. Volume 2: Habitat monitoring*. Research, Survey and Monitoring Review No. [XX]. Scottish Natural Heritage, Edinburgh.

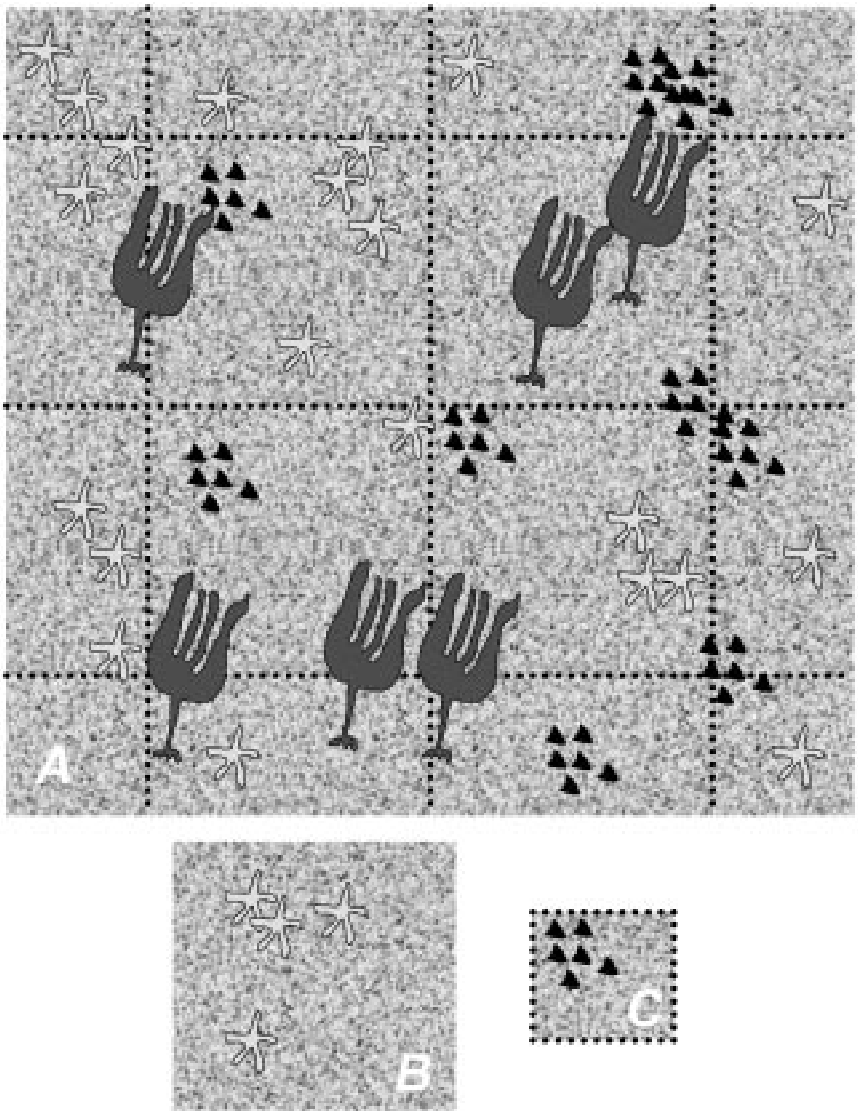


**Figure 3-1** Illustration of a nested quadrat to record different sized organisms occurring at different spatial scales. Quadrat A is subdivided into 9 quadrats of size B and 36 quadrats of size C. Quadrat size will affect frequency estimates: 'starfish' frequency is 8/9 = 0.89 for quadrat B, but 15/36 = 0.42 for quadrat C.

Trials undertaken by the UK Marine SACs project demonstrated that the species composition of reef biotopes is subject to considerable temporal fluctuation.[a,b] Determining an appropriate sampling strategy, and in particular, ensuring the sampling intensity provides sufficient *statistical power* to detect any change, is critical to the success of a monitoring programme (see Section 2).

## *Site marking and relocation*

Site marking techniques will depend on the environment (intertidal or subtidal), the rock type (hard, soft, and friable), degree of wave exposure and the likelihood of anthropogenic interference with fixed markers. Hiscock (1998)[g] lists site-marking techniques in Appendix 6. Holt et al. (2000)[h] investigated specific issues relating to site marking on a vertical, circalittoral bedrock reef. In Pen Llyn a'r Sarnau cSAC, acoustic beacons were also used to mark a horse mussel (*Modiolus modiolus*) reef, and an algal-dominated cobble reef at an offshore site.[i]

Relocation of fixed sites can be very difficult, especially underwater in poor visibility or with few conspicuous features to act as navigation aids. Global Positioning Systems (GPS) now offer the possibility of accurate site relocation to ± 15m using a standard receiver, or ± 1m if combined with an additional receiver to gather a correction signal - differential GPS (dGPS)[5]. If necessary, there are specialised GPS systems available, called Real Time Kinematic (RTK) GPS, which can achieve centimetre level accuracy, offering the possibility of returning to a very precise location. Without GPS technology, it is usual to use a map to locate the approximate position of a sampling station on intertidal reefs. Maps should be supplemented by photographs and/or diagrams of characteristic topographical features to find the precise location of a site marker. For subtidal sites, the approximate position can be located using conspicuous land features, preferably lined up to create transits. Photographs and/or diagrams should be used underwater to find the precise sample location although poor visibility creates severe problems (Figure 3-2).

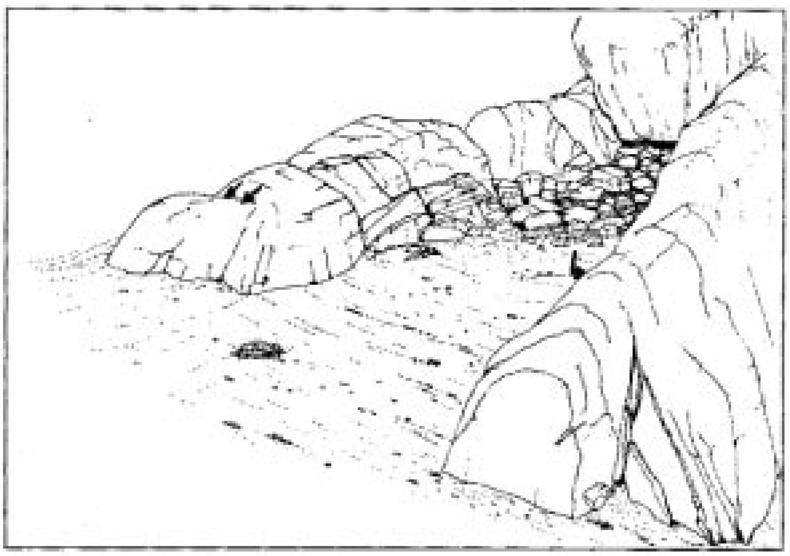

**Figure 3-2** A drawing of the conspicuous underwater scenery to aid the relocation of a sample station[h]

## *Health and safety*

All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent.

Intertidal reefs often have complex topography that, when combined with a covering of algae, create an uneven slippery surface. Considerable care must be taken to reduce the risk of staff slipping or falling, particularly in remote areas where tidal immersion could occur before emergency assistance arrives. Field staff should carry a radio or mobile telephone to ensure the emergency services are notified promptly.

Some subtidal sampling on reefs will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[6] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[7] (**http://www.hse.gov.uk/spd/spdacop.htm - a**).

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5 See Section 6: Procedural Guideline Number 6-1 for dGPS guidance.

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# Estuaries

## Definition

Downstream part of a river valley, subject to the tide and extending from the limit of brackish waters. River estuaries are coastal inlets where, unlike 'large shallow inlets and bays', there is generally a substantial freshwater influence. The mixing of freshwater and sea water and the reduced current flows in the shelter of the estuary lead to deposition of fine sediments, often forming extensive intertidal sand and mud flats. Where the tidal currents are faster than flood tides, most sediments deposit to form a delta at the mouth of the estuary.

## Introduction to the feature's interest

Estuaries are complex ecosystems linking the terrestrial and aquatic environments and are composed of an interdependent mosaic of subtidal, intertidal and surrounding terrestrial habitats. Many of these habitats, such as intertidal mudflats and sandflats, saltmarshes and reefs, are identified as habitat types in their own right in Annex I of the Directive.

*Estuaries* are defined as the downstream part of a river valley, subject to the tide and extending from the limit of brackish water. There is a gradient of salinity from fresh water in the river to increasingly marine conditions towards the open sea. Input of sediment from the river, shelter from wave action and, often, low current flows lead to the presence of extensive sediment flats. Similar large geomorphological systems where seawater is not significantly diluted by freshwater are classified within the Annex I habitat *Large shallow inlets and bays*.

The UK has a particularly large number of estuaries. Indeed, more than a quarter of the area of north-western European estuaries occurs in the UK. Davidson *et al.* (1991)[a] identified nine estuary types occurring in the UK, of which four meet the criteria for geomorphological and substrata types, and associated fauna in the definition of the Annex I habitat. The remaining five types fall within the definitions of the Annex 1 habitats *Large shallow inlets and bays* or *intertidal mudflats and sandflats*.

The structure of estuaries is largely determined by geological and physiographic factors. There are four main geomorphological types, defined by the following physiographic features.

*Coastal plain estuaries*. These estuaries were formed when pre-existing river valleys were flooded at the end of the last ice age. They are usually less than 30m deep, and widen and deepen towards the mouth, giving a large width-to-depth ratio; their outline and cross-section is often triangular. Many systems have extensive sediment flats and saltmarsh throughout. Sediment type varies from mud in the upper reaches becoming increasing sandy towards the entrance. This is the main type of estuary, by area, in the UK.

*Bar-built estuaries*. These characteristically have a sediment bar across their mouths and are partially drowned river valleys that have subsequently been partially infilled with sediment. These estuaries are generally shallow and often have extensive lagoons and shallow waterways near the mouth. Characteristically, there are abundant sediments available in the local coastal systems and hence bar-built estuaries tend to be small and linked to depositional coastlines around the UK.

*Complex estuaries*. These river estuaries have been formed by a variety of physical influences, which include glaciation, river erosion, sea-level change and geological constraints from hard rock outcrops. There are few examples of this type of estuary in the UK.

*Ria estuaries*. These are drowned somewhat steep-sided valleys not formed or modified by glacial processes, with relatively small inflowing rivers, and are mainly found in south-west Britain. Characteristically, they are relatively deep, narrow channels with a low sedimentation rate. The estuarine part of these systems is usually restricted to the upper reaches. The outer parts of these systems are little diluted by fresh water and are classified as *Large shallow inlets and bays*.

The intertidal and subtidal sediments of estuaries support biological communities that vary according to geographic location, the type of sediment, tidal currents and salinity gradients within the estuary. The parts of estuaries furthest away from the open sea are usually characterised by soft sediments and are generally more strongly influenced by fresh water. Here oligochaete worms, with few other invertebrates, typically dominate the infaunal communities. Where rock occurs, there are restricted communities characteristic of brackish flowing water, consisting of green unicellular algae, sparse fucoid algae and species of barnacle and hydroid. Often, the silt content of the sediment decreases nearer to the mouth of the estuary, and the water gradually becomes more saline. Here the animal communities of the sediments are dominated by species such as ragworms, bivalves and sandhopper-like crustaceans. In the outer estuary, closer to the open sea, the substrata are often composed of coarser sediment that supports communities of more marine bivalves, polychaete worms and amphipod crustaceans. Where rock occurs, a restricted range of species more characteristic of the open sea is found. In addition, many estuaries have extensive saltmarsh systems, and support large bird populations. Consequently, areas adjacent to some estuaries are also candidate SACs for their saltmarsh communities, and some estuaries are designated Special Protection Areas under the Birds Directive.[1]

## Typical Attributes to define the feature's condition

### *Generic attributes*

Table 3.3-1 lists the generic attributes for estuarine features and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge improves of the factors that determine the condition of estuarine ecosystems.

**Table 3.3-1** Summary of attributes that may define favourable condition of estuaries

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Extent* | | |
| Extent | Area of the estuary | Extent of the feature is a reporting requirement of the Habitats Directive. The extent of an estuary is unlikely to change significantly over time unless due to some human activity but nevertheless needs to be measured periodically. Measurement will most likely be a cartographic exercise, supported by remote sensing data if necessary. |
| Extent of a specific biotope | Area of a biotope, for example seagrass beds | |
| Extent of characteristic communities | Biotopes present at stations across a stratified sampling grid | Extent may be represented as a proportion of the records of each biotope throughout the sampling grid |
| *Physical structure* | | |
| Sediment character | Particle size distribution (to produce grain size survey map). | Important parameters to measure include % sand/silt, mean and median grain size, and sorting coefficient, which are used to characterise the sediment type. |
| Morphological equilibrium | Tidal Prism/Cross- section ratio (TP/Cs ratio) | TP = Tidal Prism = total volume of water passing a given cross-section during the flood tide ($m^3$).<br>Cs = Area of a given cross-section at high water springs ($m^2$).<br>The relationship between TP and Cs provides a measure of the way the estuary has adjusted to tidal energy. Substantial departures from the characteristic relationship (determined on a regional basis) may indicate the influence of anthropogenic factors. |
| | Position of the horizontal boundary of the saltmarsh/mudflat interface | Monitoring the saltmarsh boundary is a practical means of securing data that may indicate changes in the TP/Cs relationship.<br>Deviation from long-term trends would act as a trigger for a second-tier response involving detailed bathymetric survey and evaluation of changes in the TP/Cs relationship (as above).<br>In the absence of saltmarsh, vertical change in mudflat position can act as a surrogate for, or in addition to, saltmarsh boundary. |
| Nutrient status | Average phytoplankton concentration in summer | |
| | Extent and seasonal abundance of macro algal mats on the foreshore | The presence of green algal mats is often used as an indicator of nutrient input, and any change in their location or extent may indicate a change in the nutrient loading to the estuary. |
| Water density – salinity and water temperature | Regular measurement of salinity and water temperature throughout the estuary | These parameters should be measured periodically to determine their mean value during the reporting cycle |

1 Council of the European Communities (1979) Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Biotic composition* | | |
| Range of biotopes present | Biotope composition of the estuary from a grid of stations representing all habitats in the estuary | It may be important to specify both a representative suite of communities, and any rare/scarce communities. |
| Species composition of selected biotopes | Number and abundance of all species | Communities to be considered under this attribute are likely to include the major estuary biotopes, sheltered muddy biotopes and rare/scarce biotopes. |
| Abundance of characteristic species | Average density, measured during peak growth period, once during the reporting cycle | Such species would include those that may be an indicator of the 'health' of the system – for example, seagrass *Zostera marina* beds. |
| Presence, abundance and condition of rare/scarce species | | No species have yet been selected for this attribute. |
| *Biological structure* | | |
| Distribution of major communities within the estuaries | Proportions of the major communities present in described 'zones' of each estuary may provide an appropriate measure for target/limit setting | |
| Range and distribution of characteristic communities | Presence of characteristic biotopes in the estuary | Such communities include mudflat and sandflat biotopes, rock communities, subtidal mixed sediment communities, subtidal muddy sand communities. |
| Relative distribution of sub-features | Relative distribution of sub-features | |
| Spatial pattern of selected biotopes | Area and distribution of specified biotopes | |

### *Suggested techniques for monitoring estuary attributes*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.3-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

It is important to note that estuaries may include other Annex I habitats or Annex II species which will require their own monitoring programme. The relevant sections of this document should be consulted in addition to the advice provided in Table 3.3-2.

**Table 3.3-2** Suggested techniques for measuring the attributes of estuaries. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic attribute* | *Feature-specific attribute* | *Technique* |
|---|---|---|
| Extent | | *Air photo interpretation; Remote imaging; GIS analysis* |
| | Biotope extent | Intertidal resource mapping; Intertidal biotope ID; *Air photo interpretation; Remote imaging*; AGDS; Side scan sonar (plus mosaicing); Point sample mapping |
| Physical properties | Substratum: sediment character | Particle size analysis; sediment profile imagery |
| | Morphological equilibrium | *LIDAR; Bathymetric mapping; Current meters, tide tables* |
| | Water clarity | Measuring water quality; *Secchi disk; Water chemistry data loggers* |
| | Water chemistry (including salinity, temperature) | Measuring water quality; *Water chemistry data loggers* |
| | Nutrient status | Measuring water quality; *Water chemistry data loggers;* (Biotope extent techniques for algal mats) |
| Biotic composition | Intertidal biotope richness | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; Viewpoint photography |
| | Subtidal biotope richness | Subtidal biotope ID; Grab sampling; Drop-down video; ROV; Diver-operated video; Towed video (limited by topography and/or risk of damage) |
| | Intertidal species composition/richness | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Intertidal core sampling; Fish in rockpools |
| | Subtidal species composition/richness | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal core sampling; Grab sampling; Suction sampling; Fish in subtidal rock habitats; Fish on sediments; ROV; Drop-down video; Diver-operated video; Epibenthic trawling |
| | Intertidal characteristic species | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Intertidal core sampling; Fish in rockpools |
| | Subtidal characteristic species | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal core sampling; Grab sampling; Subtidal photography; Suction sampling; Fish – in subtidal rocky habitats, in vegetative cover, on sediments; ROV ('large' conspicuous species only); Drop-down video ('large' conspicuous species only); Diver-operated video |
| *Generic attribute* | *Feature-specific attribute* | *Technique* |
| Biotic structure | Intertidal zonation | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; *Transect survey; Shore profiling* |
| | Subtidal zonation | Subtidal biotope ID; Diver-operated video; ROV; Towed video (limited by topography and/or risk of damage) |
| | Spatial pattern of intertidal biotopes | Intertidal resource mapping; Intertidal biotope ID; Viewpoint photography; *Air photo interpretation; Remote imaging* |
| | Spatial pattern of subtidal biotopes | AGDS; Side scan sonar (with mosaicing); Point sample mapping (from Grab sampling, ROV or Drop-down video data); Towed video |

## Specific issues affecting the monitoring of estuaries

An estuary may contain other marine Annex I features – most likely *mudflats and sandflats*, *subtidal sandbanks* and *reefs*. Advice on the monitoring of saltmarsh habitats is provided by Scottish Natural Heritage.[b] Each estuarine attribute will have its own inherent source of variability that must be addressed during data collection and subsequent interpretation of the results. However, some generic issues should be considered when planning the whole monitoring study.

### *Seasonal effects*

Marine communities show seasonal patterns that could significantly affect a monitoring programme in estuaries. Algal communities show some of the most obvious seasonal trends. Banks of loose stones and gravel are often sufficiently seasonally stable to support dense assemblages of ephemeral algae. Sediment flats often support dense green algal mats during the summer months. Rapid growth of microscopic algae, and diatoms in particular, can change the appearance (colour) of intertidal flats[c]. Mud veneers and layers of leaf litter from river flood events can also influence the surface appearance of the sediment.

Many marine organisms have seasonal reproductive patterns that can alter significantly the number of individuals present at different times of the year. For example, some polychaete worms have semelparous or 'boom and bust' life-history strategies where the mature adults spawn synchronously and then die. Clearly, the number of adults present in the sediment will depend on the stage in their lifecycle. Long-lived species such as bivalve molluscs may vary their reproductive output according to the availability of food in the pre-reproductive period. Such intermittent larval settlement and recruitment of juveniles to the population can result in a massive increase in the population size at certain times of the year. In a sampling programme, the presence and number of juveniles should be enumerated separately to the adults in all samples.

Seasonal effects are also prevalent in seagrass communities. The blade density of the seagrass itself will increase during the summer and then decrease during the autumn and winter – a process known as die-back.[d] Seagrass blades may support dense assemblages of epiphytic algae during the summer months, which then decline during the winter.[e]

Seasonal patterns must be considered when planning a monitoring strategy. Sampling should be undertaken at the same time of year if seasonal variation is likely. It may be necessary to specify the duration of a sampling window – for example, to precede post-reproductive death in polychaete communities. The National Marine Monitoring Programme collects benthic macrofaunal samples between February and June. Furthermore, it recommends that samples should be collected within a 'narrow time window within the broader window' to 'minimise the effects of seasonal variability'; they define the narrow time window as ±3 weeks or ±2 weeks in May/June. Seasonal changes in seagrass have important consequences for the timing of remote sensing campaigns because the spectral signature[2] of the seagrass will change between summer and winter.

### *Meteorological changes*

Tidal range is an important factor in understanding estuarine processes and their distribution. This determines the velocity of tidal currents and residual current velocities and therefore the rates and amounts of sediment movement. Both monthly and annual tidal cycles will affect estuarine habitats and therefore any monitoring programme must be carefully planned and implemented to take account of tidal effects.

Variations in salinity are a key factor determining the character and spatial patterns of the biotic assemblages within an estuary. The volume of freshwater entering the estuary (normally a reflection of rainfall patterns) and the tidal cycle determine ambient salinity at any point within an estuary. Both factors are subject to seasonal variation and therefore ambient salinity will show a strong seasonal pattern (Figure 3-3).

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2 See Section 5 for an explanation.

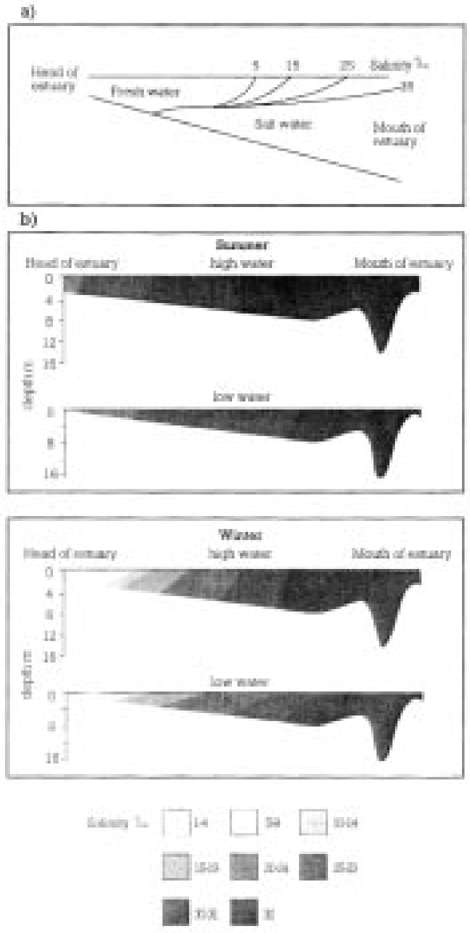


**Figure 3-3** Seasonal changes in salinity in an estuary (from Davidson *et al.* 1991)

Periods of reduced water flow can lead to marked improvements in water clarity. This must be taken into account if monitoring water clarity as an attribute, and will affect the timing of any remote sensing or SCUBA diving campaigns.

## *Access*

Land surrounding estuaries is often under private ownership and therefore it will be necessary to seek the landowner's permission to gain access to the shore, unless access is possible by boat.

Gaining access to estuarine intertidal and subtidal habitats is subject to the issues described under the sections on *reefs*, *mudflats and sandflats* and *subtidal sandbanks*, and is therefore not repeated here.

## *Sampling issues*

A monitoring programme must consider the whole estuary, even where it may contain other Annex 1 features; these features should have their own dedicated monitoring programme (see *reefs*, *sandbanks* and *intertidal flats).* An estuary's monitoring programme may therefore, be an aggregation of both the sampling programmes for a range of Annex 1 features in their own right, and a dedicated sampling programme for additional features of the whole estuary.

Measuring the extent of an estuary requires the careful definition of boundary in relation to the seaward limit, the landward transition to the river, and the high water limit. For those estuaries bounded by rocky shores or solid anthropogenic boundaries such as harbour walls or seawalls, measuring the extent may be a straightforward cartographic exercise using the most up-to-date maps of the area. Estuaries with 'soft' boundaries such as saltmarsh may require a more sophisticated mapping exercise such as remote sensing, particularly in dynamic estuaries where tidal currents result in erosion and/or accretion of these 'soft' habitats. The position of the main estuary channel, and more likely the smaller creeks, may move considerably during a monitoring cycle.[8] although the impact of such a change on the overall extent of the estuary may be negligible.

Estuary morphology – the relationship between its physical form and function – was considered an appropriate attribute to encapsulate the ecological status of an estuary.[f] In simple terms, estuary morphology is the form taken by the bed and banks of the estuarine channel. These views are based on *regime theory*, which includes the hypothesis proposed by O'Brien.[3] Initial sampling should establish the *equilibrium morphology*, and subsequent monitoring events will then establish whether the estuary remains at equilibrium. Any departure from equilibrium may be considered as deterioration from favourable condition. In practical terms, equilibrium is a function of the cross-sectional area and the tidal prism at a series of stations along the estuary.

Changes in the physical structure of the estuary will also impact on a biological sampling programme and clear guidance on sampling protocols must be established at the start of the monitoring programme. Periods of heavy rain can affect an estuarine sampling programme and sampling should avoid such conditions if it is necessary to record elements of the sediment surface. For example, Wyn and Cook (2000)[g] specified that a sampling station was deemed 'saltmarsh' if a $1m^2$ quadrat contained more than 5% cover of saltmarsh plants. Distinctions may also be required to ensure consistency in future sampling programmes.

Many of the physical environmental attributes to be monitored in estuaries (water quality, water density/temperature, nutrient status, and sediment character) are strongly linked to the tidal cycle or the level of freshwater input, and therefore subject to considerable seasonal variation. It is imperative that comprehensive records are kept of the ambient conditions (tidal and meteorological) at the time of sampling. It may also be necessary to record the recent meteorological history, particularly for those estuaries where recent rainfall can result in considerable variations in salinity/tidal flows. When collecting sediment samples for particle size analysis, it is important that the sampling technique preserves the fine sediment fraction, particularly on the surface. It may be appropriate to collect sediment samples by grab at high water to ensure all habitats are sampled in a consistent manner. If sediments are to be subsampled for trace metal and organic contaminant determinations, it will be necessary to use stainless steel buckets for grab/core samplers.

Standard texts are available on estuarine sampling methods.[h, i]

### Site marking and relocation

Marking and relocating the feature itself (the estuary) is unlikely to present any problems although the precise location of the boundary may be difficult where the edge of the estuary has 'soft' habitats. Clear guidance is necessary to define the high water and upper estuary limits to ensure consistent monitoring of the extent of the feature.

Permanent marking of sampling stations is very difficult in dynamic environments where the substrata are mobile. Garden canes (1.5m long) have been used successfully to mark stations in the Wash over a period of three years.[j] Site relocation should use dGPS,[4] particularly on extensive intertidal flats or open sea areas at the mouth. Where dGPS is used for site location, it is vital that the necessary parameters (often settings of the machine itself) influencing the position resolution are accurately recorded. These parameters will be vital for accurate relocation of the site. For less dynamic habitats, sites may be marked with acoustic transponders[k] or curly whirlies[5] or 'nylon whips' attached to sub-surface blocks.[g] Additional information is provided under the guidance for *reefs*, *mudflats and sandflats* and *subtidal sandbanks*.

### Health and safety

All fieldwork must follow approved codes of practice to ensure the health and safety of all staff. Risks specific to working in estuaries are similar to those on intertidal flats:

*Stranding due to the rising tide.* Estuaries often have irregular tidal cycles that result in long low or high water periods followed by a rapid filling or emptying of the system. On intertidal flats, a rising tide can inundate the shore faster than a person can run. Creeks can fill rapidly creating 'islands' on the flats. Tidal currents may increase very rapidly, for example the tidal bore in the Severn Estuary, creating hazardous conditions for boats, particularly whilst stationary during sampling.

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3 O'Brien – quoted in Coastal Geomorphology Partnership (1999) see reference f; no reference given.

4 See Procedural Guideline Number 6-1 for dGPS guidance.

5 Plastic corkscrews that are screwed down into the sediment: see Fowler, S L (1992) *Marine monitoring in the Isles of Scilly 1991*. English Nature Research Report No. 9. English Nature, Peterborough.

*Stuck in sediment*, particularly in soft mud in upper estuaries, on quick sands and mussel beds.

*Illness and disease from contaminated sediment*. Many estuaries have a history of anthropogenic discharges from industrial facilities. Sediments bind contaminants such as heavy metals (and radioactive isotopes) at high concentrations, which are subsequently released upon disturbance. It is possible to contract serious diseases such as hepatitis from sewage effluent, or Weils disease (from water contaminated with rat urine). In such circumstances, protective gloves should be used to avoid skin contact with the sediment.

*Boat traffic*. Many estuaries are busy waterways for both pleasure craft and commercial shipping such as ferries, and provide sheltered permanent moorings or temporary anchorages. Sampling activities, particularly when using a boat and/or when SCUBA diving, may be subject to harbour restrictions and will require the prior permission of the harbour authorities. Nevertheless field staff must be vigilant to avoid the risk of collision with other vessels.

*Gunfire*. Wild-fowling is a common activity in some estuaries although often on a seasonal basis. Similarly, military firing ranges are also present. Field staff should contact local shooting clubs or military ranges to ascertain when there will be no risk of gunfire.

Some sampling in estuaries will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[6] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[7] (**http://www.hse.gov.uk/spd/spdacop.htm - a**).

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k Sanderson, W G *et al.* (2000) Establishment of fixed stations on the north Pen Llyn horse mussel (*Modiolus modiolus*) and Sarn Badrig reefs. In: Sanderson, W G *et al.* (2000) *The establishment of an appropriate programme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998-1999 trials*, pp.191–196. CCW Contract Science Report No: 380. Countryside Council for Wales, Bangor.


6 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997, ISBN 0 11 065170 7.

7 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997. Approved Code of Practice and Guidance – L107. HSE Books 1998, ISBN 0 7176 1498 0.

# Sandbanks which are slightly covered by seawater all the time

**Definition**

Sublittoral sandbanks, permanently submerged. Water depth is seldom more than 20 m below Chart Datum. Non-vegetated sandbanks or sandbanks with vegetation belonging to the *Zosteretum marinae* and *Cymodoceion nodosae*.

## Introduction to the feature's interest

This habitat type occurs widely on the north-east Atlantic coast of Europe and is extensive in the UK. Sites have been selected to represent the main geographical and ecological range of variation of the habitat type and are amongst the most extensive in the UK.

The habitat type consists of soft sediment types that are permanently covered by shallow sea water, typically at depths of less than 20 m below chart datum. Sites have been selected to cover the geographical and ecological range of variation of the following categories:

(i) gravelly and clean sands

(ii) muddy sands

(iii) eelgrass *Zostera marina* beds

(iv) maerl beds

The latter two categories are distinctive communities associated with shallow sublittoral sandy sediments and are of particular value because of the diversity of species they may support.

The diversity of species and communities associated with subtidal sandbanks is determined by sediment type and a variety of other physical factors. These include geographical location reflecting biogeographical trends, the relative exposure of the coast (from wave-exposed open coasts to tide-swept coasts or sheltered inlets and estuaries) and differences in the depth, turbidity and salinity of the surrounding water. The site series includes a range of physiographic types to encompass the variation within the four main sub-types of this Annex I habitat.

Shallow sandy sediments are typically colonised by a burrowing fauna predominantly of worms, crustaceans, bivalve molluscs and echinoderms. Mobile fauna at the surface of the sandbank may include shrimps, prosobranch molluscs, crabs and fish. Sandeels, an important food for birds, live in sandy sediments. Epifaunal organisms such foliose algae, hydroids, bryozoans and ascidians may occur where coarse stable material such as small stones, shells or maerl is present. Mixtures of sand and hard substrata can lead to the presence of very rich communities. Shallow sandy sediments may be important nursery areas for fish and feeding grounds for seabirds (especially puffins *Fratercula arctica*, guillemots *Uria aalge* or razorbills *Alca torda*) and seaduck (for instance common scoter Melanitta nigra).

## Typical attributes to define the feature's condition

### *Generic attributes*

Table 3.4-1 lists the generic attributes for subtidal sandbank features and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge improves of the factors that determine the condition of sandbank ecosystems.

**Table 3.4-1** Summary of attributes that may define favourable condition of subtidal sandbanks.

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Extent* | | |
| Extent of feature | Area of subtidal sediment | Extent of the feature is a reporting requirement of the Habitats Directive. In dynamic situations, fluctuations in extent may be great, but are attributable to natural coastal processes beyond management control. A full understanding of such variability will only be gained after a number of monitoring cycles. |
| Extent of a sub-feature | Extent (ha) of seagrass, normally measured during peak growth period (*likely between May-August*) | The extent of seagrass is a key structural component of some sandbanks and provides a long-term integrated measure of environmental conditions across the feature. |
| | Extent of mussel beds | The extent of mussel beds is a key structural component of the sediments and, depending on the size and distribution of the beds, they may play an important functional role within the feature, e.g. by stabilising the sediment. It should be recognised that mussel beds are a dynamic habitat although in many cases beds tend to remain in the same place in the long term whilst patchiness within them is often much more dynamic. |
| | Extent of brittlestar beds | The extent of brittlestar beds is a key structural component of the sediments, represents a major concentration of biomass within the feature, and may play an important role in local carbon and nutrient cycles.[b] Fluctuations in brittlestar beds have been shown to relate both to large-scale hydrographic processes and to short-term localised events; thus they will indicate environmental change at a range of scales. |
| *Physical properties* | | |
| Sediment character | Particle size analysis: parameters include the percentage sand/silt/gravel, mean and median grain size, and sorting coefficient, used to characterise sediment type | Sediment character defined by particle size analysis is vital to the structure of the feature, and reflects all of the physical processes acting on it. Particle size composition varies across the feature and can be used to indicate spatial distribution of sediment types thus reflecting the stability of the feature and the processes supporting it. |
| Topography | Depth and distribution of sandbanks | Depth and distribution of the sandbanks reflects the energy conditions and stability of the sediment, which is key to the structure of the feature. Depth of the feature is a major influence on the distribution of communities throughout. |
| Water density – temperature and salinity | Regular measurement of water temperature and salinity in the subtidal periodically throughout the reporting cycle | Temperature and salinity are characteristic of the overall hydrography of the area. Changes in temperature and salinity influence the presence and distribution of species (along with recruitment processes and spawning behaviour) including those at the edge of their geographic ranges and non-natives. |
| Nutrient status | Extent (range and area) of macroalgae across whole or parts of the feature, measured during peak growth period (*likely between May-August*) | Nutrient status is a key functional factor that influences the sub-feature as opportunistic macroalgae compete with important biotopes (sub-features) such as seagrass, and affect the associated species. Note that an increase in filamentous green algae may be a related natural phenomenon or may indicate eutrophication |
| Nutrient enrichment – phytoplankton | Average phytoplankton concentration (ChlA) | Chlorophyll A concentration provides an indication of nutrient levels and their effect on the sediment communities. |
| Water clarity | Average light attenuation measured periodically throughout the reporting cycle | Water clarity is important for maintaining extent and density of algal and plant dominated communities. Clarity decreases through increases in amounts of suspended organic/inorganic matter. |

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Biotic composition* | | |
| Spatial distribution of all or a range of biotopes | Relative distribution of biotopes throughout the feature | The relative distribution of biotopes is an important structural aspect of the feature. Changes in extent and distribution may indicate long term changes in the physical conditions at the site. |
| Biotope composition | Number and occurrence / frequency of range of characteristic biotopes measured during the summer months, once during reporting cycle. | The number and occurrence/ frequency of characteristic biotopes is an important structural aspect of the feature. |
| Presence and distribution of a specific biotope | Distribution/ presence-absence/frequency of a typical or notable biotope | The biotopes chosen should be a key structural component of the sediments, and may be important because they are *notable, i.e. of nature conservation importance due to their rarity/scarcity, or region importance;have high species richness;* *an extensive example;* *sensitive to anthropogenic activity .eg introduction of non-native species; and/or* *indicative of changes in the supporting processes of the ecosystem.* |
| Species composition of specific biotopes | Frequency and occurrence/ diversity index of composite species (total or sub-set) | Species composition is an important contributor to the structure of some biotopes. A measure of species diversity also gives an indication of the quality of a biotope, where any change in diversity may indicate a cyclic change or trend in sediment communities. |
| Population status of characteristic species | Estimate population size using abundance/occurrence/ frequency/biomass Measure the population structure using for example age structure | The species selected may be of interest in its own right and/or be indicative of the structure of an important biotope. A change in the population status of a species may indicate cyclic change/trend in the host biotope and/or the sediment (sub) feature as a whole. |
| *Zostera marina* density | Average density, measured during peak growth period (*likely between May–August*) | An early indicator of seagrass under stress is a reduction in biomass, normally measured by the number and length of leaves. Density is preferred as a surrogate for biomass, being less destructive, based on a baseline survey to establish the relationship between density and biomass at a site. |
| *Sabellaria spinulosa* | Measure recruitment from the age structure (see Holt *et al*. 1998).[a] | Recruitment processes are important to the species (or sub-feature) with respect to both the maintenance of the biogenic reef (structure) and then functional role that the sub-feature plays within the feature as a whole. |
| Status of notable species | Measure the occurrence and frequency of a specified species | A *notable species*: has nature conservation importance due to its rarity/scarcity, or regional importance; has high abundance and contributes to sediment structure; may be used as an indicator of environmental stress if it is a species sensitive to pollution e.g. molluscan sensitivity to TBT. |
| *Biological structure* | | |
| Spatial distribution of biotopes or sub-features | Distribution and extent of characteristic biotopes | The relative distribution of biotopes, for instance sand and sandy gravel biotopes, is an important structural aspect of the site. Changes in the extent and distribution may indicate long-term changes in the prevailing physical conditions at the site. |
| | Relative distribution of different maerl biotopes | The relative distribution of different maerl biotopes, live/dead maerl and patchiness within the maerl bed, are important structural aspects of the sub-feature and therefore feature as a whole. Changes in relative extent and distribution may indicate long-term changes in the physical conditions influencing the feature. |
| Spatial patterns of characteristic species | Presence/absence and density of different brittlestar species | The sub-feature (subtidal brittlestar beds biotope complex) is defined by the occurrence of brittlestars at high densities. Hence density is critical to the structure of the sub-feature; note that beds usually have a patchy internal structure with localised concentrations of higher density. The main bed-forming species are *Ophiothrix fragilis* (the most common bed-forming species) and *Ophiocomina nigra* (less frequently forming beds on sublittoral sediments). Sometimes the beds comprise mixed populations of both species. The two species have different environmental requirements and feeding strategies, and hence recording which species is relevant to the function of the sub-feature and feature as a whole is necessary. |

## *Suggested techniques for monitoring sandbank attributes*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.4-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

**Table 3.4-2** Suggested techniques for measuring sandbank attributes. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Extent | | AGDS; Side scan sonar; Point sample mapping; Towed video (for shallow areas: *Air photo interpretation; Remote imaging)* |
| | Biotope extent | AGDS; Side scan sonar; Mosaicing sonar images; Point sample mapping (using grab, ROV or Drop-down video samples |
| Physical properties | Substratum: sediment character | Particle size analysis; Sediment profile imaging; *Sediment chemical analyses* |
| | Topography | *Bathymetric mapping* (Depth is recorded by AGDS) |
| | Tidal regime | *Current meters; Tide gauges; Water chemistry data loggers* |
| | Water clarity | Measuring water quality; *Water chemistry data loggers; Secchi disk* |
| | Water chemistry (including salinity, temperature) | Measuring water quality; *Water chemistry data loggers* |
| | Nutrient status | Measuring water quality; *Water chemistry data loggers*; (Biotope extent techniques for algal mats) |
| Biotic composition | Biotope richness | Subtidal biotope ID; Grab sampling; Subtidal core sampling |
| | Species composition/richness | Grab sampling; Subtidal core sampling; Suction sampling; Fish on sediment (Epibiota only: Drop-down video; ROV; Diver-operated video; Towed video; *Epibenthic trawling*) |
| | Characteristic species | Grab sampling; Subtidal core sampling; Suction sampling; Fish on sediment |
| Biological structure | Spatial pattern of subtidal biotopes | Point sample mapping (from Grab sampling, ROV or Drop-down video data); AGDS; Side scan sonar (with mosaicing); Towed video |

## Specific issues affecting the monitoring of sandbanks

Each attribute will have its own inherent source of variability that must be addressed during data collection and subsequent interpretation of the results. However, some generic issues should be considered when planning the whole monitoring study.

### *Seasonal effects*

Marine communities show seasonal patterns that could significantly affect a monitoring programme on subtidal sandbanks. Algal communities show the most obvious seasonal trends and sandbank habitats may support dense ephemeral algal communities during the summer months. Maerl beds support rich algal assemblages with distinct seasonal variation. For instance, a marked change in the abundance of algae in tidal rapids was observed in Loch Maddy between autumn 1998 and summer 1999.[c]

Many marine organisms have seasonal reproductive patterns that can significantly alter the number of individuals present at different times of the year. Some polychaete worms have semelparous or 'boom and bust' life history strategies where the mature adults spawn synchronously and then die. Clearly, the number of adults present in the sediment will depend on the stage in their lifecycle. Larval settlement and recruitment of juveniles to the population can result in a massive increase in the population size at certain times of the year. The presence and number of juveniles should be enumerated separately to the adults in all samples.

Seasonal effects are also prevalent in seagrass communities. The blade density of the eelgrass itself will increase during the summer and then decrease during the autumn and winter – a process known as die-back.[d] Seagrass blades may support dense assemblages of epiphytic algae during the summer months, which then decline during the winter.

Seasonal patterns must be considered when planning a monitoring strategy. Sampling should be undertaken at the same time of year if seasonal variation is likely. It may be necessary to specify the duration of a sampling window – for example, to precede post-reproductive death in polychaete communities. Seasonal changes in seagrass have important consequences for the timing of remote sensing campaigns because the spectral signature[1] of the seagrass will change between summer and winter.[e]

### *Meteorological changes*

Prevailing weather conditions will affect any monitoring study. Periods of calm conditions will improve underwater visibility and improve sampling efficiency and reliability. Subtidal sandbanks are often located in areas of strong tidal streams and therefore sampling should take place at slack water. If possible, sampling exercises should avoid the equinoctial tides when the duration of slack water will be at its shortest.

A change in the strength of prevailing wave action, or a change in the frequency of winter storms, could lead to a gradual change in the topography, or even the location, of a sandbank. Such changes could affect a sampling programme, particularly where a grid sampling strategy was used.

Weather cycles can result in changes in the biotic assemblages. Changes in perennial algae on Loch Maddy maerl beds were possibly due to an unusually warm preceding summer. [See note c above]

### *Access*

Boats are required to sample subtidal sandbanks. Where necessary, sampling should be timed to coincide with slack water and calm conditions.

### *Sampling issues*

Subtidal sandbanks pose a number of logistical and methodological problems to a monitoring study. It is important to establish the extent of the entire feature to plan an effective monitoring strategy. Often, sandbanks will form a mosaic of patches that are distributed throughout an SAC. In such circumstances, it may be necessary to develop a stratified monitoring strategy based on an initial inventory of the entire sandbank resource. Individual sandbanks may be categorised – for example, by topographical structure or sediment type, to stratify a monitoring programme. Such a programme should ensure that all categories are sampled. For individual categories (a single sandbank), sample sites should be spread throughout to ensure adequate consideration of spatial variation. It cannot be assumed that a single sample station will be representative of the habitat as a whole. The actual number of stations necessary to describe the full range of species present should be determined from a pilot study. A sampling strategy should consist of many stations with few replicates per station (even just one) when considering attrib-

1 See Section 5 for an explanation

utes relating to biological description.

Unfortunately, mapping the extent of sandbanks is difficult, particularly in shallow areas where boat access is difficult, and water clarity is too low to use remote sensing techniques based on electromagnetic spectral radiation. In such conditions, it would be necessary to use a grid sampling technique to map extent. Prevailing hydrodynamic conditions will shape the topographic structure of sandbanks, for instance by creating sand waves on the surface. Small fluctuations in the hydrodynamic regime, often at the scale of metres (or less) will affect the physical structure of the sediment, which in turn may lead to significant differences in the biotic assemblage. A recent investigation into the populations of sandeels on sandbanks in the Firth of Forth recorded considerable fine scale heterogeneity in sediment structure (over tens of metres) that resulted in huge variations in the density of fish present in sediment. It will be necessary to map a subtidal sandbank during each monitoring cycle, both to estimate its extent and to plan more detailed sampling.

Ambient physical conditions, particularly sediment type, determine the precise biotic composition of sediment biotopes. Whilst attributes relating to biotic composition should use the terminology in the national biotope classification, it will be necessary to define carefully the actual species composition recorded locally. Such local descriptions will help to avoid any ambiguities when assigning a future sample to a biotope class.

The choice of actual technique used to sample the sediment within an SAC will be influenced by the type of sediment present, but must be consistent throughout all samples used to monitor an individual attribute. Samples should be processed through a 1mm sieve, unless previous investigations indicate a finer mesh is necessary to sample the target biotic assemblage adequately. Where a finer mesh is necessary, the sample should be subdivided to provide a 1mm mesh fraction. It is important to consider any other established sampling/monitoring studies in an SAC prior to finalising the mesh size. If the data from such studies can contribute to an SAC monitoring programme, it will be necessary to harmonise the mesh size between all subsequent monitoring studies to ensure data are comparable.

### *Site marking and relocation*

Permanent marking of sandbanks may not be possible because of their dynamic nature and their geographic location may move between monitoring events. Site relocation will rely on dGPS,[2] particularly in offshore areas.

For less dynamic habitats, sites may be marked with acoustic transponders[3] or curly whirlies.[4]

### *Health and safety*

All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent.

Subtidal sandbanks often create shallow shoals that generate rough sea conditions in comparison to adjacent level areas of seabed. Strong tidal streams may also be present which, when combined with strong winds, will create rough sea conditions. Prevailing sea conditions must be assessed prior to any sampling exercise.

Sublittoral sediment sampling often involves heavy equipment (grabs, dredges) and deck machinery (winches) that have specific health and safety requirements which must be followed at all times. Furthermore, sea conditions have a significant effect on the safe use of this equipment – unexpected movement of the vessel due to a boat's wake can result in a grab violently swinging across the deck.

Some sampling on subtidal sandbanks will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[5] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[6] (**http://www.hse.gov.uk/spd/spdacop.htm - a**).

2 See Procedural Guideline 6-1 on dGPS guidance.

3 See Procedural Guideline 6-2 on site marking

4 Plastic corkscrews that are screwed down into the sediment: see Fowler, S L (1992) *Marine monitoring in the Isles of Scilly 1991*, English Nature Research Report No. 9. English Nature, Peterborough.

5 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997, ISBN 0 11 065170 7.

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# Mudflats and sandflats not covered by seawater at low tide

**Definition**

Sands and muds of the coasts of the oceans, their connected seas and associated lagoons, not covered by sea water at low tide, devoid of vascular plants, usually coated by blue algae and diatoms. They are of particular importance as feeding grounds for wildfowl and waders. The diverse intertidal communities of invertebrates and algae that occupy them can be used to define subdivisions of 11.27, eelgrass communities that may be exposed for a few hours in the course of every tide have been listed under 11.3, brackish water vegetation of permanent pools by use of those of 11.4.[1]

## Introduction to the feature's interest

This is a widespread habitat type on the coasts of Atlantic Europe and occurs widely throughout the UK. Sites were selected to encompass the range of geographical and ecological variation of this habitat type in the UK. Sites with large areas of intertidal flats as well as a range of shelter, mobility and diversity of sub-types were favoured.

Intertidal mudflats and sandflats are submerged at high tide and exposed at low tide. They form a major component of estuaries and embayments in the UK but also occur on the open coast. The physical structure of the intertidal flats can range from the mobile, coarse-sand beaches of wave-exposed coasts to the stable, fine-sediment mudflats of estuaries and embayments. This habitat type can be divided into three broad categories: clean sands, muddy sands and muds, although in practice there is a continuous gradient between them. Within this range, the plant and animal communities present vary according to the type of sediment, its stability and the salinity of the over-lying water.

*Clean sands*. These communities occur on clean, sandy beaches on the open coast and in bays around the UK, where wave action or strong tidal streams prevent the deposition of finer silt. Clean sands also occur in estuaries where the supply of silt in suspension is low. In such conditions, there is a high proportion of the heavier grains of sediment. Owing to the mobility of the sand and consequent abrasion, species that inhabit clean sands tend to be mobile and robust and include amphipod crustaceans, such as sandhoppers *Bathyporeia* spp., some polychaete worms and bivalve molluscs.

*Muddy sands*. These occur in a particular combination of conditions. Shelter from wave action is sufficient to allow the deposition of fine sediments, but some water movement or the lack of supply of silt leads to a sandier substratum. Such conditions may occur at the mouths of estuaries or behind barrier islands, where sediment conditions are more stable. A wide range of species, such as lugworms *Arenicola marina* and bivalve molluscs, can colonise these sediments. Substantial beds of mussels *Mytilus edulis* may develop on the lower shore. Beds of intertidal dwarf eelgrass *Zostera noltii* or narrow-leafed eelgrass *Zostera angustifolia* and eelgrass *Zostera marina* may also occur on the lower shore. In estuaries, reduced salinity may cause a variation in these communities.

*Mudflats*. These form in the most sheltered areas of the coast, usually where large quantities of silt derived from rivers are deposited in estuaries. The sediment is stable and communities are dominated by polychaete and oligochaete worms, and bivalve molluscs. Soft mudflats often support very high densities of some infaunal species, where the high biomass of intertidal species provides an important food source for waders and wildfowl.

The complex nature of the Annex I feature *mudflats and sandflats* means that many sites will contain a mixture of the types described above.

## Typical attributes to define the feature's condition

### *Generic attributes*

Table 3.5-1 lists the generic attributes for mudflat features and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge improves of the factors that determine the condition of intertidal sediment ecosystems.

1 These numbers are the habitat codes in the Palaearctic classification (originally the CORINE classification). For further information refer to *The Interpretation Manual of European Habitats – EUR 15* (version 2, October 1999) published by the European Commission (see: **http://europa.eu.int/comm/environment/nature/docum.htm**)

**Table 3.5-1** Summary of attributes that may define favourable condition of intertidal mudflats and sandflats

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Extent* | | |
| Extent of the feature | Area of the intertidal flats | Extent of the feature is a reporting requirement of the Habitats Directive. For dynamic coastlines, fluctuations in extent may be great, but are attributable to natural coastal processes. |
| Extent of a sub-feature or characteristic biotope | Area of seagrass measured during peak growth period (*likely between May–August*) | Where present, the extent of seagrass is an important structural component of sediment flats, and provides a long-term integrated measure of environmental conditions across the feature. |
| | Area of mussel beds | The extent of mussel beds is an important structural component of sediment flats and, depending on the size and distribution of the beds, they may play an important functional role within the feature, e.g. by stabilising sediment. It should be recognised that mussel beds are a dynamic habitat, although in many cases beds tend to remain in the same place in the long term whilst patchiness within them is much more dynamic. |
| *Physical structure* | | |
| Sediment character | Particle size distribution of the sediment used to characterise sediment type. The analysis should include the parameters: % sand/silt/gravel, mean and median grain size, and sorting coefficient | Sediment character defined by particle size analysis is key to the structure of the feature, and reflects all of the physical processes acting on it. Particle size composition varies across the feature and can be used to indicate spatial distribution of sediment types (*and some or all sub-features*), thus reflecting the stability of the feature and the processes supporting it. |
| | Sediment penetrability by the degree of sinking | Penetrability is an indicator of sediment stability, degree of compaction indicates the shear strength of the sediment and thus the susceptibility of that sediment type to erosion. Compaction of the sediment influences the biological community within the sediment. |
| | Proportion of organic carbon from sediment sample | Organic content critically influences the infaunal community and can cause deoxygenation of the feature, which can be detrimental to the biota. |
| | Oxidation/reduction potential by the depth of any black layer, or by an in situ measurement (Eh of redox potential) | Degree of oxidation/reduction, reflecting oxygen availability within the sediment, critically influences the infaunal community and the mobility of chemical compounds. It is an indicator of the structure of the feature. |
| Topography | Tidal elevation and shore profile | Topography reflects the prevailing energy conditions and the stability of the sediment, which is key to the overall structure of the feature. Height on the shore has a major influence on the distribution of communities throughout the feature.<br>Measuring topography may also indicate the position of channels through the feature, which is another important indicator of the processes influencing the site. |
| Water density: temperature and salinity | Regular measurement of water temperature and salinity | Temperature and salinity are characteristic of the overall hydrography of the area. Any changes in the prevailing temperature and salinity regimes may affect the presence and distribution of species (along with recruitment processes and spawning behaviour), including those at the edge of their geographic ranges. |
| Nutrient status of overlying water mass | Abundance of macroalgae on the feature | Nutrient status is a key functional factor that influences biota associated with sediments including infauna as well as plants/algae at the surface. *Indicator macroalgae* indicate elevated nutrient levels that reduce the quality of the sediments and their communities, primarily through smothering and deoxygenation. Opportunistic macroalage compete with important species such as seagrass and affect the associated species assemblage. An increase in filamentous green algae may be a related natural phenomenon or may indicate eutrophication |
| Notable species - macroalgae | Extent (ha) across whole or parts of site, measured during peak growth period (*likely between May–August*) every three years (*more frequently depending on site*) during reporting cycle. | Nutrient status is a key functional factor that influences the sub-feature as opportunistic macroalgae compete with important biotopes (sub-features) such as seagrass, and affect associated species.<br><br>Note that an increase in filamentous green algae may be a related natural phenomenon or may indicate eutrophication. |

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Biotic composition* | | |
| Biotope composition | Number and occurrence/frequency of a range of specified biotopes | The number and occurrence/frequency of biotopes is an important structural aspect of the feature. |
| Species composition of a specific biotope | Measure the frequency and occurrence/diversity index of composite species (total or sub-set) | Species composition is an important contributor to the structure of a biotope. A determination of species diversity gives an indication of the quality of the biotope, and a change in diversity may indicate cyclic change/trend in sediment communities. |
| Population status of a characteristic species | Estimate the population size using a measure of *abundance/occurrence/ frequency/biomass* Measure relevant population parameters, e.g. age structure | The species selected may be of interest in its own right, and/or may be indicative of the structure of a characteristic or notable biotope. A change in the population status of the species may indicate a cyclic change/trend in the host biotope, and/or the sediment communities in the feature as a whole. |
| Notable species | Occurrence and frequency of characteristic species | Notable species:<br>are of nature conservation importance due to e.g. rare/scarce, regionally important;<br>contribute to sediment structure; and/or<br>can be used as an indicator of environmental stress e.g. molluscan sensitivity to TBT. |
| *Zostera marina* and/or *Zostera noltii* density | Average density of a sea-grass species, measured during peak growth period (*likely between May–August*) | An early indicator of seagrass under stress is a reduction in biomass, normally represented through the number and length of leaves. Density is preferred as a surrogate for biomass, being less destructive, based on baseline survey to establish the relationship between density and biomass at a site. |
| *Biological structure* | | |
| Spatial distribution of all biotopes, or a range of specified biotopes | Relative distribution of biotopes throughout the (sub) feature | The relative distribution of biotopes is an important structural aspect of the feature. Changes in extent and distribution may indicate long-term changes in the physical conditions at the site. |
| Spatial distribution of a specific biotope | The distribution/presence or absence/frequency of a specified typical or notable biotope | The spatial distribution/occurrence of a biotope is a key structural component of the sediments, and is particularly important if:<br>it is notable for nature conservation due to its rarity/scarcity or regional value;<br>it has high species richness;<br>it is an extensive example;<br>it is sensitive to anthropogenic activity; and/or<br>an indicator of changes in the supporting processes of the feature. |
| Spatial patterns in populations of characteristic species | For mussel *Mytilus edulis* beds, measure the extent, abundance and/or size/age profile, or spatfall[2] | If present, mussels are an important structuring species of the (sub) feature and therefore a key influence on the associated community. An indication of the population dynamics of the species and whether it is sustaining itself within the bed is necessary in addition to extent of all mussels beds in the feature. |

2 Settlement of juvenile mussels onto the seabed.

### *Suggested techniques for monitoring attributes of mudflats and sandflats*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.5-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

**Table 3.5-2** Suggested techniques for measuring attributes of mudflats and sandflats. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Extent | | *Air photo interpretation; Remote imaging;* Intertidal resource mapping; |
| | Biotope extent | Intertidal resource mapping; Intertidal biotope ID; *Air photo interpretation; Remote imaging* |
| Physical properties | Substratum: sediment character | Particle size analysis; *Sediment chemical analyses* |
| | Topography | *LIDAR; Shore profiling* |
| | Water chemistry (including salinity, temperature) | Measuring water quality; *Water chemistry data loggers* |
| | Nutrient status | Measuring water quality; *Water chemistry data loggers;* (Biotope extent techniques for algal mats) |
| Biotic composition | Biotope richness | Intertidal resource mapping; Intertidal biotope ID; Intertidal core sampling |
| | Species composition/richness | Intertidal core sampling; Intertidal ACE |
| | Characteristic species | Intertidal core sampling; Intertidal ACE; Intertidal biotope ID; Mollusc shell ageing |
| Biological structure | Spatial pattern of biotopes | Intertidal resource mapping; Intertidal biotope ID; *Air photo interpretation; Remote imaging; Transect survey* |

## Specific issues affecting the monitoring of mudflats

Each attribute will have its own inherent source of variability that must be addressed during data collection and subsequent interpretation of the results. However, some generic issues should be considered when planning the whole monitoring study.

### *Seasonal effects*

Marine communities show seasonal patterns that could significantly affect a monitoring programme. Algal communities show the most obvious seasonal trends and sediment flats often support dense green algal mats during the summer months. Rapid growth of microscopic algae, and diatoms in particular, can change the appearance (colour) of intertidal flats.[b] Similar changes may be caused by nutrient enrichment and therefore it is important to exercise a degree of caution when interpreting the results of a monitoring study. It would be prudent to avoid sampling during the spring and summer months where such seasonal changes are known to occur at a site and are not linked to the attribute under investigation.

Many marine organisms have seasonal reproductive patterns that can significantly alter the number of individuals present at different times of the year. Some polychaete worms have semelparous or ‘boom and bust’ life history strategies where the mature adults spawn synchronously and then die. Clearly, the number of adults present in the sediment will depend on the stage in their lifecycle. Larval settlement and recruitment of juveniles to the population can result in a massive increase in the population size at certain times of the year. This phenomenon is often visible on mussel *Mytilus edulis* beds where the entire surface may be covered with tiny mussels.

Seasonal effects are also prevalent in eelgrass *Zostera* spp. communities. The blade density of the eelgrass itself will increase during the summer and then the decrease during the autumn and winter – a process known as die-back.[c] Eelgrass blades may support dense assemblages of epiphytic algae during the summer months.

It is important to consider seasonal patterns when planning a monitoring strategy. Sampling should be undertaken at the same time of year if seasonal variation is likely. It may be necessary to specify the duration of a sampling window – for example, to precede post-reproductive death in polychaete communities.

### *Meteorological changes*

Meteorological changes that may affect intertidal flats include:

- erosion following winter storms or river flood events will affect the extent of the flats;
- accretion of saltmarsh will reduce the intertidal area;
- movement of river channels[d] or drainage creeks will change the topography:
- different rainfall patterns may lead to a change in sediment depositional patterns through to changes in run-off and/or a river flow rates.

### *Access*

Intertidal sediment flats may cover a vast area and therefore present significant logistical problems for sampling. Sampling must coincide with low water during the spring tide part of the tidal cycle to gain access to the entire feature. There are important health and safety issues to consider in relation to access (see Health and Safety), especially in relation to tidal inundation and the stability of the sediment. Sites may have local restrictions on bait collection and therefore it will be necessary to advise the local organisation responsible for enforcement of any sampling activity. It may be tactful to ensure local fishermen and bait collectors are fully informed that sampling activities (perhaps undertaken by ‘outsiders’) are for monitoring the SAC.

It may be necessary to use a boat to gain access to the lowest shore areas, and any 'island' areas created by tidal creeks. Motorised transport such as small All Terrain Vehicles (ATVs), tractors (wheels can get stuck in soft sediment) or hovercraft (very noisy) can maximise the time available for sampling within the tidal cycle, and to carry any samples collected.

Sediment flats often support large populations of birds and, in some cases, seals. Sampling activities are likely to disturb these animals and therefore field visits should not coincide with important periods in the life-cycle (breeding, rearing of offspring).

Sampling in soft sediment poses additional problems, particularly through the instability of the substratum. Plastic sledges are useful for carrying sampling equipment and providing support in soft sediment areas. 'Mud shoes' help spread an individual's body weight over a larger area to reduce the risk of sinking, and thus improve their ease of movement. Subtidal sampling techniques may be used to sample extensive areas of soft mud at high water if access from land is particularly difficult or dangerous.

Any areas of quicksand should be identified; gathering knowledge from local inhabitants is often vital in this respect. Mussel beds, whilst appearing to give a solid surface, are often unstable and the sediment underneath may be very soft.

### *Sampling issues*

The whole feature must be considered when planning a sampling programme. Clearly, this poses considerable logistical problems when dealing with very extensive sites (such as the Wash and Morecambe Bay). A monitoring strategy will need to encompass techniques to consider broad-scale, whole feature attributes such as extent, and detailed sampling to assess the biotic composition. A broad-scale mapping exercise would both provide data on the extent of the whole feature and show any spatial patterns in the habitat/biotopes present within the feature. Broad-scale maps provide the necessary information to apply a stratified sampling programme to select locations to monitor sediment structure and the composition of biotopes via direct sampling.

Monitoring trials supported by the UK Marine SACS Project investigated three approaches to direct sampling: a transect-sampling approach in the Wash & North Norfolk Coast cSAC[e] and the Mawddach Estuary, Pen Llyn a'r Sarnau cSAC[f] and an *in situ* biotope recording and Phase 2 sampling with a grid strategy in the Mawddach Estuary.[g] All sampling techniques collected core samples, for sediment analysis and the enumeration of infaunal species assemblages, at pre-determined points along a transect or at a grid node. These strategies will also identify any spatial patterns in the biotic composition of the feature, such as zonation from the top to the bottom of the shore.

If access by foot is restricted or impossible, it is possible to sample intertidal flats by boat at high water where there is sufficient tidal range. Small versions of ship-borne sampling devices are available, such as hand-operated grabs or corers, and a suction sampler.[h] Note that sampling at high water does not allow any visual appraisal of the broad-scale character of intertidal flats.

It is important to select the most appropriate mesh size for an infaunal sampling campaign on sediment flats. A general recommendation is that a 1mm mesh is sufficient for most sediment types from mud to sand, unless previous investigations indicate a finer mesh is necessary to sample the target biotic assemblage adequately. The studies in the Wash and the Mawddach used a 0.5mm mesh when sampling predominantly sandy sediments. Where a finer mesh is necessary, the sample should be sub-divided to provide a 1mm mesh fraction. It is important to consider any other established sampling and monitoring studies in an SAC prior to finalising the mesh size. If the data from such studies can contribute to an SAC monitoring programme, it will be necessary to harmonise the mesh size between all monitoring studies to ensure data are comparable.

### *Site marking and relocation*

Intertidal flats are dynamic environments that present considerable problems for site marking. Markers can be buried or washed away if the flats change their profile. When using a transect approach, it will be necessary to fix the end of the transect with a marker pole taking care to record its position accurately either by dGPS or via photographs/drawing of any conspicuous landmarks. The position of samples along a transect can be recorded by dGPS and/or marked with a permanent marker. Long canes (1.5m ) pressed down into the sediment to leave approximately 30cm exposed lasted at least 3 years in the Wash.[f]

DGPS should be used for recording position on extensive intertidal flats.[3] Whilst landmarks may often be extremely valuable when relocating stations, it is important not to rely on the location of features within sediment flats (creeks, scars, old tyres!!) as they are liable to change.

### *Health and safety*

All fieldwork must follow approved codes of practice to ensure the health and safety of all staff. Risks specific to working on intertidal flats are:

- *Stranding due to the rising tide.* Due to the 'flat' nature of this environment, a rising tide can inundate the shore faster than a person can run. Creeks can fill rapidly creating 'islands' on the flats.
- *Stuck in the sediment*, particularly in soft mud, on quick sands and mussel beds.
- *Illness and disease from contaminated sediment.* Sediments bind contaminants such as heavy metals (and radioactive isotopes) at high concentrations, which are subsequently released upon disturbance. It is possible to contract serious diseases such as hepatitis from sewage effluent, or Weils disease (from water contaminated with rat urine). In such circumstances, protective gloves should be used to avoid skin contact with the sediment.

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3 See Procedural guideline No 6-1.

# Large shallow inlets and bays

**Definition**

Large indentations of the coast where, in contrast to estuaries, the influence of freshwater is generally limited. These shallow indentations are generally sheltered from wave action and contain a great diversity of sediments and substrates with a well developed zonation of benthic communities. These communities generally have a high biodiversity. The limit of shallow water is sometimes defined by the distribution of the *Zosteretea* and *Potametea* associations.

Several physiographic types may be included under this category provided the water is shallow over a major part of the area: embayments, fjards, rias and voes.

## Introduction to the feature's interest

*Large shallow inlets and bays* are large indentations of the coast, generally more sheltered from wave action than the open coast. They are relatively shallow, usually averaging less than 30m in depth across at least 75% of the site. They are often complex systems composed of an interdependent mosaic of subtidal and intertidal habitats. Several of these habitats form Annex I features in their own right. The physiographical character of Large shallow inlets and bays is similar to that of the Annex I feature Estuaries, but the influence of freshwater is reduced by comparison.

In the UK, three main physiographic types can be identified that meet the EC definition:

*Open coast bay and embayment*: a type of marine inlet typically where the line of the coast follows a concave sweep between rocky headlands, sometimes with only a narrow entrance to the embayment.

*Fjardic sealoch*: a series of shallow basins connected to the sea via shallow and often intertidal sills. Fjards are found in areas of low-lying ground, which have been subject to glacial roughening. They have a highly irregular outline, no main channel and lack the high relief and U-shaped cross-section of fjordic sealochs.

*Ria*: a drowned valley in an area of high relief; most have resulted from the post-glacial rise in relative sea level. This sub-type is known in Scotland as a Voe, where it is restricted to the Shetland Islands. (The type is distinguished from the Ria estuaries described in the Section Esturies by their relative lack of freshwater inflow and near full salinity conditions.)

This is a very variable habitat type. The different sub-types vary in their distribution and extent. While some are widespread in Europe, others are found mainly in the UK. The habitat type is widespread in the UK, but some sub-types are localised in their distribution. Sites have been chosen to represent the range of physiographic types, the geographical range and the ecological variation of this habitat type. Selection favoured larger sites, which tend to encompass the greatest variety of habitats.

There are only a few large embayments around the coast of the UK. Rias occur only in southern Wales and south-west England, while voes (which are similar in physical character to rias) occur only in Shetland and fjards occur in western Scotland and Northern Ireland. Rias are particularly well represented in the UK compared with other parts of northern Europe.

Large shallow inlets and bays vary widely in habitat and species diversity according to their geographic location, size, shape, form and geology, depending on whether they occur on hard (rocky) or soft (sedimentary) coasts. The degree of exposure is a critical factor in determining habitat and species diversity. This affects communities on the shore and in the sublittoral zone. The range of plants and animals associated with this habitat type is therefore very wide. Intertidal communities may be dominated by *Fucus* species, particularly in more sheltered locations. Extensive beds of mussels *Mytilus edulis* may be present on mixed substrata. Sediment shores may vary widely, depending on the degree of exposure. Very exposed conditions may result in shingle beaches, while less exposed shores may consist of clean sand. In sheltered conditions shores may consist of fine sand and mud. Very exposed sediment shores are unable to support animal populations. On less exposed shores, communities of crustaceans and polychaetes develop, while shores of fine sand and mud are characterised by polychaete and bivalve communities and beds of eelgrass *Zostera* spp. In the sheltered conditions of Scottish fjards, loose-lying mats of green algae and the unattached form *mackaii* of the wrack *Ascophyllum nodosum* may occur.

In the sublittoral zone, more exposed rocky coasts support forests of the kelp *Laminaria hyperborea,* with forests of sugar kelp *Laminaria saccharina* occurring in more sheltered conditions. Communities of ephemeral algae and maerl (including *Phymatolithon calcareum* and *Lithothamnion corallioides*) may be present on exposed or current-swept coasts, whilst sheltered shallow sediments may be covered by communities of filamentous red and brown algae, by loose-lying mats of algae or by beds of eelgrass *Zostera marina*.

Animal-dominated rocky communities in the sublittoral zone also vary according to local conditions of wave exposure and tidal streams. In more wave-exposed coasts, soft corals, anemones, sponges, seafans, feather stars and hydroids may be dominant, whilst more sheltered coasts support different species of sponges, hydroids, brachiopods and solitary ascidians. A particular feature of rias is the presence of sublittoral rock in conditions of strong tidal flow but negligible wave action. Particular growth forms of sponges and ascidians, as well as specific biotopes, occur in these unusual conditions. In tide-swept areas communities of hydroids and bryozoan turf or beds of brittle stars may be dominant. Beds of horse mussel *Modiolus modiolus* characterise some habitats. Animal-dominated sediment communities range from gravel and coarse sands dominated by burrowing sea cucumbers, large bivalve molluscs and heart urchins, through finer sediments supporting communities of polychaetes and small bivalves, to fine muds with beds of seapens, large burrowing crustaceans and bottom-dwelling fish.

## Typical Attributes to define the feature's condition

### *Generic attributes*

Table 3.6-1 lists the generic attributes for inlets and bays and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge improves of the factors that determine the condition of inlet and bay ecosystems.

**Table 3.6-1** A summary of attributes that may define favourable condition of large shallow inlets and bays

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Extent* | | |
| Extent of the feature | Overall area of the entire inlet or bay | It is likely that such measurements will be a cartographic exercise from existing maps although satellite remote sensing could be used.<br>There are likely to be significant difficulties in defining the actual boundary, particularly for dynamic systems. |
| Extent of sub-feature or specific biotope | Measure the area of a sub-feature | Some sub-features will be Annex I habitats (reefs, subtidal sandbanks, sediment flats) and therefore subject to their own monitoring programme. |
| | Extent of characteristic biotopes | Often biogenic reefs will be included here, such as mussel beds and honeycomb worm (*Sabellaria* spp.) reefs. |
| *Physical properties* | | |
| Habitat composition | Sediment character, structure of biogenic reefs | |
| Nutrient status | Average phytoplankton concentration in summer measured annually | This should only be measured if it is considered to have an effect on the biological structure of the feature. |
| Water clarity | Average light attenuation measured on a monthly basis from March to September, annually | This should only be measured if it is considered to have an effect on the biological structure of the feature. |
| Water density – salinity and temperature. | Derive mean annual salinity and mean annual water temperature from monthly measurements | These data should be derived for each year of the monitoring cycle. |
| Morphological equilibrium | Long-term trend in the horizontal boundary of the saltmarsh/mudflat interface, measured annually | This will only apply to an estuary included within the Large shallow inlets and bays. |

| *Attribute* | *Measure* | *Comment* |
|---|---|---|
| *Biotic composition* | | |
| Species composition of characteristic biotopes | Frequency and occurrence of composite species from specific biotopes | The biotopes selected should reflect the biological character of the feature, and/or be particularly important for their nature conservation value: for example, rich and diverse mussel beds, maerl beds. |
| Species composition of characteristic habitats | Species composition of specific habitats | The habitats selected should reflect the biological character of the feature, and/or be particularly important for their nature conservation value: for example rich and diverse low-shore boulder communities, or lagoon communities. |
| Population status of characteristic species | Estimate the population size of species characteristic of the feature | The species selected should represent the character of the site and may include those at the limits of their geographical range, or which form an important structural aspect of the feature, e.g. kelp beds. |
| *Biological structure* | | |
| Spatial distribution of sub-features | Area and pattern of all the sub-features within the SAC | The distribution of sub-features will be an important aspect to the overall character of the SAC and any change in their location and extent may act as a proxy to identify low-level, diffuse anthropogenic activities. |
| Spatial distribution of characteristic biotopes | Area and frequency of important biotopes throughout the feature | Examples include the relative distribution of intertidal rocky shore communities, distribution of maerl beds, tidal rapids. |

### *Suggested techniques for monitoring attributes of inlets and bays*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.6-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

It is important to note that inlets and bays may include other Annex I habitats or Annex II species which will require their own monitoring programme. The relevant sections of this document should be consulted in addition to the advice provided in Table 3.6-2.

**Table 3.6-2** Suggested techniques for measuring the attributes of inlets and bays. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Extent | | *Air photo interpretation; Remote imaging; GIS analysis* |
| | Biotope extent | Intertidal resource mapping; Intertidal biotope ID; *Air photo interpretation; Remote imaging;* AGDS; side scan sonar (plus mosaicing); Point sample mapping |
| Physical properties | Water clarity | Measuring water quality; *Secchi disk; Water chemistry data loggers* |
| | Water chemistry (including salinity, temperature) | Measuring water quality; *Water chemistry data loggers; Sea surface measurements by satellite remote sensing* |
| | Nutrient status | Measuring water quality; *Water chemistry data loggers; Phytoplankton abundance using satellite remote sensing* (Biotope extent techniques for algal mats) |
| Biotic composition | Intertidal biotope richness | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; Viewpoint photography |
| | Subtidal biotope richness | Subtidal biotope ID; Grab sampling; Drop-down video; ROV; Diver-operated video; Towed video (limited by topography and/or risk of damage) |
| | Intertidal species composition/richness | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Intertidal core sampling; Fish in rockpools |
| | Subtidal species composition/richness | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal core sampling; Grab sampling; Suction sampling; Fish in subtidal rock habitats; Fish on sediments; ROV; Drop-down video; Diver-operated video; *Epibenthic trawling* |
| | Intertidal characteristic species | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Intertidal core sampling; Fish in rockpools |
| | Subtidal characteristic species | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal core sampling; grab sampling; Subtidal photography; Suction sampling; Fish: in subtidal rocky habitats, in vegetative cover, on sediments; ROV ('large' conspicuous species only); Drop-down video ('large' conspicuous species only); Diver-operated video; Mollusc shell ageing |
| Biological structure | Intertidal zonation | Intertidal resource mapping; Intertidal biotope ID; Intertidal ACE; *Transect survey; Shore profiling* |
| | Subtidal zonation | Subtidal biotope ID; Diver-operated video; ROV; Towed video (limited by topography and/or risk of damage) |
| | Spatial pattern of intertidal biotopes | Intertidal resource mapping; Intertidal biotope ID; Viewpoint photography; *Air photo interpretation; Remote imaging* |
| | Spatial pattern of subtidal biotopes | AGDS; Side scan sonar (with mosaicing); Point sample mapping (from Grab sampling, ROV or Drop-down video data); Towed video |

## Specific issues affecting the monitoring of inlets and bays

Large shallow inlets and bays may include several other Annex I features in their own right, and support populations of Annex II species. The monitoring advice presented below is therefore generic in nature and specific advice is available for the individual features: *reefs*, *subtidal sandbanks*, *intertidal mudflats and sandflats*, and *sea caves*. Annex II species are covered under Chapter 4.

### *Seasonal effects*

Marine communities show seasonal patterns that could significantly affect a monitoring programme in large shallow inlets and bays. Some of the more obvious visual changes occur in algal assemblages, and following massive settlements of juvenile animals such as mussels and barnacles. In Loch Maddy cSAC, the largest changes observed in shallow communities between autumn 1998 and summer 1999 were due to a increase in diversity and abundance of algae.[a] Banks of loose stones and gravel are often sufficiently seasonally stable to support dense assemblages of ephemeral algae. Sediment flats often support dense green algal mats during the summer months. Rapid growth of microscopic algae, and diatoms in particular, can change the appearance (colour) of intertidal flats.[b] Maerl beds support rich algal assemblages with distinct seasonal variation.

Many marine organisms have seasonal reproductive patterns that can significantly alter the number of individuals present at different times of the year. Some polychaete worms have semelparous or 'boom and bust' life history strategies where the mature adults spawn synchronously and then die. Clearly, the number of adults present in the sediment will depend on the stage in their lifecycle. Larval settlement and recruitment of juveniles to the population can result in a massive increase in the population size at certain times of the year. The presence and number of juveniles should be enumerated in all samples.

Seasonal effects are also prevalent in eelgrass communities. The blade density of the eelgrass itself will increase during the summer and then the decrease during the autumn and winter – a process known as die-back.[c] Eelgrass blades may support dense assemblages of epiphytic algae during the summer months, which then decline during the winter.

Seasonal patterns must be considered when planning a monitoring strategy. Sampling should be undertaken at the same time of year if seasonal variation is likely. It may be necessary to specify the duration of a sampling window – for example, to precede post-reproductive death in polychaete communities. Seasonal changes in seagrass have important consequences for the timing of remote sensing campaigns because the spectral signature[1] of the seagrass will change between summer and winter.

### *Meteorological changes*

Prevailing weather conditions and tidal state will affect any monitoring study. Sites open to the prevailing wind and swell will require calm conditions for effective field survey. Periods of calm conditions will improve underwater visibility and improve sampling efficiency and reliability. For sediment habitats and adjacent areas, excessive water movement will mobilise fine sediment into the water column, thereby reducing underwater visibility. Conversely, calm conditions will cause suspended sediment to deposit out of the water column, and visibility will improve, but reef assemblages may then become smothered with sediment, obscuring some species from view. For any areas subject to strong tidal streams (for instance, the tidal rapids in Loch Maddy cSAC), sampling must take place at slack water, avoiding the equinoctial tides when the duration of slack water will be at its shortest.

Freshwater input to large shallow inlets and bays is not as marked as to estuaries, although it may be locally important in parts of these systems. In such circumstances, monitoring events should avoid periods of heavy rainfall if changes in ambient salinity are likely to influence the results.

Ambient atmospheric pressure affects the height and time of low and high tide: high pressure decreases the height of high and low tide, and the time of the highest and lowest water is later than predicted. Low pressure has the opposite effect.

Weather cycles can result in changes in the biotic assemblages. Changes in perennial algae on Loch Maddy maerl beds were possibly due to an unusually warm preceding summer.[d] Periods of extreme cold coinciding with low water can result in mass mortality of kelp plants.[e] Storm events can result in the mass displacement of sediment communities – for example, populations of the long-armed brittlestar *Amphiura filiformis* in Galway Bay, Ireland.[f]

When establishing a monitoring strategy, meteorological effects must be integrated with seasonal effects to ensure that sites can be monitored reliably through time.

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1 See Section 5 for an explanation

### Access

There are no specific issues associated with gaining access to inlets and bays. Access to intertidal habitats will be gained from the land, except for islands and offshore banks or remote sites where boat access will be necessary. Most subtidal habitats would require boat access although land access would be possible for those habitats immediately adjacent to the shore.

Further information is provided under the advice for individual features: *reefs*, *estuaries*, *subtidal sandbanks*, *intertidal mudflats and sandflats*, and *sea caves*. Annex II species are covered under Section 4.

### Sampling issues

A monitoring programme must consider the whole feature, even where it may contain other Annex 1 features; these features should have their own dedicated monitoring programme. A monitoring programme for a large shallow inlet and bay may therefore, be an aggregation of both monitoring for Annex 1 (sub) features in their own right, and specific sampling of attributes for the entire feature (such as extent).

Measuring the extent of a large shallow inlet and bay requires the careful definition of boundary in relation to the seaward limit and the high water limit. For those sites bounded by rocky shores or solid anthropogenic boundaries such as harbour walls or seawalls, measuring the extent may be a straightforward cartographic exercise using the most up-to-date maps of the area. Sites with 'soft' boundaries such as saltmarsh may require a more sophisticated mapping exercise such as remote sensing, particularly in dynamic systems where tidal currents result in erosion and/or accretion of these 'soft' habitats. The positions of channels and offshore banks may move considerably during a monitoring cycle, although the impact of such a change on the overall extent of the large shallow inlet and bay may be negligible.

Monitoring physical and biological attributes to assess the condition of the entire feature will require careful consideration of the overall sampling strategy. A comprehensive sampling programme throughout the entire feature may be prohibitively expensive and time-consuming. It would be necessary to devise a tiered sampling programme at different spatial scales aiming to cover key physical attributes and characteristic biota. That is, a programme would be structured in such a manner that detailed sampling in a number of small areas would allow an assessment over the whole feature.

### Site marking and relocation

Marking and relocating the *feature* itself is unlikely to present any problems, although the precise location of the boundary may be difficult where the edge of the feature has 'soft' habitats. Clear guidance is necessary to define the high water limit and the position of the entrance boundary to ensure consistent monitoring.

Permanent marking of sampling stations is very difficult in dynamic environments where the substrata are mobile. Site relocation will rely on dGPS,[2] particularly on extensive intertidal flats (Morecambe Bay and the Wash) or open sea areas (Wash). For less dynamic habitats, sites may be marked with acoustic transponders[8] or curly whirlies.[3] Detailed site drawings (Figure 3-2) with transits (Figure 3-5) may be necessary to relocate sampling stations in complex sites.

Additional information is provided under the guidance for *reefs*, *mudflats and sandflats*, *subtidal sandbanks* and *caves*.

### Health and Safety

All fieldwork must follow approved codes of practice to ensure the health and safety of all staff. See the comments on health and safety for the individual features: *reefs*, *subtidal sandbanks*, *mudflats* and *caves*. There are considerable health and safety issues associated with:

- fast moving tidal streams, particularly in shallow rapids (Loch Maddy);
- heavy wave action particularly at the mouth and/or habitats exposed to the prevailing wind;
- poor visibility caused by high turbidity (mostly in sedimentary areas) or freshwater inflow;
- boat traffic near harbours or ports;
- contaminated waters and sediments at sites with a history of anthropogenic inputs and/or adjacent

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2 See Procedural Guideline 6-1 on dGPS guidance.

3 Plastic corkscrews that are screwed down into the sediment: see Fowler, S L (1992) *Marine Monitoring in the Isles of Scilly 1991*. English Nature Research Report No. 9. English Nature, Peterborough.

to industrial or military installations: appropriate protective clothing must be worn.

Some sampling in inlets and bays will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[4] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[5] (**http://www.hse.gov.uk/spd/spdacop.htm - a**).

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4 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997, ISBN 0 11 065170 7.

5 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997. Approved Code of Practice and Guidance – L107. HSE Books 1998, ISBN 0 7176 1498 0.

# Submerged or partly submerged sea caves

**Definition**

Caves situated under the sea or opened to it, at least at high tide, including partially submerged sea caves. Their bottoms and sides harbour communities of marine invertebrates and algae.

## Introduction to the feature's interest

The UK has the most varied and extensive sea caves on the Atlantic coast of Europe, encompassing a range of structural and ecological variation. Well-developed cave systems, with extensive areas of vertical and overhanging rock, and those that extend deeply into the rock, generally support the widest range and highest diversity of plants and animals.

Cave communities vary considerably depending on the structure and extent of the cave system, their degree of submergence and of exposure to scour and surge, and the nature of their geology. Caves can vary in size, from only a few metres to more extensive systems, which may extend hundreds of metres into the rock. There may be tunnels or caverns with one or more entrances, where vertical and overhanging rock faces provide the principal marine habitat. Caves are typically colonised by encrusting animal species but may also support shade-tolerant algae near their entrances.

Physical conditions, such as inclination, wave surge, scour and shade, change rapidly from cave entrance to the inner parts of a cave and this often leads to a marked zonation in the communities present. Sites in which these zonation patterns are well developed have been favoured in selection.

A high proportion of caves is found in the intertidal or in shallow water. Caves on the shore and in the shallow sublittoral zone are frequently subject to conditions of strong wave surge and tend to have floors of coarse sediment, cobbles and boulders. These materials are often highly mobile and scour the cave walls. Caves that are subject to strong wave surge are characterised by communities of mussels *Mytilus edulis*, barnacles *Balanus crenatus*, cushion sponges, encrusting bryozoans and colonial sea-squirts, depending on the degree of water movement and scour at particular points in the cave system.

Caves that occur in deeper water are subject to less water movement from the surrounding sea, and silt may accumulate on the cave floor. The sponges *Dercitus bucklandi* and *Thymosia guernei*, the soft coral *Parerythropodium corallioides*, solitary sea-squirts, bryozoans and sessile larvae of jellyfish are characteristic of deeper cave systems. These caves, particularly where they are small, provide shelter for crabs, lobsters *Homarus gammarus*, crawfish *Palinurus elephas*, and fish, such as the leopard-spotted goby *Thorogobius ephippiatus*.

The type of rock in which the cave is formed has an important influence on its shape and qualities as substrata for plants and animals. In chalk caves in south-east England bands of microscopic algae occur, including Chrysophyceae and *Pilinia maritima*, which are highly specific to this habitat type. The UK holds a high proportion of the total area of coastal chalk, a comparatively rare habitat in Europe.

## Typical attributes to define the feature's condition

### *Generic attributes*

Table 3.7-1 lists the generic attributes for sea cave features and presents examples of the measures proposed for some of the candidate SACs in the UK. This list is not exhaustive and will be further developed as our knowledge improves of the factors that determine the condition of cave ecosystems.

**Table 3.7-1** A summary of attributes that may define favourable condition of submerged or partly submerged sea caves

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Extent* | | |
| Extent of the feature | Number and location, measured once during reporting cycle | |
| *Physical structure* | | |
| Internal dimensions of each cave within an SAC | | |
| *Biotic composition* | | |
| Diversity of sea cave biotopes | Number of all sea cave biotopes (or presence of specified biotopes) | This can be measured both within an individual cave where it is a representative example of that type within an SAC.<br>It may also be evaluated throughout all sea caves in the SAC where there is a range of different types of cave in the site. |
| Species composition of characteristic biotopes | Presence and abundance of composite species of characteristic biotope. | The diversity and relative species-richness of representatives of cave biotopes should be assessed using a number of representative monitoring stations. |
| *Biological structure* | | |
| Spatial pattern of characteristic biotopes | Identity and distribution of biotopes within a cave | The spatial arrangement of biotopes within a cave is normally a reflection of the prevailing physical condition, and thus any change may indicate other physical changes within the SAC.<br>This should be measured both within an individual cave, and throughout all sea caves in the SAC. |

### *Suggested techniques for monitoring attributes of sea caves*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.7-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

**Table 3.7-2** Suggested techniques for measuring the attributes of sea caves. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Extent | Intertidal | Intertidal resource mapping; *GIS mapping* |
| | Subtidal | Surveying sea caves; *GIS mapping* |
| | Biotope extent | Intertidal resource mapping; Intertidal biotope ID; Subtidal biotope ID |
| Physical properties | Physical dimensions | Surveying sea caves; *Land surveying techniques; Cave exploration techniques* |

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Biotic composition | Intertidal biotope richness | Intertidal biotope ID; Intertidal ACE |
| | Subtidal biotope richness | Subtidal biotope ID; Diver-operated video |
| | Intertidal species composition/richness | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling) |
| | Subtidal species composition/richness | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal photography; Suction sampling; Diver-operated video |
| | Intertidal characteristic species | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling) |
| | Subtidal characteristic species | Subtidal quadrat sampling; Subtidal biotope ID; Subtidal photography; Suction sampling (small epibiota); Diver-operated video |
| Biological structure | Spatial pattern of biotopes within a sea cave | Surveying sea caves; Intertidal biotope ID; Intertidal ACE; Surveying sea caves plus Subtidal biotope ID; Diver-operated video; *Transect surveys* |
| | Spatial pattern sea cave biotopes within a SAC | Intertidal resource mapping; Subtidal biotope ID with *GIS mapping* |

## Specific issues affecting the monitoring of caves

Each attribute will have its own inherent source of variability that must be addressed during data collection and subsequent interpretation of the results. Many cave attributes will be similar to *reefs* and the guidance described above should also be consulted in relation to cave monitoring. However, some generic issues should be considered when planning the whole monitoring study.

### *Seasonal effects*

Marine communities exhibit seasonal change, although the precise effects are poorly understood for many cave communities. Some of the more obvious visual changes occur in algal assemblages (at the entrance), and following settlements of juvenile animals such as ascidians, mussels and barnacles. Boulders present at the entrance are often seasonally stable allowing ephemeral algal communities to develop. The degree to which seasonal change will influence the monitoring of a cave attribute will depend on the community under investigation. Where possible, a community should be investigated either directly or via a literature review to gather information on the likelihood of seasonal change affecting an attribute. In general, algal assemblages should be studied during the summer months. Where seasonal affects are not fully understood, it is vital that a monitoring strategy explicitly states that data collection must always be undertaken at the same time of year.

### *Meteorological changes*

Prevailing weather conditions and tidal state will affect any monitoring study. Sites open to the prevailing wind and swell will require particularly calm conditions for effective field survey. Where a cave is adjacent to sediment habitats, excessive water movement will mobilise fine sediment into the water column, thereby reducing underwater visibility. Conversely, calm conditions will cause suspended sediment to deposit out of the water column, underwater visibility will improve and therefore assist sampling efficiency and reliability. Sublittoral caves located in areas with a large tidal range should be sampled during neap tides, at or near high or low water to reduce water movement. If possible, sampling exercises should avoid the equinoctial tides when the duration of low and slack water will be at their shortest.

Ambient light levels within a cave will have a significant influence on the sampling exercise. If possible given the many other constraints, sampling should be timed to maximise light levels (for instance, in bright sunny conditions at midday).

### *Access*

Caves through their very structure pose a number of serious problems to a monitoring study. Issues pertaining to gaining access to a cave may be considered on two levels: gaining access to the site (cave entrance) and entering the cave itself.

To gain access to the site, the surveyor must consider the issues of permission (intertidal sites), tidal state (high or low water/slack water), prevailing wind/wave/swell conditions and underwater visibility (for locating caves, see below). It will be necessary to use a boat to gain access to some caves and therefore it will be necessary to consider the availability of harbours and/or launching facilities.

The relative ease of gaining access to a cave itself will depend on its physical size and structure. There are considerable health and safety issues to be considered prior to entry. Cave exploration may require staff with appropriate training and/or specialist equipment such as ladders, lighting helmets, guide ropes on reels. For caves in the intertidal zone, careful consideration must be given to the tidal cycle to ensure that staff can complete the monitoring exercise and exit before the tide rises.

### *Sampling issues*

A monitoring programme must collect sufficient information to assess the condition of the whole feature. The complexity of such monitoring will depend on the physical dimensions of a cave and its location (in terms of time available for sampling), and the number and variety of caverns in the system. Basic techniques for surveying the physical structure were investigated for intertidal and subtidal caves in the Berwickshire & North Northumberland Coast cSAC during the *UK Marine SACs project*.[a] These techniques were simple and straightforward and could be undertaken without specialist training in cave surveying, although they relied on an estimate of the internal height rather than an accurate measurement. This work recommended that:

- The level of accuracy required should be specified prior to the survey.
- The accuracy and precision of the measuring tools (e.g. compass, depth gauge) should be established at the start, and linked to the required accuracy of the survey.
- It may be necessary to measure local magnetic variation at the cave.
- Difficulties may arise when a highly accurate survey is specified, but the practical application dictates that it is only possible to estimate some distances (such as cave height). It may be necessary to incorporate two levels of accuracy in a controlled manner by specifying estimated distances and measured distances.
- Cave morphology will dictate whether there is a 'ceiling' to the cave - tall thin caves have little ceiling area. It must be made clear to recorders from the outset as to whether a separate record is required for the ceiling.
- Trigonometric methods (as opposed to using a ruler and protractor) should be used for plotting cave plans.
- Inherent differences in the way field recorders interpret the distribution of cave biotopes may be minimised by providing a survey team with previous biological records and maps from the same site.

Specialist guidance is available on cave survey techniques both on the Internet[1] and from cave exploration associations.[b] There are also many sources of bespoke software for analysing and visualising the results of cave mapping surveys.[2]

Monitoring the biotic composition of caves is similar to monitoring reefs. There are often marked spatial patterns in cave biotopes, particularly algal dominated biotopes whose presence declines in relation to the availability of light. Transect sampling techniques are most appropriate for monitoring biotope distribution throughout a cave. Zonation patterns must be considered when planning a sampling strategy within an individual biotope to ensure that sample stations (individual quadrats) are not located in

1 For example, see: **http://rubens.its.unimelb.edu.au/~pgm/asf/stds.html**

2 For example: **http://www.survex.com/** or **http://members.aol.com/caverdave/CPHome.html**

the transition zone between biotopes. Scale drawings of cave walls and floors are useful aids for location when undertaking biological sampling. Where full diagrams are not available, for instance if they were being compiled at the same time as the biological recording, the recorders should be aware (or agree) the ‘nodal’ points of the cave for accurate spatial correlation (Figure 3-4). Video recording with a voice-over commentary is an extremely useful aid to cave monitoring because it provides a permanent record to support both physical and biological monitoring. Recording should be undertaken by the monitoring staff to ensure the images and sound match the attributes under investigation. Nevertheless, there are severe problems with lighting when recording video in caves, and there is a risk that a video recording could turn into a time-consuming ‘production’. It is possible to use an ROV to record video in some subtidal caves, although there are severe operational problems and in practice it should only be considered for caves beyond normal safe diving depths. Furthermore, the video resolution may be insufficient to confidently identify many species.

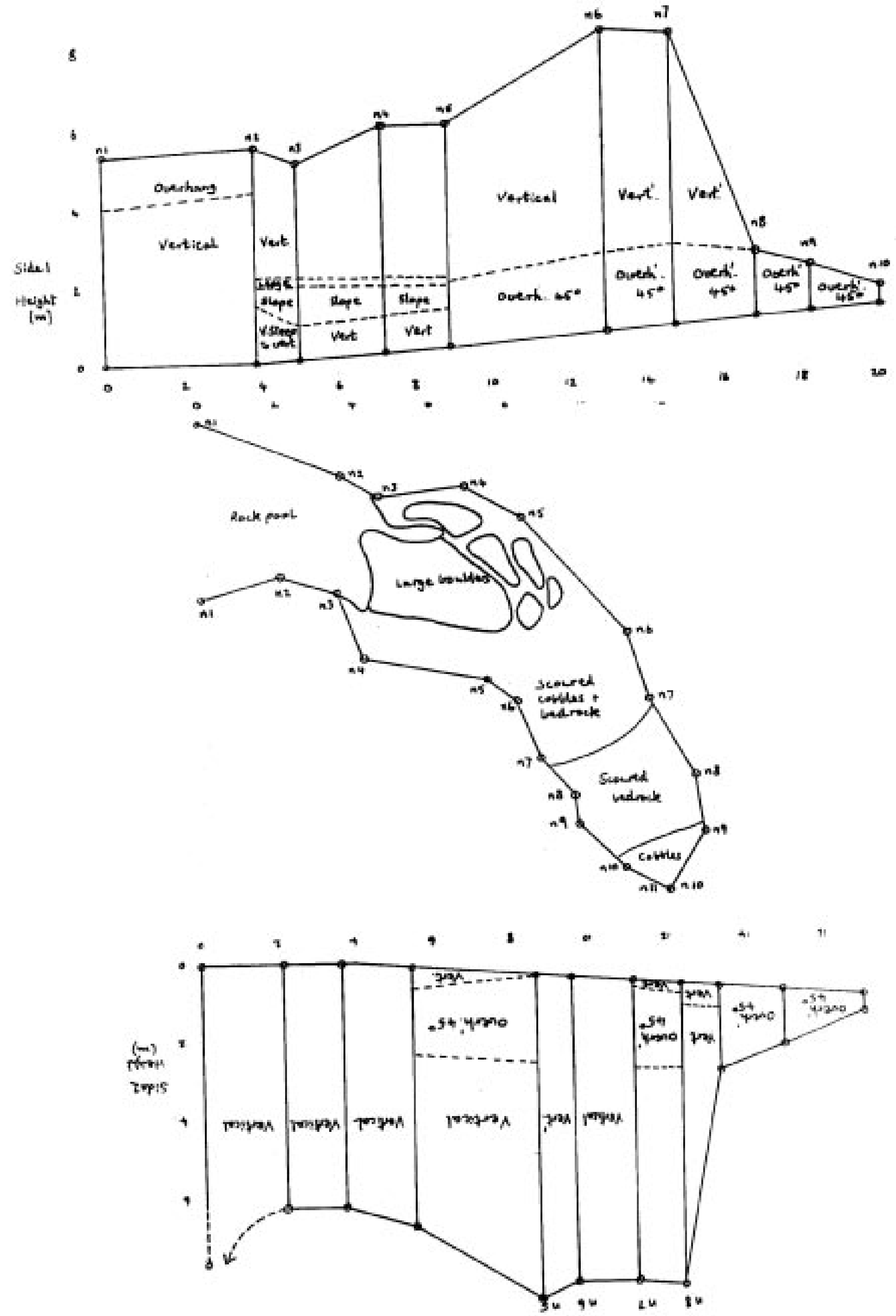


**Figure 3-4** An example of a cave diagram showing the 'nodal' points of the system.[a]

A recent trial encountered many difficulties in identifying cave biotopes in the field that resulted in considerable inconsistencies between field teams studying the same cave.[a] Interestingly, the patterns of zonation and species compositions were similar between field teams, but diverged when assigning biotopes to the data. Two issues were identified: non-familiarity with cave-dwelling taxa, and the scale of biological changes over small distances. Clearly, the former should be addressed when selecting and training field staff. The scale issue could be addressed by directly mapping those species responsible for the observed patterns and hence not assign biotopes. Alternatively, unambiguous biotope descriptions should be derived from the baseline survey (see Section 5), possibly for individual caves, and/or the smallest biotope ‘patch’ size must defined at the outset. Photographs or video recordings of the defining features and species would create an important permanent record to support future monitoring interpretations.

## *Site marking and relocation*

Most issues relate to the location (intertidal or subtidal) and physical dimensions of a cave. For intertidal caves, there are fewer problems in relocating the entrance (except if very small), although it should be noted that dGPS may not provide an accurate fix near high cliffs. Accurate drawings of local landscape features provide an invaluable aid to relocation (Figure 3-5).

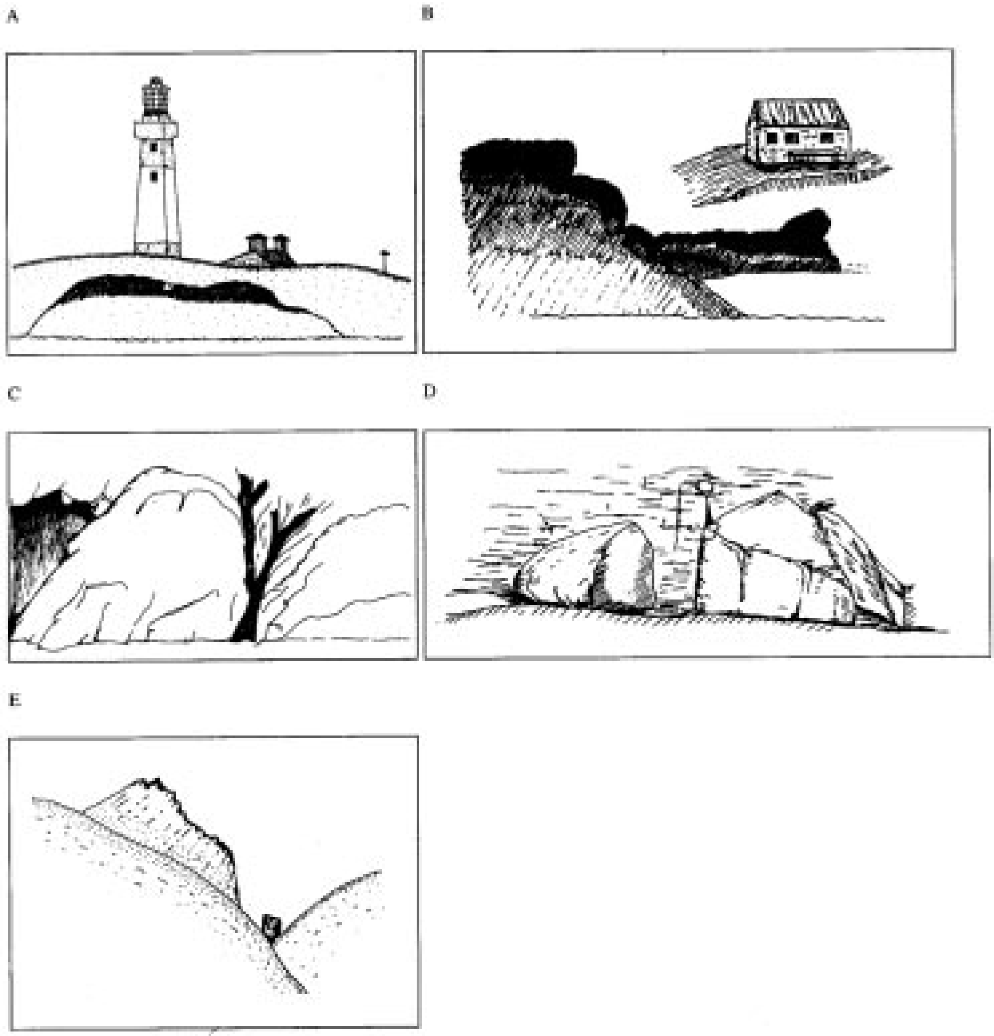


**Figure 3-5** A example of the use of transits to relocate sampling stations.[c,3] Transits are straight sight-lines between land-based features (for example in B where the prominent rock aligns with the middle of the house) which intersect over the position of the sampling station. The best accuracy is attained by having the intersecting lines close to 90° apart.

For subtidal caves, relocation may be difficult particularly in poor visibility and/or where the entrance is small. Box 3.7-1 lists a series of options for relocating a subtidal cave, in descending order of the probability success.

3 See Procedural Guideline 6-2 on site marking

**Box 3.7-1** Options for relocating a subtidal cave

Installation of a permanent marker buoy (surface or subsurface)

Installation of a permanent subsurface beacon/transponder unit[d]

Engaging a local dive guide to assist in site marking at the start of the project (e.g. an SAC warden)

Engaging the use of non-divers with good local knowledge (e.g. boat skippers)

Annotated site drawings or photographs (ideally at low and high water)

Transits or bearings

Detailed maps with locations marked

Differential GPS co-ordinates[4] (with datum)

GPS (with datum)

The installation of permanent markers may require prior consent or permission and there will be an ongoing requirement for their maintenance.

Relocation of sampling stations and mapping 'nodes' requires carefully consideration. Fixing pitons or bolts into the rock may damage the rock, particularly soft friable rock, and create a hazard to other visitors to the cave. Paint or fluorescent markers would avoid physical damage to the rock but may attract unwanted attention from the public and reduce the scenic value of the site. The final choice of station marking will depend on the local situation but should always consider the risk of failing to find the cave or station in future monitoring studies.

### *Health and safety*

There are many health and safety implications for cave monitoring studies, although the degree of risk will depend on the location and dimensions of each cave. All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent. Guidance on cave safety is published by cave exploration societies and available on the Internet (for example: **http://www.sat.dundee.ac.uk/~arb/speleo.html** or **http://wasg.iinet.net.au/asf_safe.html**). Field staff must be briefed on the risks associated with cave survey prior to undertaking any monitoring studies. Examples of these risks are:

- The energy from a wave entering a cave becomes more 'focused', creating a powerful surge. Waves that appear relatively innocuous at the entrance can become rather dangerous at the head of a cave.
- Long caves, particularly complex systems with many caverns, will be dark and there is a risk of disorientation and loss of bearings.
- The incoming tide may trap surveyors in intertidal caves.
- Seals often haul out at the head of caves: surveyors may inadvertently prevent a seal leaving a cave and thereby risk being attacked. This situation could be exacerbated during the breeding season when a surveyor may separate young seal pups from their mothers, or come between a bull seal and its female mate.

Subtidal sampling in caves will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[5] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[6] (**http://www.hse.gov.uk/spd/spdacop.htm - a**). Divers may require specific training in cave-diving procedures to ensure their safety when surveying caves.

4 See Procedural Guideline 6-1 on dGPS guidance.

5 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997, ISBN 0 11 065170 7.

6 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997. Approved Code of Practice and Guidance – L107. HSE Books 1998, ISBN 0 7176 1498 0.

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# Lagoons

## Definition

Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sandbanks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall and evaporation, or the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae, Potametea, Zosteretea or Charetea* (CORINE 91: 23.21 or 23.22).[1]

Flads and gloes, considered a Baltic variety of lagoons, are small, usually shallow, more or less delimited water bodies still connected to the sea or have been cut off from the sea very recently by land upheaval. Characterised by well-developed reedbeds and luxuriant submerged vegetation and having several morphological and botanical development stages in the process whereby sea becomes land.

## Introduction to the feature's interest

Lagoons have a restricted distribution on the Atlantic coast of Europe. The habitat type is complex, and a wide range of physical types and origins are included, with much geographical and ecological variation. Some of the types of lagoon found in the UK are rare elsewhere in Europe. This is a priority habitat type and is relatively uncommon in the UK. Therefore a high proportion of the sites identified as meeting the definition of the habitat type have been selected.

Although uncommon, lagoons may be clustered together on particular stretches of coast, where they are dependent on specific local physical processes. Such clusters have been considered particularly important for conservation of their structure and function. Some of the sub-types of lagoon have a very restricted distribution in the UK, with one type being found mainly in the Outer Hebrides and a high proportion of another type occurring on the east coast of England.

Lagoons are areas of shallow, coastal salt water, wholly or partially separated from the sea by sandbanks, shingle or, less frequently, rocks. Five main sub-types of lagoon have been identified in the UK, on the basis of their physiography, as meeting the definition of the habitat type.

*Isolated lagoons* are separated completely from the sea by a barrier of rock or sediment. Seawater enters by limited ground water seepage or by over-topping of the sea barrier. Salinity is variable but often low. Isolated lagoons are often transient features with a limited life-span due to natural processes of infilling and coastal erosion. Isolated lagoons may have less water exchange than percolation lagoons and consequently a more impoverished biota.

*Percolation lagoons* are normally separated from the sea by shingle banks. Seawater enters by percolating through the shingle or occasionally by over-topping the bank (e. g. in storms). The water level shows some variation with tidal changes, and salinity may vary. Since percolation lagoons are normally formed by natural processes of sediment transport, they are transient features, which may be eroded and swept away over a period of years or decades or may become infilled by movement of the shingle bank.

*Silled lagoons* occur where water is retained at all states of the tide by a barrier of rock (the 'sill'). There is usually a small tidal rise-and-fall, the extent depending on the height of the sill in relation to the tidal range. Seawater input is regular and frequent, and although salinity may be seasonally variable, it is usually high, except where the level of the sill is near to high tide level. These lagoons are restricted to the north and west of Scotland and may occur as sedimentary basins or in bedrock (where they are called 'obs'). Muddy areas are dominated by filamentous green algae, amongst which may be colonies of rare charophytes, such as foxtail stonewort *Lamprothamnium papulosum*. Beds of tasselweeds *Ruppia* spp. and, in the deeper, most stable lagoons, eelgrass *Zostera marina* may be present.

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1 These numbers are the habitat codes in the Palaearctic classification (originally the CORINE classification). For further information refer to *The Interpretation Manual of European Habitats – EUR 15* (version 2, October 1999) published by the European Commission (see: **http://europa.eu.int/comm/environment/nature/docum.htm**)

*Sluiced lagoons* occur where the natural movement of water between the lagoon and the sea is modified by human mechanical interference such as the construction of a culvert under a road or valved sluices. Communities present in sluiced lagoons vary according to the substrate type and salinity, and therefore may resemble all other silled lagoon types.

*Lagoonal inlets* are lagoons that have a permanent, but restricted, connection channel to the sea where seawater enters lagoonal inlets during each tidal cycle. Salinity is usually high, particularly at the seaward part of the inlet. Larger examples of this sub-type may have a number of different basins, separated by sills, and may demonstrate a complete gradient from full salinity through brackish to fresh water. This salinity gradient significantly increases the habitat and species diversity of the sites in which it occurs.

Only sites on natural substrata have been selected. Sites that are entirely artificial in origin, e. g. some docks, have been excluded from the selection, although in some cases the communities present may be similar to those of more natural sites.

The water in lagoons can vary in salinity from brackish (following dilution with fresh water) to hypersaline (i. e. saltier than seawater because of evaporation). A significant factor determining the biology of a lagoon is whether the salinity fluctuates markedly (tending to lead to low species richness), or is more stable (tending to lead to higher species richness). Thus the plant and animal communities of lagoons vary according to the physical characteristics and salinity regime of the lagoon, and therefore there are significant differences between sites. Although a limited range of species may be present, compared with other marine habitats, these species are especially adapted to the varying salinity and some are unique to lagoon habitats. The vegetation may include beds of eelgrasses *Zostera* spp., tasselweeds *Ruppia* spp., pondweeds *Potamogeton* spp., and stoneworts such as foxtail stonewort *Lamprothamnium papulosum*. In more rocky lagoons, communities of fucoid algae *Fucus* spp., sugar kelp *Laminaria saccharina*, red algae and green algae are also found. The fauna is often characterised by mysid shrimps and other small crustaceans, worms which burrow into the sediment, prosobranch and gastropod molluscs and some fish species such as stickleback. Species that are particularly found in lagoons and consequently have restricted distributions in the UK include the starlet sea anemone *Nematostella vectensis*, lagoon sandworm *Armandia cirrhosa*, lagoon sand shrimp *Gammarus insensibilis* and foxtail stonewort *Lamprothamnium papulosum*.

## Typical attributes to define the feature's condition

### *Generic attributes*

The attached generic guidance does not preclude the inclusion of other attributes that may be required in relation to particular threats to a site, but any such additions would need to be clearly justified. For example the characteristic species *Lamprothamnium papulosum* could be used as an indicator of phosphate levels where nutrient enrichment is considered a threat to the lagoon feature.

Table 3.8-1 lists the generic attributes for lagoons and presents examples of the measures proposed for some of the candidate SACs in the UK. This table is based on guidance developed for the lagoons in England and may change when equivalent guidance is available for lagoons in the remainder of the UK. For example, biotopes have not been referred to within the attributes as many lagoons in England comprise variations on only one biotope (ENLag.IMS.Ann) and the presence of another (ENLag.Veg). However, where other biotopes are present which are of note, e.g. *Zostera* beds, there would be justification for their inclusion in the overall monitoring programme.

**Table 3.8-1** A summary of attributes that may define favourable condition of lagoons

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Extent* | | |
| Extent of lagoon | Area of the lagoon basin | Extent of the feature is an attribute on which reporting is required by the Habitats Directive. Extent influences both sensitivity of the habitat and (together with shape, i.e. length to breadth ratio) the diversity of the biological community present. |
| | Area of water occupying the basin measured at the same time of year (preferably in late winter/early spring *and* late summer) | Critical to both the definition and maintenance of a lagoon, and the community of species it supports, is the retention of most or all of the water mass within the system at low water in the adjacent estuary or sea. Concomitant with this is maintenance of a relevant depth of water.<br><br>Extent of water in late winter/spring may be taken as the likely extent of the lagoon basin. Extent of water in late summer in lagoons with a shallow basin is likely to be less than the extent of the basin.<br><br>Monitoring the extent of water within the lagoon basin, in conjunction with the presence and nature of the isolating barrier, will provide a surrogate for the attribute *water depth* once the relationship between these attributes has been established, based on the profile of the lagoon bed, from survey to characterise the site. |
| *Physical properties* | | |
| Topography | Average water depth within the lagoon basin (metres) at low tide, measured at same time of year (preferably in late winter/early spring *and* late summer). | Many (the majority in England) saline lagoons are shallow. The influence of depth is a balance between sufficiently shallow to enable light penetration, and therefore photosynthesis, and sufficiently deep to submerge vegetation (and thereby affect oxygenation, food resource, habitat diversity and colonization by lagoonal fauna), determining temporal duration of stratification, and buffering against environmental change, particularly dehydration.<br><br>*Empirical analysis of English lagoons suggests the majority of the bed should be less than 1m deep, particularly in smaller lagoons, but with a small proportion of deeper habitat. Actual values will depend on the site. Where it is more appropriate to a site, e.g. those with steep banks, water depth should be monitored.* |
| Isolating barrier – presence and nature | Most appropriate measure of integrity and nature of the barrier –<br><br>*Percolation*: length, width and height (relative to basin and to tidal levels)<br><br>*Isolated*: length, width and height (relative to basin and to tidal levels)<br><br>*Inlet*: width, depth of inlet channel (or, as a surrogate, an indicator of hydrological conditions around the mouth of the inlet).<br><br>*Sluiced*: Height of base of sluice(s) (relative to basin and to tidal levels), integrity (leaking or not) and frequency of opening/closure. | The presence of an isolating barrier is fundamental to the structure and function of a saline lagoon (indeed the nature of the barrier and degree of separation from the sea defines the type of lagoon in the UK). Except in the case of over-topping (isolated and some percolation lagoons) the key factor determining input and output of seawater is the height of the bottom of the inlet bed (channel, sluice, weir or impermeable base of a percolation route) relative to ambient low water levels to allow retention of the majority of the lagoonal water at low tide. Generally speaking, experience suggests the horizontal level should be a little below high water neaps. |
| Salinity regime | Seasonal averages (‰) to be measured at least once during the reporting cycle (preferably in late winter/early spring and later summer to indicate seasonal low and high)<br><br>*Depending on the size and shape of the lagoon, it may be necessary to measure along a salinity gradient.* | Salinity is critical to both the structure and function of a lagoon, e.g. in defining the habitat, contributing to diversity within a site, and determining what species are present. The evolution of a specialist lagoonal community appears to be related to intrinsic variation in salinity both in time (short-term tidal, seasonal) and space.<br><br>It is essential that salinity is measured at a similar time of the year and state of tide on a site. Salinity of the adjacent open coastal waters should be measured at the same time.<br><br>*Empirical analysis of lagoons and specialist lagoonal species in the UK suggests a salinity range predominantly between 15‰ and 40‰. Variation outside this range is tolerable in the short term (days rather than weeks) but <10‰ and >50‰ should trigger remedial action.*<br><br>*N.B. Percolation lagoons: the long-term natural trend at some sites is to become freshwater as silting within the lagoon prevents percolation of sea water and shingle builds up preventing overtopping.* |

| *Attribute* | *Measure* | *Comments* |
|---|---|---|
| *Biotic composition* | | |
| Species composition | Presence and abundance of composite species, measured at least once during the reporting cycle, measured at same time of year. | Composite species are important contributors to the structure of the saline lagoon habitat, The community will reflect to varying degrees the structure and function of the habitat as a whole. |
| | | The species will include one or all of the flora, infauna, epifauna, plankton/nekton and phyton. The community is likely to (and indeed should) include species characteristic of lagoons. It may include specialist and rare/scarce species of interest in their own right. Reference should be made to such species but only if there is a clear case for a species as an indicator of the community as a whole (there are almost no known examples) or an attribute that is of specific relevance at the individual site level, e.g. *Lamprothamnium papulosum* as an indicator of phosphate levels on sites where such levels are a concern to condition of the feature. |
| | | Where infauna are monitored, associated monitoring of the sediment, e.g. particle size analysis, would be sensible, but not essential unless it is critical to the species composition of the biotope concerned. |

## *Suggested techniques for monitoring attributes of lagoons*

For each of the attributes likely to be selected to monitor the condition of a feature, there are many techniques available to measure its value. To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures (Table 3.8-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (recording biotope richness, species counts), but further work is required on other techniques (such as measuring extent with remote sensing techniques). The advice presented below will be updated when new information becomes available.

**Table 3.8-2** Suggested techniques for measuring lagoon attributes. The terms under *Technique* appear under the heading *Summary title* in the procedural guidelines provided in Section 6. Guidance will be developed for the techniques in italics.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Extent | Extent of lagoon (basin; area of water) | *Air photo interpretation; Remote imaging*; Intertidal resource mapping; *Direct measurement (small lagoons only)* |
| | Biotope extent | *Air photo interpretation; Remote imaging*; Intertidal resource mapping; Intertidal biotope ID; Point sample mapping; transect survey (by snorkelling or diving) AGDS; Side scan sonar (large lagoons only) |
| Physical properties | Substratum: sediment character | Particle size analysis; *Sediment chemical analysis* |
| | Salinity regime | Measuring water quality; *Water chemistry data loggers* |
| | Water depth | *LIDAR; Bathymetry survey; On-site measurement (stick/gauge)* |
| | Presence and nature of isolating barrier | *Air photo interpretation*; Direct measurement (small lagoons only) |
| | Nutrient status | Measuring water quality; *Water chemistry data loggers*; Algal mats: see *Species composition/ richness* below for abundance measures; see *Biotope Extent* for the extent of algal mats |
| Biotic composition | Species composition, Species richness Characteristic species | Intertidal ACE; Intertidal quadrat photography; Intertidal quadrat sampling (see Subtidal quadrat sampling); Intertidal core sampling; Subtidal quadrat sampling; Subtidal biotope ID; Subtidal core sampling; Grab sampling; Suction sampling; Fish on sediments; *Plankton sampling* |
| Biological structure | Spatial pattern of biotopes | Intertidal resource mapping; Intertidal biotope ID; *Air photo interpretation; Remote imaging*; Point sample mapping; *Transect survey (by snorkelling or diving)* AGDS; Side scan sonar (large lagoons only) |

## Specific issues affecting the monitoring of lagoons

Lagoons are listed as a priority habitat in the Habitats Directive and under the UK Biodiversity Action Plan.[a] The Habitat Action Plan for saline lagoons[b] includes some basic advice on monitoring. Comprehensive guidance on the management of saline lagoons in England, Scotland and Wales, including monitoring their condition, is being prepared by the Saline Lagoon Working Group.[c] The information presented below is a brief summary of the main points to consider, and the more comprehensive guidance mentioned above must be fully consulted when planning a monitoring study of a saline lagoon.

It is important to consider the whole ecosystem of a lagoon when planning a condition monitoring programme. It may be necessary to consider attributes of the sediment infaunal, epifaunal, phytoplankton and vegetative components of the lagoon system to comprehensively evaluate the condition of the lagoon itself.

Lagoons are a rare and vulnerable habitat in their own right, and support a variety of scarce and rare species. In Great Britain, 12 species of invertebrates and plants associated with lagoons are protected under the Wildlife and Countryside Act 1981.[2] A licence is required from the relevant statutory conservation agency[3] to collect any scheduled species but many, with training, can be identified *in situ*.

The minimum frequency of monitoring is at least once per reporting cycle (six years). Whilst it is important not generate an unnecessarily burdensome monitoring programme, it may be necessary to have more frequent monitoring because of the conservation importance of lagoons, and their sensitivity to damage. Any decision on whether to monitor more than once during a reporting period will need to take account of other factors, i.e. degree of threat, management action, or research needs; this obviously cannot be indicated at a generic level. It is likely that some monitoring of at least part of each SAC will be required more than once every six years.

### *Seasonal effects*

Most lagoonal submerged plant species show marked seasonal cycles of growth and/or die back. For example, populations of the important charophyte *Lamprothamnium papulosum* die back in the winter and should thus be monitored in the summer. Seagrasses (*Zostera* spp. and *Ruppia* spp.) have similar seasonal patterns in their population density. Seasonal changes in vegetation must be considered when undertaking any remote sensing investigation because a change in 'colour' of the land surface will significantly affect any temporal comparison between images[d]. Most invertebrate species are present throughout the year although some species have an annual life cycle and will show seasonal patterns in abundance. Bamber *et al.* (in prep.)[c] concluded that '... unsynchronised annual monitoring, i.e. not at the same time each year, is likely to give results of little value where seasonal patterns do exist.' In general, monitoring studies should be undertaken in late summer and late winter/early spring to identify, and coincide with, seasonal low and high salinity/water levels.

Seasonal changes in rainfall may affect the salinity regime, water depth and extent of a lagoon. Such changes will be directly related to the dimensions of the lagoon. Lagoons with a large water volume are more able to buffer seasonal variations. Seasonal changes in the rate of inundation may affect the rate of sediment deposition or re-suspension, with a consequent change in turbidity that may influence the lagoon vegetation.

### *Meteorological changes*

Salinity is a key factor determining the biological composition and its associated spatial organisation. A lagoon, by definition, has a limited exchange with the open sea where the restriction is often linked to tidal cycles. Tidal inundation may vary with ambient conditions (air pressure has an inverse effect on tidal height), storm action and the stage of the monthly or annual tidal cycle. Rainfall will also influence the salinity in a lagoon, particularly those lagoons with very restricted links to the open sea.

Weather cycles can result in changes in the biotic assemblages. Wind may push algal communities or floating vegetation over sediment, particularly after a seasonal die-back. A large bank of detached vegetation had been blown onto the shore of the Fleet lagoon by recent strong winds during November 1999.[d] This vegetation obscured the underlying habitat and affected the classification of remote sensing images.

### *Access*

Land surrounding a lagoon will often be under private ownership and therefore it will be necessary to seek the landowner's permission to gain access to the water. Where boat access is required, it may be necessary to seek permission to use a private pier or jetty.

Access for monitoring a lagoon will depend on the size and depth of the lagoon and its substrata. Small, shallow lagoons may be sampled from the edge or by wading carefully. Large, shallow lagoons may be snorkelled while large, deeper lagoons may require boat access. Nevertheless, the substrata will have an overriding influence on the mode of access. In Loch Maddy cSAC, the mud in the lagoons was so soft and flocculent that even snorkelling would cause undesirable disturbance to the habitat, and direct sampling was not feasible.[e] In the extensive Fleet lagoon, Dorset, a prohibition order on motorised vessels made biological sampling difficult and arduous, and restricted the options available when planning a survey strategy.

In all cases, field staff must take account of the need for minimal disturbance to this fragile habitat.

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2 Or the Wildlife (Northern Ireland) Order 1985. At the time of writing there are no lagoon species listed in Northern Ireland.

3 Countryside Council for Wales, English Nature, Scottish Natural Heritage.

### *Sampling issues*

The following three points are mentioned above but merit re-emphasising when planning a sampling exercise in a saline lagoon:

- Lagoons are a fragile habitat and disturbance must be kept to a minimum. It may be appropriate to use sampling devices that take a smaller volume of sediment (e.g. *Ekman* grab rather than a Day grab; smaller diameter cores[4]), or reduce the number of samples recorded.[5]
- One possible development that could compromise disturbance and improve data on the key attribute of salinity is the use of data loggers. However, the technology for measuring salinity (usually conductivity) is such that sufficiently small and cheap loggers, such as for temperature, may not be available for some time.
- Lagoons can support species scheduled under the Wildlife and Countryside Act 1981 and a licence is required for their collection. If collection is required, the quantity of specimens should be kept to the minimum necessary, and if possible, returned to their habitat alive if a permanent record is not required.

A monitoring programme must collect sufficient information to assess the condition of the whole lagoon, or suite of lagoons within the SAC. The complexity of such monitoring will depend on the physical dimensions and the ease of access to a lagoon. It must consider both the physical, water quality (e.g. salinity) and biological aspects of a lagoon to assess the integrity of the entire lagoonal ecosystem. Bamber *et al*. (2000)[c] provide detailed guidance on sampling issues for lagoon monitoring studies, including the main attributes to measure. They note:

> 'The scale of larger lagoons, such as many sites in Scotland and the Fleet, Dorset, poses particular challenges for monitoring. Many lagoons can be treated as a collection of sub-habitats which may therefore be studied separately, whereas extensive areas of uniform habitat will need to be "sub-sampled" by transects or by stratified random sampling. The greatest difficulty is posed by mosaic habitats, where site-specific protocols will need to be devised. In larger lagoons remote sensing techniques may enable monitoring of the extent and other attributes of certain biotopes.'

### *Site marking and relocation*

It is unlikely that a lagoon site will require marking or pose any problems for relocation. Marking sampling stations within a lagoon is more difficult and must take full account of the fragile nature of the habitat. For hard substrata, the site marking and relocation issues discussed under Reefs earlier will equally apply to lagoons. Similarly, the section on subtidal sandbanks will apply to sand habitats including eelgrass beds. For small sites, permanent marking of stations in sediment is unlikely to be necessary; larger sites should be considered case-by-case. Pooley and Bamber (2000)[d] concluded that dGPS was satisfactory for recording position within the Fleet lagoon, Dorset; this conclusion should apply to most extensive lagoons in the UK. For smaller lagoons, the location and relocation of sampling stations could use transits/bearings from landscape features (Figure 3-5) and drawings/sketches of specific local features (Figure 3-4).

### *Health and safety*

All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent. Risks specific to working in lagoons are:

- *Wading in soft sediment*. Tthere is a risk of getting stuck or, worse, drowning after falling when the feet are immobilised.
- *Illness and disease from contaminated sediment*. Sediments are known to bind contaminants such as heavy metals (& radioactive isotopes) at high concentrations, which are subsequently released upon disturbance. It is possible to contract serious diseases such as hepatitis from sewage effluent in sediment.

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4 It is important to consider the body size of the characteristic infaunal organisms to ensure that a smaller sampling device will collect adequate samples.

5 A pilot investigation may be necessary to fully evaluate the minimum number of samples necessary to record any change.

If there is any history of such discharges into the lagoon under investigation, protective gloves should be used to avoid skin contact with the sediment.

Subtidal sampling in lagoons may involve snorkelling and SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[6] (see: **http://www.hse.gov.uk/spd/spddivex.htm**) and must follow the Scientific and Archaeological Approved Code of Practice[7] (**http://www.hse.gov.uk/spd/spdacop.htm - a**).

## Bibliography


a Anon (1994) *Biodiversity: The UK Action Plan*, ISBN 0-10-124282-4.

b UK Biodiversity Group (1999) *Tranch 2 Action Plans. Volume V – maritime species and habitats.* English Nature, Peterborough.

c Bamber, R N, Gilliland, P M and Shardlow M E A (in prep.) *Saline lagoons: a guide to their management and creation* (interim version, draft August 2000). Written and issued on behalf of the Saline Lagoon Working Group.

d Pooley, M and Bamber, R (2000) *Evaluation of aerial and diving techniques to survey vegetation in the Chesil and Fleet European marine site*, unpublished report to English Nature. English Nature, Wareham.

e Howson, C M and Davison, A (1999) *Trials of monitoring techniques using divers and ROV in Loch Maddy cSAC, North Uist.* Scottish Natural Heritage, Edinburgh.


6 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997, ISBN 0 11 065170 7.

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# 4 Guidance for establishing monitoring programmes for some Annex II species

Jon Davies

# Introduction

**Aim**

To provide guidance on marine Annex II species to assist the selection of appropriate monitoring techniques and their field deployment

Of those Annex II species that occur in the marine environment around the UK,[1] this section only provides advice for three species for which the UK has currently selected sites (November 2000) – namely, grey seal, common (or harbour) seal and bottlenose dolphin. The present section only presents some basic advice on aspects relating to the establishment and implementation of monitoring programmes for these three species. There are many standard texts available that provide more detailed guidance on generic issues relating to species monitoring.[2]

Each section starts with a basic introduction to the species and some background information on the site selection policy for sites in the UK. It is followed by advice on selecting appropriate techniques for monitoring each generic attribute[3] and information specific to monitoring these attributes. Finally, specific advice is given on health and safety issues for monitoring studies.

Under the Conservation of Seals Act 1970, the Natural Environmental Research Council (NERC) has a statutory obligation to provide the UK Government with advice on the size and status of British seal populations. NERC's Sea Mammal Research Unit (SMRU)[4] regularly monitors grey and common seals using standard techniques. Surveying is mostly restricted to sites in Scotland where over 90% of each species are found. Data from these and other monitoring programmes were used to identify and define candidate SACs and will provide important contextual information against which the results from future SAC monitoring studies may be compared.

A considerable amount of research data is available for aspects of the life cycle and life history of these species at some sites – for example, Aberdeen University[5] have studied the Moray Firth area; Aberdeen University, the Sea Watch Foundation and Nekton have studied Cardigan Bay. Nevertheless, there are significant gaps in our understanding of the biology and population dynamics of all three species, but particularly the bottlenose dolphin. Consequently the scope of the advice presented below is limited and will be revised, as the results of on-going research become available.

It should be noted therefore that:

- very little information is available for Annex II species, particularly the bottlenose dolphin;
- at present, it is not possible to complete all the sections of the attribute table – more research is required on appropriate attributes to define favourable condition;
- many monitoring techniques are not fully tested or established.

*Therefore, the advice provided in this section is based on our present understanding (Spring 2001) and is likely to change as our practical experience of SAC monitoring increases. In particular, the Joint Nature Conservation Committee is developing detailed guidance during 2001 to implement the UK's Common Standards for Monitoring programme that will probably result in a significant revision of this section.*

*The listing of an attribute in the tables in this section does not imply that it should form part of a monitoring programme for the feature, but it may need to be considered.*

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1 Grey seal, common seal, bottlenose dolphin, harbour porpoise, otter, twaite shad, allis shad, Atlantic salmon, river lamprey and sea lamprey.

2 For example: Ecoscope (2000c) *A species and habitats monitoring handbook. Volume 3: Species*. Research, Survey and Monitoring Report No. [XX]. Scottish Natural Heritage, Edinburgh; also Sutherland, W J (1996) *Ecological Census Techniques*. Cambridge University Press, Cambridge.

3 See **Section 2** for an explanation.

4 See **http://smub.st-and.ac.uk/**

5 See **http://www.abdn.ac.uk/~nhi104/seals/marmamm.htm**

# Grey seal *Halichoerus grypus*

**Figure 4.1** Grey seal *Halichoerus grypus* (Paddy Pomeroy, SMRU)

## Introduction to the species' interest

The grey seal *Halichoerus grypus* is the larger of the two resident species in the UK, reaching a length of up to 2.45m and weighing up to 310kg (both measurements for adult males)[1] (Figure 4.1). Typically they breed on exposed rocky coasts and in caves but occur in most coastal habitats at other stages of their life cycle. They are predominantly fish feeders taking a variety of species including sandeels, gadoids, salmonids, and flatfish, with cephalopod and crustacean invertebrates occasionally consumed. Their dietary composition varies seasonally and is linked to the availability of prey species. Grey seals form polygynous breeding groups but the size of the groups and the sex ratio varies with the nature of the habitat. Sites with open access may have a ratio of one male to two females but where access is restricted, for example in caves, the ratio may rise to one male for every ten females. The timing of breeding varies but in general, it occurs in September–October in S.W. Britain, October–November in west and north Scotland, and November–December at the Isle of May (Firth of Forth) and the Farne Islands. A single pup is produced and weaned after 16–21 days. Females come into oestrus towards the end of lactation when mating occurs. Females leave the breeding site soon after mating, and so there is no parental care for the pups post-weaning. In the UK, humans are the only major predator of adult grey seals, although potentially, predation by large cetaceans (e.g. killer whales) or sharks may occur in offshore areas. Starvation and infection are established sources of pup mortality.

The Sea Mammal Research Unit (SMRU) of the Natural Environmental Research Council (NERC) has extensively studied grey seal biology and population dynamics in the UK. In particular, they have completed surveys of population size,[2] diet, movements and foraging behaviour (using Satellite Relay Data Loggers attached to seals)[3] and genetic diversity.

Approximately 40% of the world population of grey seals breed at UK sites, which represents 95% of the EC population. There are breeding colonies all round the coast, from the Scilly Isles clockwise to the North Norfolk Coast. These colonies vary greatly in size with the main breeding colonies located in the Inner and Outer Hebrides, Orkney, Shetland, the mainland coast of north and north-east Scotland, the Isle of May, the Farne Islands and west Wales.

The largest breeding colonies, based on pup production, are candidate SACs. Sites were selected using the most up-to-date population information available at the time, although populations at individual sites may fluctuate. Sites were also chosen to reflect the geographical distribution of breeding sites – for example in west Wales, which is the most southerly breeding population.

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1 These statistics and the following text are taken from: Bonner, W N and Thompson, P M (1990) Seals, etc.: Order Pinnipedia – Grey seal. In: Harris, S and Corbet, G B (eds) *The Handbook of British Mammals*, Chapter 11, pp. 472–480. Blackwells, Oxford.

2 See **http://smub.st-and.ac.uk/ch1_1.html**

3 See **http://smub.st-and.ac.uk/ch3_2.html**

## Monitoring requirements and suggested techniques for grey seal

To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures for each attribute (Table 4-1). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (for example acoustic versus visual counts of dolphins), but considerable further work is required to establish suitable techniques for many attributes. The advice presented below will be updated when new information becomes available.

**Table 4-1** Suggested techniques for measuring the attributes that may be used to define favourable condition of grey seal populations. Guidance will be developed for the techniques listed.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Quantity (abundance) | Population size | Aerial photo-monitoring; Direct counts from boat or shore; Mark-recapture; Photographic mark/recapture[4] |
| Population dynamics | Recruitment | Pup counts; |
| | Mortality | Track adult survivorship; Adult and pup carcass recovery |
| | Emigration | Tracking pups |
| | Immigration | Tracking pups |
| Population structure | Age structure | Estimate natural population structure; ID of known individuals |
| | Sex ratio | |
| | Fragmentation/isolation | |
| | Genetic diversity | DNA analysis |
| Habitat requirements | Area for breeding | Aerial photography; Habitat mapping; Airborne remote sensing; Shore survey |
| | Area for feeding | Fish census techniques; AGDS; Side scan sonar; Acoustic fish monitoring |
| | Undisturbed area for breeding | Monitor disturbance events[5] |
| | Environmental processes | Measure water quality factors[6]; Debris/litter survey[7]; Survey injury to animals[7] |

## Specific issues affecting the monitoring of grey seal

### *Estimating population size*

The current surveillance programme undertaken by the SMRU is likely to make a substantial contribution to condition monitoring of SACs. Currently, each discrete breeding site in the Inner and Outer Hebrides, Orkney and the Isle of May is photographed between three and six times at regular intervals every year throughout the breeding season. Aerial surveys are carried out from a light twin-engine aircraft, using a large format aerial camera mounted in a vibration-damped, motion-compensating cradle. At sites in Pembrokeshire, the Farne Islands, Orkney and Lincolnshire, population size is estimated by ground counts from boat and shore. These techniques (aerial or ground) should be

4 See *Grey seals: Status and monitoring in the Irish and Celtic Seas* **http://www.ucc.ie/ucc/research/crc/pages/research/project1.htm**

5 Disturbance in breeding areas may reduce pup production.

6 To determine levels of nutrients, pollutants and pathogens.

7 For example, discarded monofilament nets and ropes may entangle seals causing lacerations.

used for all other sites not surveyed by these existing programmes. Counting grey seals at breeding or haul-out sites will only provide an *estimate* of the population size and structure because it cannot take account of the proportion of the population at sea.

Seals can travel up to 100km per day, and individual animals have been tracked for 3,000km. Consequently there may be large migrations between breeding and haul-out sites. There is a regular interchange of individuals between sites on the east coasts of Scotland and England, although there remains some genetic differentiation between each population. Some of these movements may be seasonal and linked to seasonal changes in the spatial distribution/availability of prey species. There is limited information on the fidelity of individuals to a particular breeding site but some have been recorded returning to the same location on an annual basis for at least 15 years. These movements must be considered when interpreting the results of condition monitoring studies on population size in an SAC.

### *Population dynamics*

Pup counts are taken at the breeding sites and may provide an estimate of birth rate. Mortality amongst newborn pups can be as much as 15%, with a further mortality rate of between 40 and 60% occurring within 12–18 months.

The main causes of mortality are difficult to quantify as many seals (adults and pups) die at sea, but disease caused by parasites, pollution and entanglement in discarded/lost fishing nets are some of the main causes.

A detailed understanding of the population dynamics needed in order to define favourable condition of the grey seal is not available.

### *Habitat requirements*

Grey seals depend on the sea for their food but also have a need for safe areas of land to haul out to rest, give birth and moult. They require undisturbed areas, usually uninhabited off-shore islands, that afford easy access to the intertidal and adjacent coastal areas above Mean High Water of spring tides. There is increasing evidence that certain habitat features, such as access to shallow freshwater pools, are important.

Studies demonstrated that grey seals can forage widely, although most feeding activity was within 50km of a haul-out site. Typical foraging trips last from two to five days. Nevertheless, satellite telemetry studies show distinct aggregations of animals at offshore locations in the North Sea, often where the seabed comprises coarse sand and gravel. Monitoring attributes in relation to foraging area and prey availability will be difficult for grey seals because of their mobility and ability to switch between prey species.

## Health and safety

Grey seal colonies are often located in remote areas that present considerable health and safety risks. Staff must follow all standard procedures, particularly in relation to working alone (to be avoided), working in remote areas and working from small boats. Some specific risks are:

- working in caves;
- working on offshore rocks, where difficulties are associated with landing, wave surges, being stranded by a rising tide;
- attack by adult seals, particularly during the breeding season and/or in confined spaces (caves or gullies);
- infection of wound if bitten;
- bacterial infection from seal faeces at breeding/haul-out sites.

The Wildlife and Countryside Act 1981[8] and the Animals (Scientific Procedures) Act 1986[9] control and regulate the study of wild animals that involve the capture and release, handling or remote sampling of individuals. Under this legislation, a licence is required from the UK Government for all activities that require the capture or handling of grey seals.

8 See: **http://www.wildlife-countryside.detr.gov.uk**

9 See: **http://www.homeoffice.gov.uk**

# Common seal *Phoca vitulina*

**Figure 4.2** Common seal *Phoca vitulina* (Lighthouse Field Station, University of Aberdeen)

## Introduction to the species' interest

The common seal *Phoca vitulina* (also known as the harbour seal) is the smaller of the two resident species in the UK, reaching a length of up to 1.85m and weighing up to 130kg (both measurements for adult males).[1] Common seals' habitual haul-out areas are generally found in shallow, sheltered waters, sea lochs and island archipelagos. They are characteristically found on sandbanks, mud flats and estuaries on the east coast of the UK (Wash, Dornoch Firth), or shores of small islands or isolated skerries in west Scotland and the outer islands. Individuals return to favoured haul-out sites and there are no known migratory movements. They are predominantly opportunistic fish feeders taking a variety of species that are locally abundant, and also invertebrates such as cephalopods, gastropods and crustaceans. Adult females bear a single pup in June or early July with no obvious regional differences around the UK. Pups are weaned after about 4–5 weeks and normally complete by late July at most colonies. Mating occurs soon after weaning. Common seals are top predators in the UK and there are few known sources of mortality. In 1988, populations were reduced by about 50% following a phocine distemper virus epizootic. Common seals are often perceived as having a great impact on fisheries. particularly those using set nets and cages, although their actual impact on fish populations is estimated to be very low. Pups were hunted for their skin in north and west Scotland and the Wash until the passing of the Conservation of Seals Act in 1970. In order to protect their catch, fishermen may kill seals if they are interfering with fishing gear.

The Sea Mammal Research Unit (SMRU) of the Natural Environmental Research Council (NERC) and Aberdeen University[2] have extensively studied common seal biology, population dynamics and diet on the east coast of Scotland. SMRU undertake annual surveys to estimate population size.[3]

The UK holds approximately 5% of the world population of common seals, and approximately 50% of the EC population. The biogeographical distribution in UK waters ranges from Strangford Lough, Northern Ireland to the south shores of the Clyde and then clockwise round the coast to the Thames estuary. The common seal is widespread, but population density varies greatly from place to place, with low numbers at many sites. This means it can be difficult to define the boundaries of specific sites. The census of the common seal population is based on numbers hauling out in coastal locations during the moulting period in August. Such haul-out areas are thought to be very important for the conservation of the species, as are the most important breeding colonies. Sites were selected using the most up-to-date population information available at the time, although populations at individual sites may fluctuate.

1 These statistics and the following text are taken from: Bonner, W N and Thompson, P M (1990) Seals, etc.: Order Pinnipedia – common seal, in: Harris, S and Corbet, G B (eds) *The Handbook of British Mammals*, Chapter 11, pp. 462–471. Blackwells, Oxford.

2 See **http://www.abdn.ac.uk/~nhi519/lighthse/seals/seals.htm**

3 See **http://smub.st-and.ac.uk/ch1_1.html**

## Monitoring requirements and suggested techniques for common seal

To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures for each of attribute (Table 4-2). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (for example acoustic versus visual counts of dolphins), but considerable further work is required to establish suitable techniques for many attributes. The advice presented below will be updated when new information becomes available.

**Table 4-2** Suggested techniques for measuring the attributes that may be used to define favourable condition of common seal populations. Guidance will be developed for the techniques listed.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Quantity (Abundance) | Population size | Thermal aerial photography; Colour aerial photography; Direct counts from boat or shore |
| Population dynamics | Recruitment | Pup counts |
| | Mortality | Pup carcass counts; Adult carcass recovery; Tagging individuals |
| | Emigration | Satellite telemetry |
| | Immigration | Satellite telemetry |
| Population structure | Age structure | ID of known individuals |
| | Sex ratio | |
| | Fragmentation/isolation | Count haul-out sites |
| | Genetic diversity | DNA techniques |
| Habitat requirements | Area for breeding | Aerial photography; airborne remote sensing; Habitat mapping |
| | Area for feeding | Habitat mapping (AGDS; Side scan sonar); Fish census techniques; Acoustic fish monitoring |
| | Environmental processes | Measure water quality factors[4]; Debris/litter survey[5]; Survey injury to animals[6] |

## Specific issues affecting the monitoring of common seal

### *Estimating population size*

The current surveillance programme undertaken by the SMRU is likely to make a substantial contribution to condition monitoring of SACs. Currently, SMRU surveys common seals every five years in Scotland and annually in Lincolnshire and Norfolk. Surveys are carried out in August during the moult within two hours of low tides occurring between 13:00 and 19:00 hours. For rocky or seaweed dominated sites, seals are surveyed using a thermal-imaging camera mounted on a helicopter to discriminate the well-camouflaged seals from the background (Figure 4.3). Helicopters are preferred to fixed-wing aircraft because they can carefully follow the shore along a complex coastline. Conventional aerial photography is used for the east coast sandbank sites where those seals hauled out are conspicuous against the background sediment.[a]

4 To determine levels of nutrients, pollutants and pathogens.

5 For example, discarded monofilament nets and ropes may entangle seals causing lacerations.

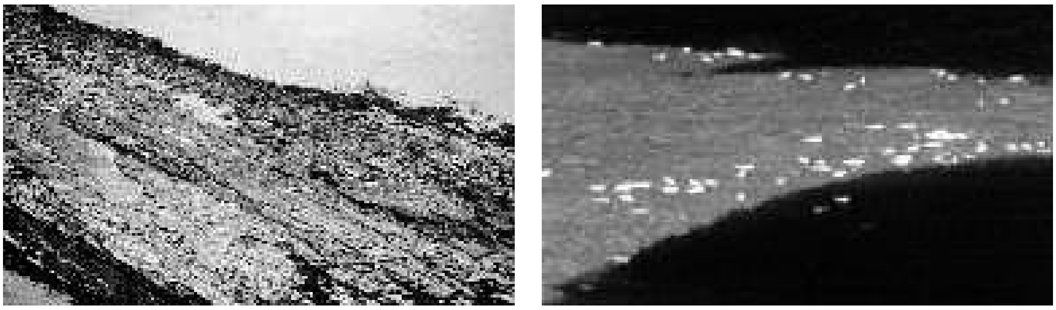

**Figure 4.3** A conventional photograph (left) and a thermal image (right) of common seals on a skerry in Scotland (from SMRU Internet site)

Although these surveys coincide with the period when the maximum number of seals are likely to be ashore, there will be an unknown number of animals in the water at the time of survey. Research studies in Orkney, the Moray Firth and the Wadden Sea developed ‘correction factors’. In the Moray Firth, the proportion of seals hauled out was estimated to be 0.5–0.75 of the total population.[b] It is important to establish the activity patterns of the seals when planning any census as the habitat can strongly influence the animal’s behaviour. For example, common seals on rocky shores in Orkney had diurnal patterns of activity, whereas in the Moray Firth the availability of haul-out sites on sandbanks depended on the tidal cycle. Census techniques must minimise within-year variation by investigating activity patterns at a local level. The study in the Moray Firth concluded that population trends may be detected over 4–6 years using annual counts based on 2–3 visits per year; >5–6 visits per year were found to be inefficient.

### *Population dynamics*

Common seal movements can be investigated by VHF or satellite-linked telemetry. Individuals are captured at the haul-out site and the telemetry device, which usually includes a data logger, glued to the fur on the top of the seal’s neck.[c,d] These tags detach from the body during the annual moult. Common seal movements are strongly influenced by local food availability, and most movements are considered ‘local’ compared with grey seals. Individuals may travel up to 45km on trips lasting six days, but then return to their ‘home’ site. Most mass movements are associated with the dispersal of young animals, although seasonal movements between haul-out sites are known.[e]

### *Population structure*

Sex ratio may be an important attribute, although any change may not manifest as a problem for several generations. It is necessary to investigate sex ratio at least twice during the annual life cycle because the sex of animals at a haul-out is biased toward female during the pupping season, and toward male during the annual moult.[b]

Common seals require suitable haul-out sites throughout their life cycle. Studies have shown that this species forms discrete populations with little interchange of individuals between populations. Any loss of haul-out sites within an SAC will affect the local common seal population. It may be necessary to monitor the number of haul-out sites with the SAC.

### *Habitat requirements*

Common seals are coastal feeders, rarely occurring further than a few kilometres offshore. Populations appear to remain within an area throughout the year, although the number of individuals at a haul-out site will change throughout the year. Studies have shown that seasonal changes in site use may be linked to a site’s physical characteristics, because they may be suitable for breeding females during pupping, or groups undergoing the annual moult, or because there are seasonal patterns in the abundance of the seal’s prey near a site.[c] Maintenance of viable populations within SACs is therefore clearly linked to the availability of suitable haul-out sites with foraging areas nearby (<60km) throughout the life cycle.

Monitoring the availability of suitable feeding areas must be linked to contemporary analyses of the seal’s diet because common seals switch their preferred prey in relation to its local abundance both within and between years.[f] Diet composition can be ascertained by analysing faecal material from samples collected at haul-out sites. The location of feeding areas can be determined by telemetry studies. The type of prey consumed will determine the technique required for monitoring prey abundance within these areas.

## Health and safety

Common seal colonies are often located in remote areas that present considerable health and safety risks. Staff must follow all standard procedures, particularly in relation to working alone (to be avoided), working in remote areas and working from small boats. Some specific risks include:

- working on sandbanks: getting stuck in the sediment, being trapped by rising tide;
- working on offshore rocks: difficulties associated with landing, wave surges, being stranded by a rising tide;
- attack by adult seals, particularly during the breeding season;
- infection of a wound if bitten;
- bacterial infection from seal faeces at breeding/haul-out sites.

The Wildlife and Countryside Act 1981[6] and the Animals (Scientific Procedures) Act 1986[7] control and regulate the study of wild animals that involve the capture and release, handling or remote sampling of individuals. Under this legislation, a licence is required from the UK Government for all activities that require the capture or handling of common seals.

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a Thompson, P M and Harwood, J (1990) Methods for estimating the population size of common seals *Phoca vitulina*. *Journal of Applied Ecology* **27**, 924–938.

b Thompson, P A, Tollit, D J, Wood, D, Corpe H M, Hammond, P S and Mackay A (1997) Estimating harbour seal abundance and status in an estuarine habitat in north-east Scotland. *Journal of Applied Ecology*, **34**, 43–52.

c Thompson, P A, McConnell, B J, Tollit, D J, Mackay, A, Hunter, C and Racey, P A (1996) Comparative distribution, movements and diet of harbour and grey seals in the Moray Firth, N.E. Scotland. *Journal of Applied Ecology*, **33**, 1572–1584.

d Thompson, P A and Miller, D (1990) Summer foraging activity and movements of radio-tagged common seals (*Phoca vitulina*. L.) in the Moray Firth, Scotland. *Journal of Applied Ecology*, **27**, 492–501.

e Allen, S G (1988) *Movement and activity patterns of harbor seals at Point Reyes Peninsula, California.* M.Sc. thesis, University of California, Berkeley.

f Tollit, D J and Thompson, P M (1996) Seasonal and between-year variations in the diet of harbour seals in the Moray Firth, NE Scotland. *Canadian Journal of Zoology*, **74**, 1110-1121.

6 See: **http://www.wildlife-countryside.detr.gov.uk**

7 See: **http://www.homeoffice.gov.uk**

# Bottlenose dolphin *Tursiops truncatus*

**Figure 4.4** Bottlenose dolphin *Tursiops truncatus* (from Lighthouse Field Station, University of Aberdeen Internet site)

## Introduction to the species' interest

Bottlenose dolphins may attain a length of 2.7m and weigh up to 275kg (both measurements for adult males).[1] They are long-lived marine mammals living up to 50 years of age. Females reach sexual maturity at 5–12 years of age and may produce a calf every 2–3 years throughout their 40–50 year life span. Births occur over an extended period with a peak in March to May, and possibly during August and September. This species is widely distributed in the North Atlantic, West African, Mediterranean and UK coastal waters, with most sightings within 10km of land. Two predominant populations occur in UK inshore waters – Cardigan Bay and the Moray Firth. In addition, small groups appear to be resident or near-resident in waters off Cornwall and Dorset. The total population in the inshore waters of the UK is probably between 300 and 500 individuals. The species used to be more widespread, especially in the southern North Sea and English Channel, and has certainly declined in range. Their diet is predominantly fish, although cephalopod invertebrates (squid and cuttlefish) are consumed.

Aberdeen University[2] and the SMRU[3] have studied the dolphin population in the Moray Firth since 1988. Since 1989 they started a joint project to develop photo-identification techniques in an attempt to study the size and dynamics of the Moray Firth population.

In order for site designation under the Directive to be an appropriate mechanism for protection of Annex II species, it is expected that clearly identifiable areas can be defined that have the physical and biological factors essential to the life and reproduction of a population of the species. Only two areas in UK waters have been identified that meet this criterion for bottlenose dolphins; both these localities have been selected holding the only two substantial resident populations of the species in UK waters. While the individuals using the two sites may range further afield for part of the year, dolphins are present throughout the year and easily recognised individuals have been seen over periods of several years. This repeated occurrence and continual presence indicates that the sites are critical for the maintenance of these populations.

## Monitoring requirements and suggested techniques for bottlenose dolphin

To help implement the UK's Common Standards for Monitoring programme, it is necessary to recommend a small number of techniques that are likely to provide comparable measures for each of attribute (Table 4-3). The UK Marine SACs project evaluated the inter-comparability of some of these techniques (for example, acoustic versus visual counts of dolphins), but considerable further work is required to establish suitable techniques for many attributes. The advice presented below will be updated when new information becomes available.

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1 These statistics and the following text are taken from: Evans, P G H (1990) Whales, Dolphins and Porpoises: Order Cetacea – Bottlenose dolphin, in: Harris, S and Corbet, G B (eds) *The Handbook of British Mammals*, Chapter 9, pp. 331–333. Blackwells, Oxford.

2 See **http://www.abdn.ac.uk/~nhi519/lighthse/dolphins/dolphins.htm**

3 See **http://smub.st-and.ac.uk/ch4_5.html**

**Table 4-3** Suggested techniques for measuring the attributes that may be used to define favourable condition of bottlenose dolphin populations. Guidance will be developed for the techniques listed.

| *Generic attribute* | *Feature attribute* | *Technique* |
|---|---|---|
| Quantity (Abundance) | Population size | Counts; Mark/recapture by photo-ID; Acoustic techniques |
| Population dynamics | Recruitment | Count juveniles |
| | Mortality | Fishery by-catch survey; Stranded carcass returns; |
| | Immigration | Photo-ID of individuals |
| Population structure | Age structure | |
| | Sex ratio | |
| | Fragmentation/isolation | |
| | Genetic diversity | |
| Habitat requirements | Area for breeding | |
| | Area for feeding | Habitat mapping (AGDS; side scan sonar); Prey census techniques |
| | Environmental processes | Measure water quality factors;[4] Debris/litter survey in relation to injury to animals;[5] Incidence of skin lesions |

## Specific issues affecting the monitoring of bottlenose dolphin

### *Population size*

For the Moray Firth population, the estimate of population size was derived from a mark-recapture model using the proportion of photographed individuals in several separate samples. It is important to standardise the recording period (using time) to avoid any bias in the results; that is, the counts are effort-limited. Consistent identification of an individual relies on markings that persist between surveys (Figure 4.5). This may require more regular surveillance visits than condition monitoring events (perhaps every six years). In the Moray Firth, there is a photo-archive of over 395 'individuals'. Some animals occur more than once either because their identifying marks were lost between photographs, or because the photographs represent left and right views that it had not been possible to link together.

4 To determine levels of nutrients, pollutants and pathogens.

5 For example, discarded monofilament nets and ropes may entangle seals causing lacerations.

**Figure 4.5** Examples of some of the main types of natural markings used to identify individual bottlenose dolphins in the Moray Firth population. Clockwise from the top left: dorsal fin nicks, depigmented areas, rake marks; and skin lesions (after Lighthouse Field Station, University of Aberdeen[6])

Shore or boat-based counting techniques that do not involve any identification of individual animals are prone to error due to the mobility of the animals both within and between counting periods. Individual dolphins can move rapidly throughout their range; for example, one individual in the Moray Firth was sighted at locations 190km apart within a 5-day period.[a] Nevertheless, visual counts at stations known to be regularly frequented by dolphins may be important for assessing the effectiveness of any management actions, and if undertaken regularly may act as a regular 'health check' between monitoring events.

Passive acoustic monitoring of dolphin vocalisations may be useful for estimating the abundance of individuals within an SAC, particularly for monitoring changes in distribution and abundance in small, localised areas[b]. This technique has the advantages of time/weather independence and it can detect dolphins over much greater ranges than visual census techniques[c]. However, it is not possible to assess the proportion of individuals calling at any one time. Acoustic monitoring can provide a valuable adjunct to a visual census, and may provide a valuable tool for the long-term surveillance of dolphin activity patterns within an SAC. Photo-identification techniques are considered to be the more appropriate method for estimating changes in dolphin abundance over a wider area (whole SAC).[b]

None of these counting techniques provides an absolute population size, rather a minimum estimate of population size for a defined period.

### *Population dynamics*

It is possible to compile an inventory of individual dolphins within an area using photographic identification. From repeated observations it should be possible to track an individual dolphin through time. Aggregating the results for many individuals may provide a basic understanding of a population's dynamics over time.

Analysis of stranded animals or corpses may provide surveillance data to support an assessment of the 'health' of dolphin populations. The UK Government funds schemes to report and collect stranded carcasses for post-mortem analysis.[7]

6 See: **http://www.abdn.ac.uk/~nhi519/lighthse/dolphins/mfdolfhid.htm**

7 For example, the Natural History Museum operates a stranding project (Tel: +44 (0)20 7938 8861); also the Collaborative Celtic Marine Strandings Project operates in Wales and Ireland.

### *Habitat requirements*

The precise habitat requirement of bottlenose dolphins is poorly understood. Dolphins used different areas in the Moray Firth through the year[a] and their distribution showed distinct geographical stratification. This stratification may restrict the animal's movements in confined sites such as firths and they may not be able to move away from localised disturbance or pollution.

Unless the entire SAC is being investigated, monitoring the extent and quality of prey habitats must be linked to contemporary surveys of the geographical location of dolphin populations rather than simply returning to the same area at each monitoring event. Dolphins can forage widely and therefore a decline in prey abundance in one area may not impact the population.

Incidence of skin lesions (Figure 4.5) has been tenuously linked to environmental factors (low water temperature and low salinity) and may be linked to anthropogenic contamination.[3] At present there is no conclusive evidence for the latter although clearly a precautionary approach to SAC management would be advisable. Populations have only been studied for a proportion of an individual's likely life cycle (~12 out of 40–50 years) and chronic effects may yet materialise.

## Health and safety

Bottlenose dolphins may occur in offshore and potentially remote areas. Staff must follow all standard procedures, particularly in relation to working alone (to be avoided), working in remote areas and working from small boats. Some specific risks include:

- using boats in offshore areas: it is imperative that suitable vessels are used in offshore locations; weather and sea conditions can deteriorate rapidly creating very hazardous conditions;
- working on isolated beaches/offshore rocks: difficulties associated with landing, wave surges, being stranded by a rising tide.

Swimming with dolphins is strongly discouraged – there is a potential risk of attack.

It is important to avoid disturbing or harassing dolphins with the survey vessel. Guidance is available on the Whale & Dolphin Conservation Society Internet site,[8] and the Department for the Environment, Transport and the Regions (DETR) Internet site.[9] DETR have recently published guidelines on minimising disturbance from whale watching operations under ASCOBANS.[10]

The Wildlife and Countryside Act 1981[11] (dolphins are a Schedule 5 species) and the Animals (Scientific Procedures) Act 1986[12] control and regulate the study of wild animals that involves the capture and release, handling or remote sampling of individuals. Under this legislation, a licence is required from the UK Government for all activities that require the capture or handling of bottlenose dolphins.

## Bibliography

a Wilson, B, Thompson, P A and Hammond, P S (1997) Habitat use by bottlenose dolphins: seasonal distribution and stratified movement patterns in the Moray Firth, Scotland. *Journal of Applied Ecology*, **34**, 1365–1374.

b Thompson, P, Tufft, L, Spencer, N, Grellier, K and Durban, J (2000) *Evaluation of techniques for monitoring the abundance and behaviour of bottlenose dolphins – the Kessock Channel as a case study.* Scottish Natural Heritage Commissioned Report F99LE01 (unpublished).

c Clark, C W and Charif, R A (1998) *Acoustic monitoring of large whales to the west of Britain and Ireland using bottom-mounted hydrophone arrays: October 1996–September 1997*, JNCC Report No. 281. Joint Nature Conservation Committee, Peterborough.

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8 See: **http://www.wdcs.co.uk/**

9 See: **http://www.wildlife-countryside.detr.gov.uk/whales/index.htm**

10 Agreement on the Conservation of Small Cetaceans of the Baltic and North Sea.

11 See: **http://www.wildlife-countryside.detr.gov.uk**

12 See: **http://www.homeoffice.gov.uk**

# 5 Advice on selecting appropriate monitoring techniques

Jon Davies

# Introduction

Sections 3 and 4 offered a restricted range of techniques for monitoring attributes to assess the condition of SAC features. The present section will offer advice on how to select the most appropriate technique from the range of techniques available. Each section starts with a summary of the overall technique followed by comparative information to assist in the final selection of a technique.

This section is under development and will be expanded as more information becomes available. In particular, it has not yet been established whether it will be necessary to aggregate data for features across the SAC site series. If this were required, it would be necessary to standardise the data recording on each SAC, probably via a single technique and/or method of deployment.

# Monitoring spatial patterns

## Introduction

Knowledge of the extent and spatial pattern of an Annex I habitat is an essential part of the assessment of its conservation status. It is necessary to measure the *extent* of an Annex I feature during the assessment of whether it is in favourable condition. Inevitably when dealing with spatial issues, the concept of *scale* becomes central to all investigations. The attribute of *extent* can be considered ont two principal scales: that of the whole Annex 1 feature, and that of individual sub-features. Recording the spatial pattern of biological resources within an SAC will contribute to monitoring the biological diversity of the site, and assessing the consequences of any localised anthropogenic activity on the remainder of the site. A map is a powerful tool for presenting a clear visual synthesis of a complex natural situation. Maps showing the distribution of habitats and their associated biota are central to many aspects of environmental management, environmental appraisal, and the assessment of the natural heritage or conservation value of an area. Unfortunately maps can also seriously mislead a user and misrepresent the real situation.[a] A map is only as good as the underlying data used for its preparation. Recording data to prepare maps is a complex, expensive and time-consuming operation. Resources (human and financial) are generally finite and therefore it is vital that the method chosen is appropriate for the objective of the study – it is *fit for purpose*.

Maps have a number of roles in a monitoring context:

- *display* the baseline spatial pattern of the features in an SAC;
- *support* the development of a sampling strategy and, in particular, provide the justification for stratifying a sampling regime in a monitoring study;
- a*nalyse* changes in the spatial pattern and/or areal extent of features in an SAC after a monitoring study.

### *Scale: broad and fine*

A map is a scale drawing of a feature on the earth's surface.[b] Scale is central to mapping and maps are often referred to as 'broad scale' or 'fine scale'. These terms are relative and there are no strict definitions to their actual real-world scale. Broad/fine scale definitions often relate to the techniques used to gather the data: broad scale maps are usually derived from remote sensing techniques; fine scale maps are based on direct observation through intensive ground surveys. Normally, 'broad scale' refers to a general picture of the distribution of habitats or biotopes, often themselves defined in general terms – for example, rock, sand, kelp forest, maerl bed. A 'fine scale' map will show the detailed distribution of habitats/biotopes, with more precise definition of the class boundaries.

### *Point distribution and continuous coverage maps*

It is important to distinguish between two very different types of map commonly used in conservation studies (see Figure 5-1).

*Point distribution* maps show the location of a single sampling point in an area, and no assumptions can be drawn on the areas between the points. For example, a series of grab samples may be taken throughout a subtidal sandbank to record the presence or absence of a particular species or distribution of biotopes. A map of the sandbank could show these samples as filled circles for presence, open circles for absence.

*Continuous coverage* maps display information on every possible location in the surveyed area. For the latter, the method of data collection for the map has a fundamental bearing on its accuracy. Direct observation through ground survey will result in a highly accurate map (assuming the method of recording location is precise and accurate). Alternatively, a map derived from a remote sensing study relies on deriving a relationship between a ground sample and a remotely recorded image. All areas of the image whose values correlate with those recorded at the ground sample point are assumed the same as the ground sample. Thus, the ground classes are not mapped directly at all locations, rather they are *predicted* from the remotely sensed image. There will be errors associated with this prediction process, and therefore the maps will have an underlying degree of uncertainty. Further sampling is required to test the reliability of these predictions and evaluate the degree of uncertainty. It is possible to create *continuous* maps from point samples using a variety of spatial statistical estimation techniques. Nevertheless, any boundary line can only be drawn midway between dissimilar sample points. The reliability of such maps is directly dependent on the density of sampling and the heterogeneity of the ground. Remote sensing can provide the underlying evidence for drawing boundaries at different positions between sample points, and for interpreting parts of an area where no sample points were recorded.

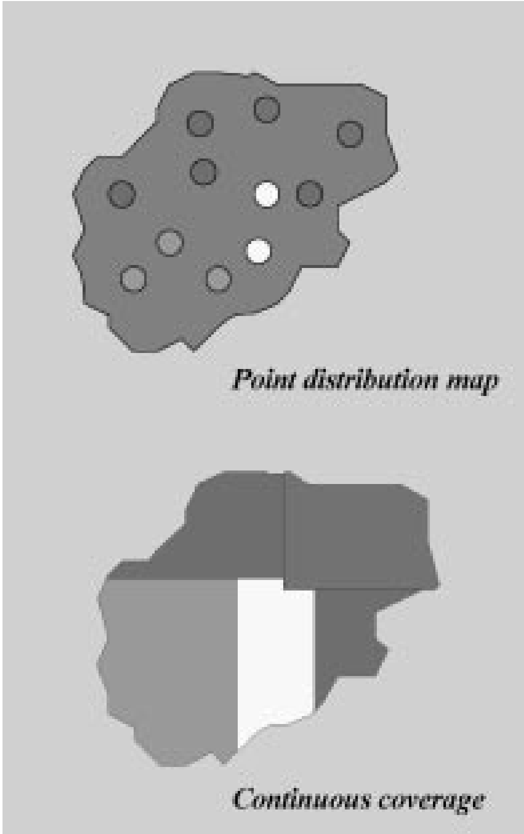


**Figure 5-1** Diagrammatic representation of point distribution and continuous coverage maps of the biotopes present within a sandbank

## Key issues to consider when measuring spatial patterns

To monitor any attribute involving extent, careful consideration must be given to the likely dimensions of the feature, and whether a *continuous* measure is required. Such issues will have a significant bearing on the selection of the most appropriate monitoring technique. It is rarely possible to undertake a direct ground survey of an area larger than a few square kilometres. For subtidal habitats, the situation is more acute and it is practically impossible to directly map an area greater than a few hundred square metres without significant resources. Direct observation is therefore only an option for monitoring the continuous extent of a sub-feature such as a biotope or biotope complex. Remote sensing techniques are the only practical solution for mapping the continuous extent of a subtidal feature or the spatial pattern of biological resources throughout an entire SAC. If a continuous measure is not required, standard remote sampling techniques can be used for point sample observations to compile a map. It then becomes vital, however, to plan the sampling strategy to ensure sufficient samples are recorded in the most appropriate spatial configuration to unambiguously sample the entire feature throughout an SAC. Figure 5-2 presents a basic decision tree for planning a spatial study.

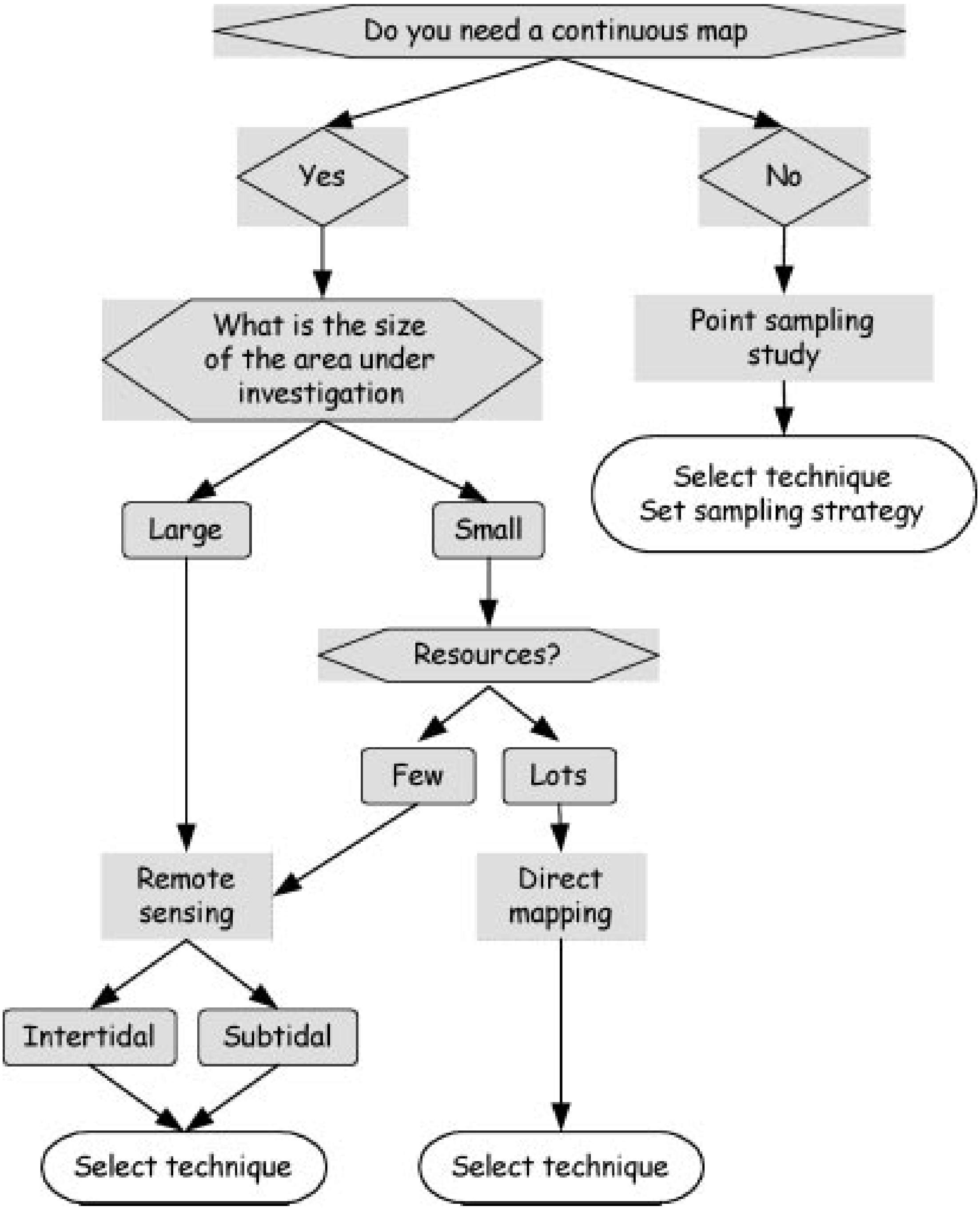


**Figure 5-2** A decision tree outlining some important questions to determine the appropriate techniques for a spatial investigation

## An overview of remote sensing in the marine environment

For many people, *remote sensing* is synonymous with satellite observation of the earth's surface. It does cover, however, a much wider range of instruments as satellite observation has, at present, a rather limited role in the marine environment. Remote sensing is a generic term describing the measurement of an attribute from a distance. In the present context, it generally refers to the measurement of an attribute of the land surface from the air, or the seabed from the water's surface. There are a wide range of remote sensing techniques available, differing principally in the type of data recorded (electromagnetic (light) or acoustic (sonar)), mode of data collection, the storage medium (film, paper or digital), and the platform on which the instrument is mounted (satellite, aircraft, boat). The optimum combination of these parameters will depend on the specific requirements of each investigation. A detailed account of *marine remote sensing* is beyond the scope of the present volume and only some basic information on these techniques is presented below. Green and King (2000)[c] provide a comprehensive review on the use of remote sensing for monitoring in the coastal zone. Ecosope (2000b)[d] provide an excellent summary of the use of remote sensing techniques for terrestrial habitat survey and monitoring, which is equally applicable to intertidal habitats. Green *et al.* (2000)[e] have published a comprehensive practical guide to the use of remote sensing for tropical coastal management applications, including subtidal regions; it is also applicable to clear temperate waters.

Satellite and airborne sensors record electromagnetic spectral (EMS) radiation at a range of wavelengths. For most nature conservation applications, the wavelengths in the visible and near infrared are most useful. Aerial photographs are perhaps the most familiar and straightforward products of airborne remote sensing. Other remote sensing instruments use an electrical sensor that converts its readings into digital numbers. These instruments scan the earth's surface recording the intensity of reflected EMS radiation over a range of wavelengths; the number of wavelengths or bands recorded varies between instruments. A black and white image has a single band, a colour photograph has three bands (red, green and blue), the Landsat satellite's *Enhanced Thematic Mapper* records eight spectral bands, and the Compact Airborne Spectrographic Imager (CASI) records 21 bands. Sensors recording many bands are termed *multispectral*. In general, more bands offer a greater potential for reliably distinguishing between features on the earth's surface.

**Box 5-1** Questions to consider when determining whether remote sensing is required for monitoring

| *Question* | *Comment* |
|---|---|
| What is the objective of the investigation? | Clearly identify the problem, establish the hypothesis |
| What are the dimensions of the area? (scale) | |
| What is the smallest unit to identify? (spatial resolution) | For example, are you looking to map a whole reef (broad scale) or individual boulders (fine scale)? |
| How similar are the different classes? (spectral resolution) | For example, are you trying to map areas of *rock* and *sand,* or trying to map subtle spatial patterns of different brown algal biotopes? |
| What type of product is required? | Do you only need printed output in the form of maps and/or photographs, or are electronic products required to integrate with other data? |
| Are the available funds sufficient? | After answering the previous questions, are additional funds required to provide a solution to the problem? |

While EMS radiation is highly effective for intertidal habitats (at low water), it is strongly absorbed by water and reflected by any suspended particulate matter. Even in the clearest tropical waters, electromagnetic spectral images will only show seabed features shallower than 30m below sea level. It is generally accepted that 15m below sea level is the maximum usable depth for habitat resource mapping purposes. In temperate marine systems, there are higher concentrations of particulate material. In the apparently clear conditions on the open coast of north-west Scotland and the Northern Isles, it is unlikely that electromagnetic sensors will record usable images for depths greater than 6m below sea level. For the turbid waters often encountered along the southern North Sea coastline of England, it is difficult to distinguish any feature below sea level. Acoustic radiation is less strongly absorbed by water and therefore sound in the form of sonar is used to record images of the seafloor. The distance sound can travel through water is dependent on its frequency: decreasing the frequency increases the distance travelled. Sonar systems are either operated from boats where the sensor (called a transducer) is mounted on the hull, or towed behind in a 'fish'. There are two basic types of sonar: single beam echo-sounders and swath sonars. Single beam echo-sounders emit a vertical cone of sound that ensonifies a discrete area of seabed (a circle in its simplest form) under the vessel. Swath sonars ensonify a strip of seabed perpendicular to the vessel, where the range either side of the vessel is dependent on the frequency of the sonar. Traditionally, the intensity of the signal reflected from the seabed was recorded onto thermal sensitive paper to create a *sonograph.* Modern systems convert the returning sonar signals into digital information.

For marine monitoring studies, the type of remote sensing technique that should be used is clearly determined by the depth of the seabed in relation to sea level. For intertidal habitats, electromagnetic spectral techniques are the most appropriate; for subtidal habitats deeper than 6m below sea level, sonar techniques are the most appropriate. For the shallow region in between the choice of technique is less straightforward. One has to consider the likely clarity of the water before considering EMS techniques,[1] and/or whether the operating depth is sufficient to allow a vessel to manoeuvre when operating a sonar system.

Prior to commissioning a remote sensing campaign,[2] it is vital that the questions posed in Box 5-1 are fully considered.

### *What final products should be specified?*

It is important to consider the format of the output products of the instrument because this has a significant bearing on the options available for their interpretation. Traditional paper or photographic film products provide a readily available image of the shore or seabed that the user can scrutinise to differentiate different features. Visual interpretation of aerial photographs has a long history of use by the conservation agencies[f] and people are generally familiar with these products. Printed EMS images look superficially like an aerial photograph but become less clear when printed at a detailed scale because they have a lower spatial resolution; they become 'pixelated'.[3] For example, field staff had some difficulty relating a CASI image with 2m pixels of intertidal habitats of Morecambe Bay to the saltmarsh features observed on the ground.[g] Specifying digital products offers more flexibility to the analysis and reporting of the results from a remote sensing campaign. Even if a printed output is required, the data can be edited and filtered to remove erroneous values to improve the final output. Multispectral data provides the facility to use band combinations other than the simple red/green/blue combination of an aerial photograph to highlight vegetation features. Digital products can also be incorporated into geographical information systems to integrate with other data products such as field sample records. Long-term storage is a further consideration when specifying the output products. There are significant storage, security and preservation issues associated with printed material that should not be overlooked. Digital products are easily replicated for storage in different locations but some consideration must be given to the format of the data. Storing data in a bespoke format may lead to compatibility issues in the future, if the associated software becomes redundant.

### *Can the sensor detect the target habitat/biotope: a question of resolution?*

Arguably, the most fundamental question to answer when selecting a remote sensing technique is: *can the sensor actually 'see' the entity to be monitored?* In technical terms, does the sensor have sufficient *spatial* and/or *spectral resolution* to identify the target habitat/biotope. *Spatial resolution* refers to the smallest physical size/area of ground that can be differentiated in the final image; for digital images this equates to the area of ground represented by each pixel. A basic understanding of the area to be studied is important, in particular the dimensions of the main spatial patterns in terms of patch sizes, prior to specifying a remote sensing technique. For example, each pixel in a *Landsat ETM* image represents an area of 40m x 40m on the ground and therefore will not resolve any feature with smaller dimensions. Aerial photographs and high-resolution side scan sonar can resolve items <30cm in diameter. Invariably there is a trade-off in cost terms where high resolution generally equates to higher cost (see below) and therefore the sensor's resolution should be matched with the dimensions of the target classes. The scale of the desired map will also set the limit to the sensor's spatial resolution – see Box 5-2.

*Spectral resolution* is more complex and often linked to ambient conditions. In simple terms, the

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1 For example, by local *in situ* measurements using a secchi disc.

2 'Campaign' is the standard term used by the remote sensing community to cover the field data collection activity.

3 An electronic image comprises a grid of rectangular picture elements or *pixels* where each pixel has an associated datum value. In its simplest form, a pixel of black and white images has a value of 1 or 0. In a remotely sensing image of the earth's surface, a pixel is referenced to a geometric grid (e.g. OS National Grid) and stores data on the spectral characteristics of the rectangular area of ground it represents.

remote sensor must 'see' a difference between the entities of interest if they are to appear distinct on the final image. For example, a green *Ruppia* seagrass bed may look the same as a green *Zostera* seagrass bed to a CASI sensor.[h,i] Similarly, bedrock covered with an algal turf may 'look' the same as bedrock covered with a faunal turf to a sonar sensor. It should be noted that the converse situation could also occur where the remote sensor can record differences within a habitat or biotope that are not easily distinguishable on the ground. Whilst it is possible to review the results of previous investigations to determine the discriminatory power of the different sensors, ambient conditions can nevertheless reduce a sensor's discriminatory power at the time of data collection. For instance, high sediment loading of the water in an estuary due to a storm event can significantly degrade sonar data. There are no simple solutions to offer here other than to spend time investigating the discriminatory powers of the different sensors in relation to the objectives of the remote sensing study. The procedural guidelines dealing with remote sensing techniques offer some further guidance in relation to quality assurance and discrimination.

**Box 5-2** An indication of how image resolution affects map scale[j]

| *Spatial resolution (m)* | *Typical map scale* |
|---|---|
| 1000 | 1:1,500,000 |
| 30 | 1:80,000 |
| 20 | 1:50,000 |
| 10 | 1:24,000 |
| 5 | 1:12,000 |
| 1 | 1:2,000 |

### *Are field visits required?*

The answer to this question is most emphatically yes! Remote sensors are recording variations in reflected energy (light or sound) of the shore or seabed and the results are no more than a series of colours on a photograph or numbers in a computer. These colours and numbers must be interpreted in terms of the habitat or biological classes present in the field. Collateral data are required to make this interpretation and a field visit is the only realistic solution. Existing information from previous field surveys may be used for an interpretation but any environmental changes between the date of recording and the date of image capture, such as a seasonal change in vegetation cover, will compromise the image interpretation. Whenever possible, the field visit should coincide with the image capture; coincident survey is essential if spectrophotometric measurements are required to calibrate the imaging equipment.[i]

How many samples are required? There are no hard and fast rules here, and in practice, the final number of samples will depend on the resources available. Nevertheless, a comprehensive (ideal?) image validation exercise to achieve statistical rigour may require at least 50 independent samples per habitat/biotope class.[k] Image interpretation is a correlation exercise where, in general, more information equates to a more certain link between the variables. Foster-Smith *et al.* (1999)[l] clearly demonstrated a reduction in the accuracy of a biotope map derived from an acoustic ground discrimination system with a reduction in the number of samples used for the image classification. Similar results were reported for satellite image classification where a 50% reduction in the number of ground samples reduced the accuracy of the image from >60% to less than 30%.[m]

A field visit will also be necessary to validate the final interpretation to determine its accuracy. It is possible to produce some very plausible and visually pleasing interpretations that bear little resemblance to reality. An assessment of accuracy is necessary for potential users to make a judgement on their degree of confidence in the final map. The simplest measure of the accuracy of a map is the frequency with which a ground sample matches the mapped interpretation beyond random chance; it is often quoted as the *Tau coefficient*.[n] Mumby *et al.* (1997)[o] reported a maximum accuracy of 37% for satellite imagery, 67% for aerial photographic interpretation and 81% for CASI imagery for detailed habitat maps (>9 reef habitat classes) of a Caribbean coral reef. Error matrices are more informative than a single measure where the sample data are listed in columns and the image data as the rows. The diagonal cells in the matrix show the frequency of a direct match, and the column and row totals show where the main mis-matches occur. Foster-Smith et al. (1999)[p] describe the use of error matrices in relation to biological mapping using acoustic ground discrimination systems. When commissioning a remote sensing study, it is vital that sufficient resources are allocated to the collection of an independent set of ground samples to verify the accuracy of the final products.

In summary:

- Ground sampling is essential for a realistic interpretation of a remotely sensed image.
- Sufficient ground samples must be recorded to give an adequate degree of accuracy for an interpretation.
- A further independent set of ground samples must be recorded to verify the accuracy of the final map.

### *How much will it cost?*

A remote sensing campaign is expensive because it requires significant hardware (from boats to computers), bespoke computer software, staff with technical expertise for data collection and image analysis and field staff with biological expertise. It does, however, provide a vast amount of information on the distribution and spatial patterns of marine habitats and biotopes. The raw data may be used by other agencies, giving the possibility of sharing the cost of data capture. For instance, CASI airborne images can also be used for assessing water quality. A carefully planned ground-sampling programme can provide both validation data to remote sensing, and provide data for the monitoring of other biological community attributes such as the presence/absence of a particular species. Mumby *et al.* (1999)[m] presented a detailed discussion on the cost-effectiveness of remote sensing for habitat mapping in tropical marine systems. They note, '... the issue is not that remote sensing is expensive but that habitat mapping is expensive', and conclude, '.. .the main issue facing practitioners is: What is the least expensive method to achieve a given habitat mapping task with an acceptable accuracy?'

It is difficult to give any definitive guidance on the cost of a remote sensing campaign due to the many options available at each stage (sensor, scale, analysis, and products). Some recent calculations were made for tropical remote sensing.[m] They also compared the cost of a CASI remote sensing campaign with a direct mapping exercise based on spot samples (see earlier) for 16km$^2$ (the median size of a marine protected area[q]) and concluded, '... a boat based survey would still be less accurate [than remote sensing], more expensive, and would involve an extra 16 person months of effort.'

## What is the most appropriate technique?

Taking account of the issues raised in the preceding text, it would be unwise to recommend a single technique to monitor an attribute. The final choice will depend on the characteristics of the attribute itself (such as scale, resolution), the resources (expertise, funds, equipment) available, and the degree of accuracy required. It is imperative that the questions listed in Box 5-1 are carefully considered prior to commissioning any spatial investigation. Table 5-2 (intertidal/shallow subtidal) and Table 5-3 (subtidal) compare the different techniques available in an attempt to make the final choice of technique easier.

Kenny *et al.* (2000)[r] provides an excellent account of the different technologies available for seabed mapping and includes a number of comparative tables (see Table 5-1). They note that there are three factors to consider when selecting the most appropriate and cost effective (acoustic) system:

1) dimensions of the area to map;
2) range of depths over the survey area;
3) size of the objects to detect (spatial resolution).

| *Water depth (m)* | *Multibeam sonar @ 12 kts* | | | *Feature attribute* | | |
|---|---|---|---|---|---|---|
| | Horizontal width (m) | Maximum footprint (m) | Coverage ($km^2$ per day) | Horizontal width (m) | Maximum footprint (m) | Coverage ($km^2$ per day) |
| 10 | 70 | 2.4 | 40 | 400 | 1.0 | 67 |
| 50 | 350 | 12 | 195 | 400 | 1.0 | 67 |
| 100 | 700 | 24 | 390 | 400 | 1.0 | 67 |
| 200 | 1400 | 48 | 780 | 400 | 1.0 | 67 |

**Table 5-1** Area of seafloor mapped by multibeam sonar and side scan sonar in a given time under operational conditions (from Kenny et al. (2000) – reproduced with the kind permission of the authors)

*It should be noted that the technologies available are changing rapidly and the specifications presented are current at the time of publication. The basic principles, however, should remain constant.*

**Table 5-2** Comparison between remote sensing techniques for monitoring intertidal and shallow (<<6m below sea level) subtidal features. Further detailed information is provided by Green and King (2000).[c] Note the technique *Aerial photo-interpretation* refers to photogrammetric analysis of aerial photographs, generally using specialist equipment. *Intertidal resource mapping from aerial photographs* is not strictly a remote sensing technique but is included here for comparison.

| | *Satellite remote sensing* | *Airborne multispectral remote sensing* | *Aerial photo-interpretation* | *Intertidal resource mapping from aerial photographs* |
|---|---|---|---|---|
| Recommended uses | Measuring extent of large features (Landsat image covers 185 x 185 km). Low resolution intertidal habitat mapping. Monitoring broad-scale intertidal vegetation change. Coastline/shoreline mapping Providing information to stratify more detailed sampling. | Rapidly assessing biological resources over a medium area (40 x 40 km). Establishing a baseline for monitoring large areas. Monitoring changes in distinguishable habitat/biotope extent. Providing information to stratify more detailed sampling. | Rapidly assessing the nature conservation resource in an area (<1000km$^2$). Establishing a detailed baseline for monitoring. Monitoring detailed changes in habitat/biotope extent. Providing information to stratify more detailed sampling. | Providing a relatively rapid inventory of biological resources in an area. Establishing a baseline for monitoring. Monitoring broad scale changes in distinct intertidal habitat/biotope distribution. |
| Efficiency | Relatively cheap to obtain although the cost increases as the area of interest decreases. Field survey of each image is essential for ground validation. | Expensive to obtain the imagery although cost decreases slightly as the area of interest increases. Field survey is essential for ground validation. | Picture cost is high. Six days maximum to evaluate each 5 x 5km square, including one day field checking. | Approximately 0.6km per hour or 2.4km per tide, assuming a 4-hour working window. |
| Cost | Moderate | High | Moderate/High | Low |
| Objectivity | Automated classification possible but improved with input from an 'expert eye'. | Automated classification possible but improved with input from an 'expert eye'. | Reasonable provided standard methods are adopted for distinguishing habitat types, and field checking used to establish accuracy. Problems arise when determining the boundaries where there is a gradual transition between habitats. Inter-operator subjectivity creates problems for repeat studies. | Reasonable, provided the surveyors are adequately trained in surveying and mapping techniques. Inter-operator subjectivity creates problems for repeat studies. |
| Spatial resolution | 15–60m with Landsat/SPOT 1m (Panchromatic) – 4m (multispectral ) with IKONOS | 0.5–10m | Variable >0.2m | <<1m |
| Spectral resolution | 3 – Landsat TM<br>4 – IKONOS | 8–21 spatial<br>24-96 hyperspectral | 1 | 1 |

4 See: **http://www.spaceimaging.com/** or **http://www.si-eu.com/** (Europe) for details on the IKONOS system

| | *Satellite remote sensing* | *Airborne multispectral remote sensing* | *Aerial photo-interpretation* | *Intertidal resource mapping from aerial photographs* |
|---|---|---|---|---|
| Typical map scale | 1:10,000 (IKONOS)<br>1:50,000 (SPOT)<br>1:80,000 (Landsat) | 1:1000 – 1:24,000 | 1:10,000 (or less) | 1:10,000 (or less) |
| Accuracy | 40–60% | Up to 80% | 60–80% | 100% (for stations visited) |
| Temporal resolution | 16–18 day (Landsat)<br>26 day (SPOT) | User specified time (depending on weather conditions). | User specified time (depending on weather conditions). | User specified time (depending on weather conditions). |
| Bias | Prevailing atmospheric conditions affect imagery and will compromise automated classification.<br>Penetration through water is affected by the prevailing turbidity and tidal state. | Prevailing atmospheric conditions affect imagery and will compromise automated classification.<br>Penetration through water is affected by the prevailing turbidity and tidal state. | Sources of bias arise from mi sidentification of habitat types and inaccurate mapping of boundaries.<br>Penetration through water is affected by the prevailing turbidity and tidal state. | Sources of bias arise from misidentification of habitat types and inaccurate mapping of boundaries.<br>Small, rare habitat types can be over/underestimated if areas are calculated from maps using sampling techniques. |
| Expertise | Image classification requires detailed knowledge of computer hardware and software.<br>An understanding of the ecosystem under investigation is helpful.<br>Each field recording team must have one marine biologist who can recognise biotopes in the field. | Image classification requires detailed knowledge of computer hardware and software.<br>An understanding of the ecosystem under investigation is helpful.<br>Each field recording team must have one marine biologist who can recognise biotopes in the field. | Operators should be trained in the recognition of different habitat types and in the use of stereoscopes. An ability to use a planimeter or digitising equipment is necessary for digital mapping.<br>An understanding of the ecosystem under investigation is helpful.<br>Each field recording team must have one marine biologist who can recognise biotopes in the field. | Each field recording team must have one marine biologist who can recognise biotopes in the field.<br>Operators must have a basic understanding of geographic information systems for digitising and analysis. |
| Key points | Penetration through water is dependent on prevailing conditions.<br>At present, satellite-based remote sensing does not provide a reliable method for monitoring changes in marine habitats.<br>Field validation is essential for accurate classification.<br>Satellite imagery can be used for broad intertidal feature mapping.<br>Image capture may not correspond to low water.<br>Image capture and associated field visits must occur at the same time of year – there is a risk that cloud cover may obscure the area of interest. | Penetration through water is dependent on prevailing conditions.<br>The use of airborne MSS for monitoring has not been fully evaluated.<br>Field validation is essential for accurate classification.<br>The digital, multispectral nature of the imagery offers the potential for other analyses – for example, vegetation changes.<br>Image capture and associated field visits must occur at the same time of year. | Penetration through water is dependent on prevailing conditions.<br>Good quality, overlapping, vertical, colour photographs recorded at low water are essential.<br>Image capture and associated field visits must occur at the same time of year.<br>Digitising pictures is a slow and complex process.<br>Field validation is essential, particularly to resolve boundary issues and differentiate similar habitats. | Good quality, vertical, colour photographs recorded at low water significantly improve the technique.<br>Surveyors must work to a consistent standard to ensure accuracy and repeatability between field visits.<br>Field visits must occur at the same time of year, particularly when using aerial photographs.<br>When estimating areas using sampling methods, particularly on sediment flats, careful planning of the sampling regime is necessary to avoid bias. |

**Table 5-3** Comparison between remote sensing techniques for mapping subtidal features

| | *Acoustic ground discrimination systems* | *Side scan sonar* | *Swath sonar*[5] | *Towed video* | *Sample mapping* |
|---|---|---|---|---|---|
| Recommended uses | Measuring extent of large features.<br>Broad-scale subtidal habitat/biotope complex mapping.<br>Providing information to stratify more detailed sampling. | Rapidly assessing the habitat over a large area.<br>Establishing a detailed baseline for monitoring large areas.<br>Monitoring changes in habitat extent. | Rapidly assessing the habitat resource over a large area.<br>Establishing a baseline for monitoring.<br>Monitoring broad scale changes in habitat and broad biotope extent.<br>Monitoring changes in bathymetry/topographical structure. | Establishing a baseline for monitoring.<br>Monitoring changes in habitat and broad biotope extent.<br>Identifying the location of boundaries between habitat/biotope classes. | Providing a relatively rapid inventory of biological resources in an area.<br>Establishing a baseline for monitoring.<br>Monitoring broad scale changes in biotope distribution.<br>Identifying the relative proportions of biotopes throughout an area. |
| Rate of coverage[r,6] | Broad scale survey: 10km$^2$/hr<br>Fine scale survey: 1km$^2$/hr | 1–8km$^2$/hr | 3–6km$^2$/hr | 0.1–0.2km$^2$/hr | < 0.003 km$^2$/hr |
| Cost: Equipment | Moderate | High | High | Low/Moderate | Low |
| Objectivity | Automated classification possible but improved with input from an 'expert eye'.<br>Inter-operator subjectivity creates problems for repeat studies. | Automated classification possible but improved with input from an 'expert eye'.<br>Data are qualitative and this inter-operator subjectivity creates problems for repeat studies. | Automated classification possible but improved with input from an 'expert eye'.<br>Inter-operator subjectivity creates problems for repeat studies. | Reasonable provided the surveyors are adequately trained in sample classification and mapping techniques.<br>Inter-operator subjectivity creates problems for repeat studies. | Reasonable provided the surveyors are adequately trained in sample classification and mapping techniques.<br>Inter-operator subjectivity creates problems for repeat studies. |
| Spatial resolution | 'Along track' resolution varies with depth/speed: typically 2–3m.<br>15° beam will insonify 7m radius circle at 30m depth.<br>Overall realistic minimum is 20 x 20m.<br>Measurement area (30m) 200m$^2$ | Frequency/range dependent[7] –10cm at 50m range (100m swath); 30cm at 150m range.<br>Along track – typically 2-3m.<br>Measurement area 10–1000m. | Frequency/range/distance from vessel dependent: typically 30cm at nadir (below vessel)<br>Along track – typically 0.3m.<br>Measurement area 10–1000m. | 'Along track' resolution will be <10cm within the field of view.<br>Measurement area 0.25–20m$^2$. | Dependent on sampling density but unlikely to be <20 x 20m.<br>Individual sample resolution will depend on the sampling device – typically 0.1 m$^2$. |

5 This combines both multibeam and inferometric systems, although there are important differences between them.

6 AGDS values adapted from Foster-Smith *et al.* (1999).[1]

7 Resolution decreases with increasing range and lower frequency. Resolution of side scan and swath sonar is a combination of along track (varies with boat speed and ping rate) and along the sonar beam, perpendicular to the track.

| | *Acoustic ground discrimination systems* | *Side scan sonar* | *Swath sonar*[5] | *Towed video* | *Sample mapping* |
|---|---|---|---|---|---|
| Accuracy | 40–60% | Not fully evaluated. | Not fully evaluated. | Not fully evaluated. | Not fully evaluated. |
| Bias | Maximum operating depth is dependent on sonar frequency.<br><br>Boat speed affects sonar signal.<br><br>Features between track lines will be missed – data interpolation will give a misleading image.<br><br>Errors in the calibration of the sonar will reduce repeatability. | Exact position of the sonar fish is not known giving a potentially large absolute position error.<br><br>Repeatability requires known, unchanged features to be present within the survey area. | Repeatability requires known, unchanged features to be present within the survey area. | Exact position of the towed vehicle is not known giving a potentially large absolute position error.<br>Features between track lines will be missed – data interpolation will give a misleading image.<br>Restricted to areas of level seabed without obstructions (such as rock outcrops). | Sources of bias arise from misidentification of habitat types and approximate mapping of boundaries.<br>Small, rare habitat types can be over/under estimated if areas are calculated from maps using sampling techniques.<br>Features between samples points will be missed. |
| Expertise | Experienced field operators are required although training is straightforward.<br><br>Data analysis requires detailed knowledge of computer hardware and software.<br>An understanding of the ecosystem under investigation is necessary. | Experienced field operators with a high degree of technical competence are required.<br><br>Image classification requires detailed knowledge of computer hardware and software.<br>An understanding of the ecosystem under investigation is necessary. | Experienced field operators with a high degree of technical competence are required.<br><br>Image classification requires detailed knowledge of computer hardware and software.<br>An understanding of the ecosystem under investigation is necessary. | Each field recording team must have personnel experienced in the sampling technique and a marine biologist who can recognise biotopes in the field. | Each field recording team must have personnel experienced in the sampling technique (e.g. an ROV pilot) and a marine biologist who can recognise biotopes in the field.<br><br>Specialist with an understanding of geographic information systems required for analysis and mapping. |
| Key points | Ensure the operating frequency is appropriate for the depth range of the area.<br><br>Track-based approach – inter-track spacing will affect resolution.<br><br>Coverage is not 100% and interpolation is necessary to predict inter-track areas.<br><br>Ambiguous sample classification will degrade the quality of the final maps. | The uses of side scan sonar for monitoring has not been fully evaluated.<br><br>Qualitative data requiring expert interpretation.<br><br>Can achieve 100% coverage giving near photo-quality images under optimal conditions.<br><br>Select the appropriate frequency for depth/spatial resolution.<br><br>No bathymetry information.<br><br>Field validation is essential for accurate classification. | Provides detailed bathymetric data for topographic mapping.<br><br>The use of swath sonar for monitoring has not been fully evaluated.<br><br>Can achieve 100% coverage.<br><br>Outputs include detailed bathymetry and topographic models.<br><br>Inferometric systems also give side scan output.<br><br>Select the appropriate frequency for depth/spatial resolution.<br><br>Field validation is essential for accurate classification. | Gives a positive identification of seabed features.<br><br>A slow technique only suited to small areas.<br><br>Many problems with towing a camera across the seabed: risk damage from rock outcrops, the camera can damage fragile habitats/communities<br><br>Track-based approach – inter-track spacing will affect resolution.<br><br>Coverage is not 100% and interpolation is necessary to predict inter-track areas. | Gives a positive identification of seabed features.<br><br>Sample classification must work to a consistent standard to ensure accuracy and repeatability between field visits.<br><br>When estimating areas using sampling methods, careful planning of the sampling regime is necessary to avoid bias. |

# Monitoring biological composition

## Background

Maintaining biodiversity is the main aim of the Habitats Directive.[8] Biodiversity itself is generally considered to encompass the variety of fauna and flora. Each Annex I feature in an SAC should have an attribute(s) that encompasses the variety of fauna and flora it supports. Theoretically, recording the total number of species present would provide the optimum measure of the biological diversity of a feature. In practice, the definition of each marine Annex I feature is sufficiently broad that enumerating the total number of species would be a near impossible task. Description of the biodiversity of ecosystems can be simplified by sub-dividing the environment into more easily recognisable units or classes, usually on the basis of the main physical habitats and their associated characterising species. The term biotope[9] is generally used for biological classes. Recording the number of classes in an area is a more practical proposition and the total number of classes is considered an appropriate proxy measurement for the total number of species. The range of biotopes supported by an Annex I feature in an SAC, termed the *biotope richness*, is an important attribute to measure the condition of a feature.[8] Prior to discussing techniques to monitor biotope richness, it is important to review some fundamental issues regarding the classification process.

## Biotope classification

Subdividing a continuous variable into categories can be a subjective or objective process. A subjective approach is straightforward but often difficult to repeat. An objective rule-based decision process is more repeatable but often difficult to apply to the 'irrational' biological world. In practice, the combination of an objective analysis with an 'experienced eye' is often the optimum solution when deciding where to put the dividing line in a classification. In 1997, the JNCC published a draft classification of marine biotopes for the UK and Ireland (Connor *et al.* (1997) a and b); the final version will be published in 2001. The biotopes were defined from the results of statistical classification analyses interpreted by marine biologists with considerable field survey experience. These analyses used data recorded around the whole of the UK and Ireland and the descriptions represented this *national* emphasis. The UK biotope classification was an important component in achieving a consistent approach to describing marine SACs throughout the UK and establishing a *framework* for common standards monitoring. How is the biotope classification used in practice?

### *Identifying biotopes from field records*

Ideally, each biotope should be a recognisable unit in the field whereby a surveyor could simply record the presence of each biotope as they move around an SAC. In practice, many biotopes require dedicated sampling techniques to collect their characterising species (for instance, sampling infauna in sediments), and/or specialist taxonomic skills to then identify these species. More importantly, simply identifying a biotope in the field without recording any supporting data does not enable subsequent auditing of field data for quality assurance purposes. Thus the issues of *biotope description* and *biotope assignment* have profound consequences for monitoring studies and should be clearly understood:

- The biotopes in the published classification were defined on a *national* basis, and cannot take account of all regional or site-specific (i.e. an individual SAC) variations in form. (***Biotope description***)
- Each biotope is a sub-division of a continuum with its description representing a nodal point. A sample from a transitional zone will have the characteristics of two or more biotopes. (***Biotope assignment***)

Most of the monitoring trials undertaken by the *UK Marine SACs Project* recorded some difficulties in assigning field records to the national biotope descriptions. It should be noted that these problems were largely only encountered with subtidal biotopes; fewer problems have been encountered with assigning intertidal records to a national biotope description. In retrospect, trying to use the national classification compromised the results for these subtidal studies and severely reduced the usefulness of their conclusions. The concluding message is therefore:

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8 The introductory section of the Directive states: 'Whereas, the main aim of this Directive being to promote the maintenance of biodiversity,...'

9 A biotope is defined as the habitat (i.e. the environment's physical and chemical characteristics) together with its recurring associated community of species, operating together at a particular scale.

> Regional or site-specific biotope descriptions are a fundamental requirement for a monitoring programme on a marine SAC

Notwithstanding this requirement, there is a need to achieve a degree of consistency in the approach to compiling any regional description, with explicit links to the national biotope classification, from a common standard for monitoring perspective (Figure 5-3).

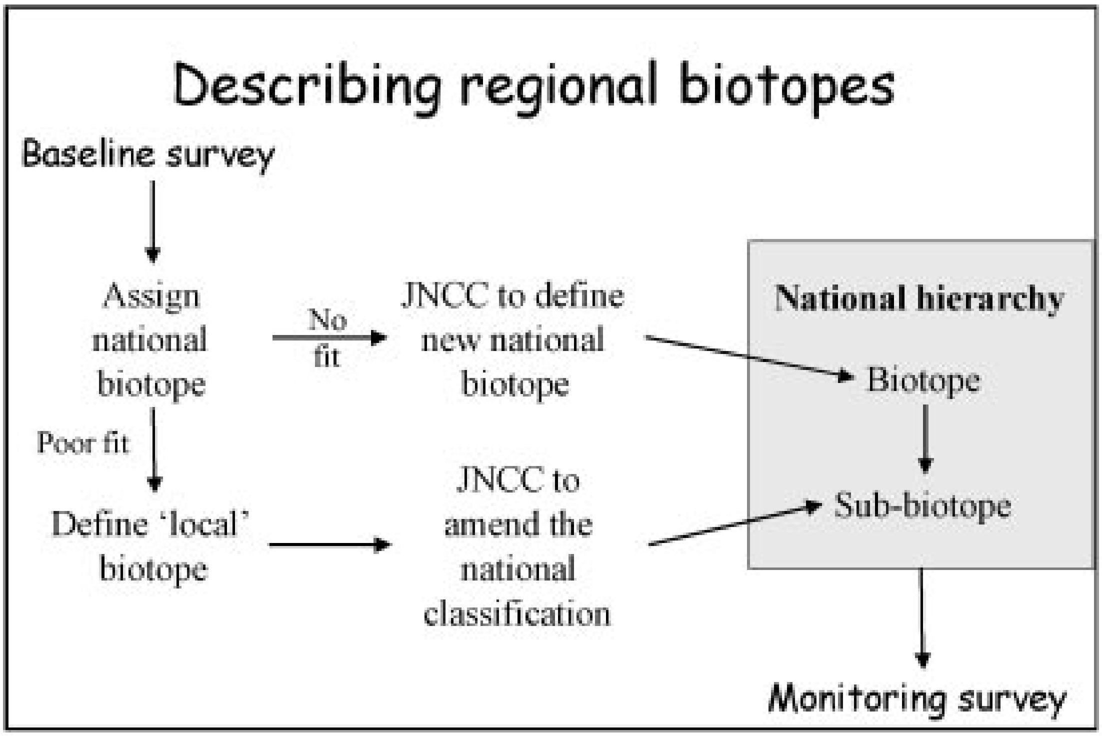


**Figure 5-3** An approach to achieve consistency in defining regional biotopes

Even with bespoke descriptions, assigning field records to a biotope will remain difficult due to the inherent variability in the natural environment. The biotope classification is hierarchical where many of the final divisions between very similar biotopes rely on the presence or absence of a small number of (often inconspicuous) species. If some of these characterising species are not present (or not recorded!), the final assignment of the record to a biotope is difficult and becomes more subjective. Field records must include sufficient information (evidence) to help reduce ambiguities in the assignment process. Moore (2000)[t] concluded, 'Problems with species identification should not occur in future monitoring, as long as surveys are carried out by experienced surveyors and using a checklist which they have studied in advance.' Similarly, Sanderson *et al.* (2000)[u] stated that 'A biotope "key" may improve future work of this nature' (when allocating field records to biotopes).

When assessing the results of a monitoring investigation, any changes in the biotope composition should consider the magnitude of the difference between the observed and expected biotopes (or the distance apart in the classification) prior to instigating any management action. A change between closely linked biotopes is perhaps less profound than between biotopes in very different parts of the classification. For instance, incomplete recording of the full range of species in a kelp forest could be interpreted as a generic kelp biotope rather than a previously more diverse tideswept variant (less worrying). Alternatively, a reduction in the density of kelp leading to a change from kelp forest to kelp park could be linked to an increase in sediment loading of the overlying water column (more worrying) that could merit further management action. In such situations, it is essential that the assessor can review previous records to check the assignment process prior to instigating potentially expensive management actions. An *audit trail* is required for *quality assurance* purposes. Sufficient data must be recorded in the field, and maintained in an appropriate database, to support future assessment by other staff.

Resolving problems where field records do not match national descriptions is not a solely marine problem. Ecoscope (2000b)[d] discuss fitting terrestrial vegetation records to the National Vegetation Classification (NVC) and mention computer programs to assist the process. JNCC are investigating whether similar computer-assisted techniques can help in the marine environment. At present, however, the concluding messages to improve biotope assignment are:

- Develop checklists to support field recording
- Ensure sufficient data are recorded and stored to support quality assurance of biotope assignments
- Use suitably qualified field surveyors[10]
- Familiarise field surveyors with local biotopes
- Develop a key for biotope identification

## Measuring biotope richness

Compiling an inventory of the biotopes present in a marine SAC requires a structured approach if *biotope richness*[11] is an attribute used to define the favourable condition of an Annex I feature. Arguably, remote sensing is the most efficient method for compiling a biotope inventory of a SAC (see previous section). Unfortunately, some biotopes are beyond the spectral resolution of remote sensors and therefore alternative techniques are necessary to record the full range of biotopes present within a feature, and thereby evaluate biotope richness. Maps derived from remote sensing studies can make a significant contribution to the process by indicating the range of habitats and, by inference, the likely number of biotopes present throughout the site. Such information can assist in planning a sampling programme to record biotopes. Accurate biotope identification requires direct observation of the seabed, which can be achieved for many biotopes[12] using a remote viewing technique via video cameras or sediment sampling devices. There are two issues to consider when planning an investigation into biotope richness for monitoring the condition of a marine SAC:

- Do I need ***fixed (permanent) stations?***
- How do I ***repeat (standardise) the recording?***

Fixed stations provide greater precision for monitoring by reducing spatial variability between sampling events, but there are significant overheads in relation to relocation and maintenance. For mobile subtidal habitats such as sandbanks, the problems of permanent marking are even more acute. Furthermore, to record biotope richness throughout a site requires many sampling stations that would in reality, become an overwhelming burden on a monitoring programme. Accurately relocating a site has clear time implications, where this extra time could usefully allow additional sites to be sampled to increase the statistical power of the sampling strategy. Thus fixed stations are not considered appropriate to measure the biotope richness of Annex I features.

It is vital to adopt a standardised approach to recording biotope richness if the results are to reliably contribute to the assessment of condition of an Annex I feature. The most important aspect to standardise is the recording effort. It is well documented that the total number of species recorded will increase with the number of samples collected. It is logical to extend this concept to recording the number of biotopes in an area. Standardising (or limiting) the recording effort must be applied at two spatial scales: the whole feature level and the individual sample level. At the feature level, clearly it will be necessary to record the same number of samples at each monitoring event. At the sample level, Sanderson *et al.* (2000) discuss various aspects of effort limitation, although perhaps the most important are time and distance. Ultimately, both time and distance relate to the area of seabed actually sampled at a location, which should remain constant between samples and monitoring events.

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10 Staff must have experience of both the recording method and sufficient taxonomic expertise to identify the likely range of species present. It may be necessary to have bespoke training sessions prior to the monitoring event. These issues are very important to achieve satisfactory QA/QC.

11 The number of biotopes supported by a feature. It will be necessary to specify the finest level in the hierarchy of the biotope classification to which any sample will be classified to ensure a standard and consistent approach.

12 Remote viewing will not discriminate between biotopes that are defined on the presence or absence of small filamentous or cryptic species.

Determining the sampling strategy and the number of samples necessary is a more complex issue that is not fully resolved at the present time. For species recording, the optimum number of samples is often derived from a pilot study where the area is intensively sampled to generate a species/effort (or area = no. of quadrats) graph. The resulting graph is used to determine the number of samples necessary to record the total number of species in the area.[v,13] For many biotopes, the number of samples required to record *all* the species present is likely to be prohibitively expensive and thus an acceptable level will need to be determined. It is possible to use mathematical techniques (rarefaction method, bootstrap procedure or jackknife estimate[14]) to estimate the *total* number of species based on a selection of random quadrats. A similar approach could be adopted for recording biotope richness. Due to the nature (habitat versus physiographic feature) and the large geographical extent of some marine Annex I features in the UK (Wash, Morecambe Bay), the optimum sampling strategy is likely to have significant financial implications. It is possible that a smaller representative area within a feature could be 'sub-sampled' as a proxy to assess condition for the whole feature. The long-term implications of such an approach have yet to be fully explored. Sub-sampling itself requires careful consideration of the location and number of sub-units necessary to reliably assess biotope richness throughout the entire feature.

In summary, to record biotope richness it is considered necessary to:

Standardise the number of stations sampled

Standardise the sampling effort at each station

## What is the most appropriate technique?

A range of techniques is available for the direct observation of the seabed (intertidal and subtidal) to identify the biotopes present. The Countryside Council for Wales (CCW) completed a comprehensive evaluation of techniques in their contribution to the *UK Marine SACs Project*.[s] Their results are included in Table 5-4 and Table 5-5. It should be noted that the level and quantity of data recorded by these different techniques do vary, and it may be possible to record information to address more than one attribute from a sampling exercise using a single technique. For example, by taking a grab sample to identify a sedimentary biotope, the sample may be retained for both particle size analysis and to enumerate the number of infaunal organisms present to estimate biomass. These additional uses of the same sample have clear implications for the cost-efficiency of the technique.

13 A review of the number of samples to take is provided by Baker and Wolff (1987)

14 For an explanation, see Krebs, C J (1998) *Ecological methodolgy*. Addison Wesley Longman Inc., California.

**Table 5-4** Comparison between techniques for monitoring the biotope richness (i.e. number of biotopes) of intertidal features.

| | *Intertidal ACE survey (Phase II)* | *In situ biotope recording* | *Intertidal sediment sampling* |
|---|---|---|---|
| Recommended uses | Identifying biotopes | Identifying biotopes | Identifying sediment biotopes |
| | Recording semi-quantitative data on a biotope | Ground validating remote sensing studies | Recording quantitative data on a biotope |
| | Describing previously unrecorded biotopes | | Describing previously unrecorded biotopes |
| Efficiency | A two person team can record a sample in 15 minutes | 8 mins per sample[16] | On sediment: 48 mins per sample[16] plus travel distance between samples |
| Cost | No additional cost over staff time | No additional cost over staff time | Enumerating infaunal species<br>Analysis of sediment |
| Objectivity | Accurately standardise sampling area | Can accurately standardise sampling area | Accurately standardise sampling area |
| | Standardise recording method | Standardise recording method | Standardise recording method |
| | Can determine position on the shore | Can determine position on the shore | Can determine position on the shore |
| Resolution | Very high for all rock and mixed biotopes, poor for sediment biotopes requiring infaunal sampling | Good for identifying most biotopes | Very high for sediment biotopes |
| | | Limited resolution on certain sediments | |

15 Hiscock, Intertidal ACE procedural guideline – PG 3-2.

16 Wyn, G and Cooke, A (2000) Application of Phase 1 intertidal survey techniques to monitoring. In: Sanderson, W G *et al.* (2000) *The establishment of an appropriate programme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998–1999 trials*, pp.115–135. CCW Contract Science Report No: 380, Countryside Council for Wales, Bangor.

| | *Intertidal ACE survey (Phase II)* | *In situ biotope recording* | *Intertidal sediment sampling* |
|---|---|---|---|
| Bias | Incomplete recording will influence biotope assignment | Limited field of view can restrict recording | Large characterising species (such as bivalves) may be missed by this method |
| | Preconceptions based on limited experience may affect recording and assignment | Incomplete recording will influence biotope assignment | Incorrect identification of sediment type (e.g. no sediment analysis) may lead to mis-identification of biotope |
| | | Preconceptions based on limited experience may affect recording and assignment | |
| Expertise | At least one experienced field marine biologist needed for biotope assignment | At least one experienced field marine biologist needed for biotope assignment | At least one experienced sediment biologist required for data interpretation |
| | Less experienced field surveyors can support experienced staff | Less experienced field surveyors can support experienced staff | Less experienced field surveyors can support experienced staff |
| Logistical requirements | Two persons and appropriate boat[17] if required | Two persons and appropriate boat if required | Two persons and appropriate transport[19] if required |
| | dGPS positioning device, preferably with a 'current position' recording function | dGPS positioning device, preferably with a 'current position' 18 recording function | dGPS positioning device, preferably with a 'current position'[18] recording function |

17 The choice of boat will depend on the location and sea conditions: a small inflatable boat can be used in sheltered conditions, near to shore; an RIB is required for offshore (<12 miles) work in more inclement conditions.

18 This function is often termed the MOB or Man Over Board function, allowing the user to save their current position, normally by pressing a single button.

19 The choice of transport will depend on the location and sediment conditions: a small inflatable boat can be used to gain access to low shore areas and within creeks; an All Terrain Vehicle (ATV) may be necessary to move efficiently across extensive sediment flats and carry sampling equipment.

| | *Intertidal ACE survey (Phase II)* | *In situ biotope recording* | *Intertidal sediment sampling* |
|---|---|---|---|
| Key Points | Relatively slow rate of coverage but high accuracy<br><br>Post-survey identification costs are limited<br><br>Limited identification of sediment biotopes<br><br>Provides quantitative information on species abundance or species richness<br><br>Using photographs and/or video can provide a permanent record | A rapid method for monitoring at low cost<br><br>No post-survey identification costs<br><br>Limited data recorded and biotope assignment relies on the experience of the surveyor<br><br>*In situ* identification QA/QC problems, and no option for future reanalysis of results<br><br>Limited identification of certain sediment biotopes | Relatively slow rate of coverage but high accuracy<br><br>Post survey costs high; also a three stage method of survey, identification and interpretation<br><br>Provides quantitative information on species abundance, species richness and sediment structure<br><br>Photographs and samples provide a permanent record |

**Table 5-5** Comparison between techniques for monitoring the biotope richness (i.e. number of biotopes) of subtidal features

| | *Diver Phase II* | *Drop-down video* | *Towed video* | *ROV* | *Grab/core sampling* | *Dredge/trawl sampling* |
|---|---|---|---|---|---|---|
| Recommended uses | Identifying biotopes at all depths to 50m below sea level<br><br>Operating in restricted environments such as caves, lagoons and shallow tidal rapids | Identifying biotopes at all depths (max. depth depends on equipment's rating) | Identifying biotopes at all depths (max. depth depends on equipment's rating) on a level seabed | Identifying biotopes at all depths (max. depth depends on equipment's rating)<br><br>Operating in restricted or hazardous environments such as caves | Identifying biotopes at all depths on unconsolidated sediments<br><br>Collecting samples for sediment analysis and enumeration of infaunal communities | Identifying sediment biotopes at all depths<br><br>Identifying epibenthic species on a level seabed<br><br>Sampling demersal fish populations |

| | | Diver Phase II | Drop-down video | Towed video | ROV | Grab/core sampling | Dredge/trawl sampling |
|---|---|---|---|---|---|---|---|
| Efficiency | | A four person team can complete 4 (possibly 6) sites per day<br><br>Biotope assignment can be done on site (but should be quality assured later) | A two-person team (plus boat and crew) can complete up to 25 sites per day<br><br>Scoring the video takes approximately 2–3 times the length of the recording | A two-person team (plus boat and crew – an experienced skipper necessary) can complete a 1 km tow in ~2.5 hours.<br><br>Ideal towing speed is 0.3–1km/hr$^{-1}$<br><br>Scoring the video takes approximately $2^1/_2$ times the length of the recording | A two-person team (plus boat and crew) can complete 15 sites per day.<br><br>Flight time depends on data required[20]<br><br>Scoring the video takes approximately 2–3 times the length of the recording | A two-person team (plus boat and crew) can complete 40 deployments (= sites if replicate samples are not required) per day[21]<br><br>Biotope assignment can be done on site by experienced staff (but should be quality assured later) | A two-person team (plus boat and crew – an experienced skipper necessary) can complete ~8 deployments per day<br><br>Ideal towing speed is <3kmhr$^{-1}$, each tow should last a minimum of 10 mins<br><br>Biotope assignment can be done on site by experienced staff (but should be quality assured later) |
| Cost: | Equipment | Low | Low | Moderate | High | Low | Low |
| | Personnel | High | Low | Moderate | Low | High | Moderate |
| Objectivity | | Accurately standardise sampling area (e.g. using a roll out transect)<br><br>Standardise recording method<br><br>Can determine position on the seabed | Difficult to standardise sampling area<br><br>Difficult to accurately determine position on seabed without expensive ancillary equipment | Can standardise area if 'field of view' is known<br><br>Can take many random samples from single tow<br><br>Difficult to accurately determine position on seabed without expensive ancillary equipment | Can standardise area if the flight technique is calibrated over a known area<br><br>Difficult to accurately determine position on seabed without expensive ancillary equipment | Accurately standardise sampling area<br><br>Standardise recording method<br><br>Can determine position on the seabed | Can standardise the area sampled<br><br>Standardise recording method<br><br>Difficult to accurately determine position on seabed without expensive ancillary equipment |

20 Howson *et al.* (2000) noted that an ROV covered approximately 1m$^2$ per 50 sec. and to characterise a biotope the minimum flight time was 6 minutes, with 7–10 minutes preferable. This is time on the seabed and does not include the time for deployment and recovery, which is dependent on depth to the seabed.

21 For a van Veen or Day grab; for larger gear such as the Hamon grab, a maximum of 30 deployments is likely.

| | *Diver Phase II* | *Drop-down video* | *Towed video* | *ROV* | *Grab/core sampling* | *Dredge/trawl sampling* |
|---|---|---|---|---|---|---|
| Resolution | Very high for all biotopes (needs infaunal data for sediments) | Generally identify most biotope complexes, and biotopes not characterised by small and/or filamentous species<br><br>Limited resolution on sediments | Generally identify most biotope complexes, and biotopes not characterised by small and/or filamentous species<br><br>Limited resolution on sediments | Can identify up to 40% of species recorded by a diver<br><br>Close-up recording techniques improve resolution over other video techniques<br><br>Limited resolution on sediments | Very high for sediment biotopes | Good for sediment biotopes if a sediment sample is recorded<br><br>Limited resolution on hard substrata |
| Bias | Incomplete recording will influence biotope assignment<br><br>Preconceptions based on limited experience may affect recording/ assignment | Limited field of view can restrict recording<br><br>Operator can be distracted by 'colourful, conspicuous' species<br><br>Resolution affects data quality<br><br>Limited use in tidal currents or windy conditions[22] | Limited field of view can restrict recording<br><br>Resolution affects data quality<br><br>Limited use in tidal currents or windy conditions[22] | Flight technique affects data quality<br><br>Operator can be distracted by 'colourful, conspicuous' species<br><br>Limited use in tidal currents or windy conditions[22] | Insufficient penetration into the sediment can miss deep burrowing species<br><br>Difficult to estimate sediment type by eye[23]<br><br>Limited collection of mobile epibenthic species | Cannot differentiate between biotopes if tow covers more than one ground type<br><br>Gear may 'skip' over the seabed reducing the area sampled<br><br>Nets may clog reducing the sample efficiency |
| Expertise | Fully qualified divers<br><br>Experienced field marine biologists needed for biotope assignment<br><br>Less experienced field surveyors can support experienced staff | At least one experienced operator<br><br>Boatman with experience of operating benthic gear (in shallow water)<br><br>Experienced marine biologist needed for scoring the video | At least one experienced operator<br><br>Boatman with experience of towing at slow speed<br><br>Experienced marine biologist needed for scoring the video | At least one experienced operator<br><br>Boatman with experience of operating benthic gear (in shallow water)<br><br>Experienced marine biologist needed for scoring the video | At least one experienced operator<br><br>Boatman with experience of operating benthic gear (in shallow water)<br><br>Experienced field marine biologists needed for biotope assignment | At least one experienced operator<br><br>Boatman with experience of operating and towing benthic gear (in shallow water)<br><br>Experienced field marine biologists needed for biotope assignment |

22 Wind affects the motion of the vessel and can limit the skipper's ability to control the position and speed of the camera over the seabed.

23 Field surveyors tend to underestimate the proportion of mud in samples. See: Wyn, G and Cooke, A (2000) Application of Phase 1 intertidal survey techniques to monitoring, in: Sanderson, W G *et al.* (2000) *The establishment of an appropriate programme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998–1999 trials*, pp. 115–135. CCW Contract Science Report No. 380, Countryside Council for Wales, Bangor.

| | *Diver Phase II* | *Drop-down video* | *Towed video* | *ROV* | *Grab/core sampling* | *Dredge/trawl sampling* |
|---|---|---|---|---|---|---|
| Logistical requirements | Four- person, fully qualified[24] diving team and appropriate boat[25]<br><br>dGPS positioning device, preferably with a 'current position'[26] recording function | Vessel suitable for local sea conditions, preferably with winch<br><br>Power supply<br><br>dGPS navigation system[27] with continuous logging[27] | Vessel suitable for local sea conditions, with winch, and capable of towing at slow speed<br><br>Power supply<br><br>dGPS navigation system with continuous logging[27] | Vessel suitable for local sea conditions, dry working area<br><br>Power supply<br><br>dGPS positioning device, preferably with a 'current position'[26] recording function | Vessel suitable for local sea conditions, with 'A' or lifting arm and winch<br><br>dGPS positioning device, preferably with a 'current position'[26] recording function<br><br>Experienced sediment biologist to analyse infaunal samples, and appropriate equipment to analyse sediment samples | Vessel suitable for local sea conditions, with 'A' or lifting arm and winch, and capable of towing at slow speeds<br><br>dGPS navigation system with continuous logging[27] |
| Key Points | Identification of some sediment biotopes requires infaunal data<br><br>Relatively slow rate of coverage but high accuracy<br><br>Can record quantitative information on species abundance or species richness<br><br>Using a video can provide a permanent record | Permanent record of each sample<br><br>Expensive equipment<br><br>Digital video systems offer improved resolution and freeze frame capability<br><br>Must synchronise time on video with survey time<br><br>Risk of damage in rugged habitats<br><br>Speed of camera over the seabed is critical to the final resolution<br><br>Can damage fragile habitats | Permanent record of each sample<br><br>Very expensive equipment<br><br>Limited choice of vessel and environment: can only be used on a level seabed, free from obstructions<br><br>Established technique that can provide quantitative data<br><br>Can damage fragile habitats | Permanent record of each sample<br><br>Very expensive equipment<br><br>Pilot must be trained for biological recording<br><br>Control and manoeuvrability of the vehicle significantly improves the resolution compared to other remote video techniques | Sampling gear must be appropriate to the likely sediment type[28]<br><br>Can record quantitative information on species abundance or species richness, and sediment structure<br><br>Processing and analysis of samples can be expensive and time-consuming<br><br>Cameras can be attached to the grab to record epibenthic organisms | Data are not quantitative<br><br>Difficult to link epibenthic species to a biotope<br><br>Dredges can take a deeper 'bite' into sediment than grabs and so sample deep burrowing and/or larger organisms |

24 Any diving team must comply with the current legislation (the Diving at Work Regulations 1997) and follow the Country Agency diving rules.

25 The choice of boat will depend on the location and sea conditions: a small inflatable boat can be used in sheltered conditions, near to shore; an RIB is required for offshore (<12 miles) work in more inclement conditions; a diving support vessel may be required for extended offshore work in remote areas.

26 This function is often termed the MOB or Man Over Board function, allowing the user to save their current position, normally by pressing a single button.

27 Continuous logging usually requires a dedicated navigation computer. This stores the vessel's current position, usually with chronological time, at user determined intervals. This facility is very useful to record the track of the camera over the seabed. Synchronising the video time to the computer time allows the analyst to estimate the position of biotopes on the seabed.

28 Day and van Veen grabs have difficulty sampling consolidated sediments or stony ground. A Hamon grab is more appropriate for such conditions.

## How do I measure the quality of the biological component of a feature?

Quality is a difficult term to define in the context of environmental management. Reminding ourselves that the Habitats Directive aims to conserve biodiversity, quality in SAC terms should be interpreted in terms of the definition of biodiversity. That is, the variety of life within an SAC. There is a scale issue to consider and the previous section considered the variety (richness) of biotopes within a site. Biotopes are defined based on a limited number of characterising species but all biotopes will also support very many additional species. Biotope definitions are not exact and the faithfulness[29] of their characterising species will not be 100%. Consequently, not all the characterising species listed in a biotope description need to be recorded for a sample to be assigned to that biotope. Simply monitoring the number of biotopes present within a feature may mask some important changes in the overall biological composition. It is possible that the number of characterising species in each biotope could decline over a series of monitoring cycles, or the range of characterising species present may change over time, without reducing the number of biotopes in the feature. Thus, only measuring *biotope richness* may not provide an accurate picture of the condition (= quality) of a feature. To monitor the quality of a feature, it is therefore vital to make a quantitative assessment of the species complement present within a biotope (characterising species and others), including the abundance of individuals[30]. The quality of a biotope is often measured using indices of species richness or species diversity (see Box 5-3) although the value of this approach for monitoring purposes is subject to debate.[w]

> **Box 5-3** What is meant by the terms 'species richness' and 'species diversity'?
>
> *Species richness* is defined as the number of species present in a biotope
> *Species diversity* is a dual concept incorporating the number of species present, and the evenness with which the individuals are divided amongst these species

The concept of *quality* can also be applied at the level of individual species where the presence or absence of a species may be an important attribute of a feature. For example, a species may be used as an *indicator* of the 'health' of a feature (for a discussion on the use of indicator species[31] see: Rowell 1994[x] and GESAMP 1995[y]), or a *surrogate*[32] for another attribute. Assessing the *favourable conservation status* of an Annex I feature includes an evaluation of the status of its typical species.

Monitoring attributes to assess the quality of a feature all require the enumeration of the number of species and/or the number of individuals present. For most marine species, the size and complexity of marine Annex 1 features, and the life-cycle/nature of marine Annex II species, preclude any attempt at counting the entire population. Sampling is therefore required.

### *How do I sample a population?*

Population estimates for species are generated from a sampling programme where the number of individuals is enumerated for a small fixed area. Brown[z] relayed the following quote to explain the concept of sampling: 'Dr Johnson said that you do not have to eat whole ox, in order to know that the meat is tough'! Brown[2] presents an excellent explanation of the principles and practices behind sampling in relation to common standards monitoring. Sampling is also described in detail by most standard ecological [aa, bb] and statistical [cc, dd] texts. Ecoscope (2000a) explain sampling procedures in the context of designing a monitoring programme to assess site condition. The most important issues relating to sampling are:

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29 A *highly faithful* species is restricted to the defined habitat for the biotope; a *poorly faithful* species is found very widely in the relevant major habitat. Definitions taken from the National Biotope Classification.

30 Determining abundance of individual is important for the same reason as counting the number of species in a biotope – the abundance could decline without reducing the number of species, indicating some management action may be necessary.

31 A species whose characteristics (presence/absence, population density, dispersion, reproductive success) are used as an index of attributes too difficult, inconvenient or expensive to measure for other species or environmental conditions of interest: Landres, P B, Verner, J, and Thomas, J W (1988) Ecological uses of vertebrate indicator species: a critique. *Conservation Biology*, **2**, 316–328.

32 Surrogate species are likely to change if the whole biotope is changing and therefore may be considered to represent the whole community.

- the pattern of sample recording
- the number of samples recorded
- the size of the sample area: the concept of the ***quadrat***
- the method of enumeration

### *What size quadrat should I use?*

To standardise field recording to ensure the results are comparable between samples and monitoring events, it is imperative that a standard recording unit is adopted. Such standardisation is most easily achieved using a *quadrat*. A quadrat is 'some sort of square, rectangular or circular frame … [that] provides some discipline for recording information about the habitat or vegetation'.[z] Quadrat size (and shape) will affect the measurement type and the efficiency of recording. The choice of the size of the quadrat is fundamentally related to the characteristics of the population under investigation, and particularly to its spatial organisation; estimates for populations with an aggregated distribution are most affected by quadrat size. The most appropriate method used for choosing the optimal quadrat size is the subject of considerable debate with views ranging from a 'gut feeling/easy deployment' approach to rigorous statistical analysis.[ee] Ecoscope (2000b) devote an appendix to the issue of selecting an appropriate quadrat size and note that 'there is no simple rule for calculating optimal size [of quadrats]'. Andrew and Mapstone (1987)[ff] present a useful discussion on the topic and provide many references to other investigations. (Boz 5-4)

The results of the UK Marine SACs Project monitoring trials provided some guidance on the most appropriate quadrat size although no dedicated investigations were undertaken. Overall, $0.1m^2$ quadrats were appropriate for dense a faunal and/or algal turf, $0.25m^2$ for most other assemblages, and $1m^2$ for counting large organisms such as the brown alga *Halidrys siliquosa* or the northern sea fan *Swiftia pallida.*

Green (1979) (quoted in Andrew and Mapstone 1987) noted that 'Those who skip this step [pilot study] because they do not have enough time, usually end up losing time.'

### *What counting technique should I use to estimate abundance?*

There are four different techniques commonly used to estimate the abundance of a species:

1) percentage cover
2) actual counts
3) frequency of occurrence (in a quadrat)
4) abundance scales

Points 1–3 are quantitative, 4 is a semi-quantitative measure based on a subjective assessment of abundance by the recorder. Even when rigorously applied, the subjective element of abundance scale data leads to considerable inter-recorder variability and therefore they are not appropriate for species monitoring.[gg] Furthermore, semi-quantitative data cannot be used for most statistical analyses routinely used for hypothesis testing.

There are no hard and fast rules for the choice between the three quantitative counting techniques. In a 'straw poll' of participants in the *UK Marine SACs Project* monitoring trials, staff felt that frequency estimates were simpler to undertake and therefore they had more confidence in the results; a view borne out by the conclusions drawn from a study of Loch Maddy,[hh] but contradicted by a similar study in Plymouth.[ii] Table 5-6 provides some basic recommendations based on the studies completed by the *UK Marine SACs project*.

**Box 5-4** Key conclusions from Andrew & Mapstone (1987) on the choice of quadrat size.

Estimates of average abundance obtained from larger quadrats will be less affected by the spatial patterns of the organisms under investigation.

For a given sample size, the precision of a sample estimate will increase with increasing quadrat size until the size exceeds the average distance between aggregations in the population.

Shape of the quadrat may affect the precision, and the amount of 'boundary' relative to the area or volume of the sample unit should be minimised.

Where the spatial arrangement of the organisms is unknown (or not important), the smallest quadrat should be at least one order of magnitude larger than the size of the largest organism being counted.

A cost/benefit analysis is essential to compare quadrat size, number of samples and efficiency.

It is often more economical to take a larger number of the smallest quadrat size

*Table 5-6 Suggested monitoring application of different counting techniques*

| *Type of count* | *Application* |
|---|---|
| Percentage cover | Estimating community composition; density of indicator species; algal composition of a community; density of colonial species |
| Actual counts | Estimating ratio of kelp species; density of sea fans; density of cup corals |
| Frequency of occurrence | Estimating community composition; density of mobile species |

*This table will be expanded to include the advantages and disadvantages of each counting technique when information becomes available.*

## *How do I sample sediment habitats*

Most of the fauna of sediment habitats lives within the sediment. For subtidal sediment habitats, there is some debate on whether the biotope can be defined by the species living on the surface (the epibenthos). There are few epibenthic species visible on intertidal sediment flats at low water. It is necessary to excavate the sediment to sample the full range of species in sediment habitats. All the earlier discussions on quadrat size and counting methods equally apply to sediment sampling techniques. The only difference is that one needs to sample a standard volume of sediment rather than a standard area as provided by a quadrat. A standard volume is collected with a container of known dimensions although the actual method of deployment will vary between intertidal and subtidal habitats. For intertidal habitats, the most common method of sampling uses a core or box, which is driven into the sediment and then carefully dug out with its contents intact. Divers can also use a similar technique for subtidal sediments, particularly coarse sediments such as maerl. Divers may use a suction sampling device to excavate a known volume of sediment from within a frame. However, a mechanical grab or corer operated remotely from a support vessel is the most common method of sampling subtidal sediments. After recovering a standard volume, the contents are passed through a mesh to separate the fauna from the sediment and the biotic material is then preserved for enumeration in the laboratory.

**Box 5-5**

Standard texts for sediment monitoring

- Green book for UK National Marine Monitoring Programme[33]
- ICES (Rumohr, H. ed.) Techniques in marine monitoring: soft bottom macrofauna: collection, treatment and quality assurance of samples. See: http://www.ices.dk/pubs/times/times.htm
- International Standards Organisation (ISO) guidelines for quantitative investigations of marine soft bottom benthic fauna (*draft only*)

Infaunal species vary in size from the meiofauna attached to individual sand grains (µm) to large (>10cm) bivalve molluscs. The size of the mesh will determine the precise fraction of the infaunal assemblage retained for future analysis. The most common mesh sizes used are 2mm, 1mm, 0.5mm and 0.125mm. Mesh size is an extremely contentious subject in benthic ecology and it is difficult to provide any specific recommendations without starting a heated debate. Clearly the size distribution of individuals in the target community must be considered: there is little value in using a coarse mesh (2mm) to sample an assemblage of tiny polychaetes in soft mud because most individuals will pass through the mesh! In contrast, using too fine a mesh in coarse sediments will result in a large volume of residue that will take a long time to sort through in the laboratory and therefore have significant financial implications. A study of sandbanks in Plymouth Sound cSAC for the UK Marine SACs Project[jj] investigated the difference between three mesh sizes (5mm, 1mm and 0.5mm). Similar results were obtained for 0.5mm and 1mm mesh although significantly lower values were recorded for abundance, species richness and species diversity for the larger mesh. Nevertheless, they concluded that a 1mm sieve would '... probably be the optimum size for future sampling', because the reduction in sampling efficiency (of species/individuals) would be more than compensated by the reduction in the time taken for sample analysis. The National Marine Monitoring Programme[34] requires samples to be sieved at both 0.5mm and

33 The Green Book is a controlled document distributed by Fisheries Research Service, Marine Laboratory, Aberdeen (contact Dr Gill Rodger **rodgergk@marlab.ac.uk**). The text may be downloaded from. **http://www.marlab.ac.uk/greenbook/GREEN.htm**

34 See Chapter 1.

1mm, but only the 1mm results are reported for offshore and intermediate sites; both the 1mm and 0.5mm results are reported for estuarine sites. The International Council for the Exploration of the Seas (ICES) guidance on sediment sampling (Rumohr 2000) recommends a 1mm sieve for 'descriptive surveys', and further recommends that where a finer mesh is required, the samples are split into fractions by mesh size. Thus:

- Samples should be processed through a 1mm sieve, unless previous investigations indicate a finer mesh is necessary to adequately sample the target biotic assemblage. Where a finer mesh is necessary, the sample should be sub-divided to provide a 1mm mesh fraction.

So what techniques should I use? Sediment monitoring has a long history and there are many texts describing 'standard' methods (Box 5-5). Clearly, the most important issue is to ensure the sampling method will fully address the attribute under investigation, and the parameters are fixed for future monitoring.

Finally, the clear recommendation for sediment sampling is:

**There should be a pilot study to compare the relative accuracy and relative precision and the cost-benefit of different sample and mesh sizes, prior to establishing a monitoring programme**

# Future developments

The information provided in Chapter 5 was drawn from both the scientific literature and the results of the monitoring trials undertaken by the UK Marine SACs project. Thus it is mostly theoretical (although derived from practical studies) and its applicability to SAC monitoring programmes has yet to be fully evaluated. These sections will be updated in the electronic version of the handbook when more information becomes available.

Additional sections are planned to address other attributes. Specifically, we hope to prepare advice on monitoring biological structure and the physical properties of Annex I habitats, and techniques for monitoring Annex II species.

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# 6 Procedural guidelines

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The following table lists the techniques for which guidance will be available. The status column indicates the current stage of development for each procedural guideline. Those guidelines whose status is listed as in prep.' or 'planned' are not included in the current version (March 01).

| *Attribute* | *Number* | *Full title of guideline* | *Summary title* | *Status* |
|---|---|---|---|---|
| Extent | | | | |
| | 1-1 | Intertidal resource mapping using aerial photographs | Intertidal resource mapping | finished |
| | 1-2 | Fixed viewpoint photography | Viewpoint photography | finished |
| | 1-3 | Seabed mapping using acoustic ground discrimination interpreted with ground truthing | AGDS | finished |
| | 1-4 | The application of side scan sonar for seabed mapping | Side scan sonar | finished |
| | 1-5 | Mosaicing side scan sonar images to map seabed features | Mosaicing sonar images | in prep. |
| | 1-6 | Mapping extent using point samples | Point sample mapping | in prep. |
| | | Satellite and airborne multispectral remote sensing | Remote imaging | planned |
| | | Aerial photography and photogrammetry | Air photo interpretation | planned |
| | | LIDAR | LIDAR | planned |
| Physical properties | | | | |
| | 2-1 | Measuring water quality parameters: clarity, chemistry, density, salinity and temperature | Measuring water quality | in prep. |
| | 2-2 | Sediment profile imagery | Sediment profile imagery | finished |
| | 2-3 | Undertaking a physical survey of littoral and sublittoral sea caves | Surveying sea caves | finished |
| | 2-4 | Determining the structure and particle size composition of sediment | Particle size analysis | in prep. |
| | | Routine monitoring of water chemistry parameters using in situ data loggers | Water chemistry data loggers | planned |
| | | Analysing the chemical structure of marine sediments | Sediment chemical analyses | planned |
| | | Measuring bathymetry using standard hydrographic techniques | Bathymetric mapping | planned |

| *Attribute* | *Number* | *Full title of guideline* | *Summary title* | *Status* |
|---|---|---|---|---|
| Biotic composition | | | | |
| Biotopes | | | | |
| | 3-1 | *In situ* intertidal biotope recording | Intertidal biotope ID | finished |
| | 3-2 | *In situ* survey of intertidal biotopes using abundance scales and checklists at exact locations (ACE surveys) | Intertidal ACE | finished |
| | 3-3 | *In situ* survey of subtidal (epibiota) biotopes and species using diving techniques | Subtidal biotope ID | finished |
| | 3-4 | Descriptive and quantitative surveys using remote operated vehicles | ROV | in prep. |
| | 3-5 | Identifying biotopes using video recordings | Drop-down video | finished |
| | 3-6 | Quantitative sampling of intertidal sediment species using cores | Intertidal core sampling | finished |
| | 3-7 | *In situ* quantitative survey of subtidal epibiota using quadrat sampling techniques | Subtidal quadrat sampling | finished |
| | 3-8 | Quantitative sampling of sublittoral sediment biotopes and species using diver-operated cores | Sublittoral coring by diver | finished |
| | 3-9 | Quantitative sampling of sublittoral sediment biotopes and species using remote-operated grabs | Grab sampling | finished |
| | 3-10 | Sampling marine benthos using suction samplers | Suction sampling | finished |
| | 3-11 | Littoral monitoring using fixed quadrat photography | Intertidal quadrat photography | finished |
| | 3-12 | Quantitative surveillance of sublittoral rock biotopes and species using photographs | Sublittoral photography | final draft |
| | 3-13 | *In situ* surveys of sublittoral epibiota using hand-held video | Subtidal hand-held video | finished |
| | 3-14 | *In situ* survey of sublittoral epibiota using towed sledge video and still photography | Towed sledge | finished |
| Species | | | | |
| | 4-1 | Sampling fish and demersal fish populations in subtidal rock habitats | Fish in subtidal rock habitats | finished |
| | 4-2 | Recording benthic and demersal fish in dense vegetative cover | Fish in vegetative cover | finished |
| | 4-3 | Sampling benthic and demersal fish populations on sediments | Fish on sediments | finished |
| | 4-4 | Sampling fish in rockpools | Fish in rockpools | finished |
| | 4-5 | Techniques for monitoring the abundance and behaviour of bottlenose dolphins | Bottlenose dolphins | draft |
| | | Using the National biotope classification for monitoring | | planned |
| Biological structure | | | | |
| | 5-1 | Assessing the population structure of *Modiolus modiolus* reefs by shell ageing techniques | Mollusc shell ageing | in prep. |
| | | Measuring the vertical distribution of species or biotopes using levelling | *Shore profiling* | planned |
| | | Measuring spatial patterns using transect survey techniques | *Transect survey* | planned |
| General | | | | |
| | 6-1 | Positioning by differential GPS in near-shore tidal waters | dGPS | finished |
| | 6-2 | Relocation of intertidal and subtidal sites | Site relocation | finished |
| | 6-3 | Specimen collection, preservation and storage | Specimen collection | finished |

# Procedural Guideline 1-1 Intertidal resource mapping using aerial photographs

Francis Bunker, MarineSeen,[1] Bob Foster-Smith, SeaMap[2] and James Perrins, exeGesIS SDM Ltd[3]

## Background

Shore mapping aims to create maps showing the distribution of biotopes along with associated information, such as the occurrence of rare species, details of habitat, etc. Biotopes are located on the shore and matched to features shown on recent colour aerial photographs (corrected to allow an Ordnance Survey grid overlay). The biotope boundaries are then defined on the photograph (as 'polygons') and target notes made on biotopes and features of interest together with detailed quantitative data if required. Integral to the methodology is the collating of the biological data, together with aerial photographs and digitised 1:10,000 OS maps on a PC-based Geographical Information System (GIS) such as MapInfo™ or ArcView™ (ideally linked to a database).

The precise methodology varies slightly between workers, but generally follows that described in Foster-Smith and Bunker (1997) and Wyn *et al.* (2000). Shore biotopes are classified according to the national classification (Connor *et al.* 1997); however, it is important to recognise and properly describe the regional character and variants of biotopes in each area of study. Maps may be displayed in a variety of ways, depending on the end-user requirements, either using life form colours (Foster-Smith and Bunker 1997) or biotope complex colours (Connor *et al.* 1997). Perrins and Bunker (1998) discuss the merits of presenting the same map in different ways.

Shore mapping is primarily designed to record the broad-scale distribution of biotopes for baseline mapping. However, following trials on rocky shores oiled by the *Sea Empress* spill, Bunker and Bunker (1998) concluded that the method also has a useful role in surveillance studies and in the planning of monitoring strategies. A useful discussion of the limitations of shore mapping in monitoring sediment biotopes is given in Perrins and Bunker (1998).

A study of shores in Pembrokeshire, Wales affected by the *Sea Empress* oil spill provided examples of how large-scale changes over time were detected by detailed shore mapping and target noting (Bunker and Bunker 1998). Figure 1 shows biotope maps of a limestone shore approximately 6 months and 17 months after the spill. These maps are coloured according to life form (Foster-Smith and Bunker 1997) and show biotopes classified according to Connor *et al.* (1997). Local variants of biotopes were recognised in order to describe particular characteristics of the shore, and subtle changes that took place. Many of the subtle changes that occurred on the shore were not easily shown on a map. Examples of these included the bleaching and subsequent recovery of crustose coralline algae in some kelp biotopes and growths of *Pelvetia canaliculata,* which appeared in the ELR.MB.BPat.Cht (*Chthamalus montagui* and *Lichina pygmaea*) biotope. Such details were recorded as target notes and subsequently discussed in the report.

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# Purpose

## Attributes measurable by shore mapping

- distribution of individual or groups of biotopes, biotope complexes and life forms present in an area
- extent of individual or groups of biotopes, biotope complexes and life forms present in an area
- diversity of biotopes present in an area
- other attributes attached to polygons in the form of target notes, such as species information, condition of biotopes (Bunker and Bunker 1998) and sensitivity (Cooke and McMath 2000)

Although not essential, the use of GIS, especially when linked to a database, greatly facilitates measuring of various attributes of shore mapping, including the following.

## Applicability of shore mapping to other survey objectives

Compile an inventory / re-inventory biotopes or biotope complexes present in a defined area.

## Advantages

- The maps can show the overall distribution of biotopes over large areas of shoreline and can be invaluable for developing resource management and monitoring strategies.
- The maps can highlight and help quantify large-scale changes in biotope distribution.
- Aerial photograph interpretation is a tried and tested technique.
- Data stored in a GIS are more flexible and can be interrogated in a number of ways. Entering field data directly to a PC has several advantages. As well as being quick, it cuts out sources of error which can be created by in-between paper stages.

## Disadvantages

- It is important that the limitations are fully understood. The colour maps produced on a GIS can appear impressive, but their accuracy together with the biotope boundaries must always be scrutinised. Many shore species and communities occur along a continuum and therefore biotope boundaries are often artificial and subjective.
- Mapping biotopes with strict adherence to the present national classification (Connor *et al.* 1997a, b) may not take account of regional characteristics. So it is essential that proper local descriptions are prepared.
- Small features or species of interest may be overlooked where a large area is being studied. For example, intertidal *Zostera* plants may virtually disappear from sediment flats due to winter die-back and grazing by wildfowl (Perrins and Bunker 1998) and the low density may be missed by ground validation.
- It is difficult to represent the quality of a biotope. The importance of target notes and quantitative studies associated with mapped biotopes is stressed.
- An important biotope may not be a mappable unit resolved by the aerial photograph.
- Photographs may not be taken at the same time as the survey, particularly at low water. However, it is important to use recent aerial photographs. On sediment shores, features can shift over short time scales (between tides in some cases) and this will affect the accuracy of maps produced (see discussion in Perrins and Bunker 1998).

The aerial photographs available to a study may not be of high enough resolution or quality for shore mapping.

# Logistics

## Pre-survey

Time should be allowed before the survey to obtain aerial pictures, scan, digitise and orthorectify[4] them prior to incorporation into a GIS. If data are to be collated electronically at the time of the survey, aerial photographs for annotation must be prepared prior to the work commencing. Photos must be recorded/analysed at the start, prior to planning fieldwork.

Proper planning of fieldwork is essential for efficient use of the limited time the whole shore is uncovered. As a guide, effective shore mapping work can be carried out for a maximum of 4 hours (2 hours either side of low water) in any period of one low water. Fieldwork should only be carried out during the two to three days either side of spring tides.

## Field

The amount of shore that can be covered during a single low tide by a pair of surveyors will vary depending on a number of factors. These include the quantity of information required as well as the complexity and accessibility of the coastline. Wyn *et al.* (2000) discuss survey speeds on different shore types and quote an average speed of 0.6 km/hour or 2.4 km/tide assuming four hours of survey per tide.

The precise equipment to be taken into the field depends upon the information required, but as a guide, a list is given below. Most of the items for general shore work are self-explanatory. A dGPS is essential, especially where points of reference are unclear in the field, e.g. in the middle of an extensive sediment area or positioning or the confirmation of boundaries.

Biotopes on hard substrata do not generally require specialised equipment for sampling. However, for sediment habitats some sampling of the infauna is needed to identify the biotope. A general description of sediment biotopes can be obtained by digging over an area for conspicuous macrofauna and sieving for smaller macrofauna; voucher specimens should be kept for detailed laboratory examination.

A small boat (e.g. an RIB or inflatable) can be useful, even essential along inaccessible rocky coasts and in areas of extensive sediment. (Flat-bottomed boats are most suitable for use on sediment flats.)

## Equipment

- clipboard (weather-writers are good for fieldwork)
- printouts of scanned aerial photographs for annotating (laminated copies are most sturdy)
- space pen or 4B pencils for annotating colour photographs
- A4 copies of Ordnance Survey maps (enlarged if necessary)[5]
- field notebook for recording biotopes, target notes and shore profiles
- Site Forms (the MNCR site record form)
- MNCR Biotope Forms (for new biotopes)
- collecting equipment for voucher specimens
- camera (for transparencies/prints and preferably weatherproof) or digital camera/video (or Polaroid camera)
- compass and hand-held differential Global Position System (GPS) (tracking facilities and an interface to download to a PC are desirable features)
- hand lens
- safety equipment including mobile phone, VHF radio, personal protective clothing, first aid kit, life jacket
- tide tables

### *Extra equipment needed for sediment shores*

- spade
- sieve (1mm mesh size)
- sample containers (if voucher specimens are to be kept)

### *Optional equipment*

- hard-hat (for working under cliffs or in caves)

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4 Otho-rectification removes all the camera distortions, and also corrects what is known as relief displacement (the fact that the top of a hill is closer to the camera and so appears artificially enlarged).

5 N.B. A licence is required to copy OS maps.

- hand held flares
- binoculars
- MNCR Biotopes Manual (where a good working knowledge is lacking)
- *Field Guide to Seashore Mapping* (Bunker and Foster-Smith 1996)

### Personnel/time

Each field recording team requires at least one marine biologist, skilled in the recognition of biotopes in the field. Other skills required are the ability to operate a GPS, and to interpret maps and aerial photographs. When a boat is used, appropriate seamanship skills are required. For lab-based work, basic skills in the use of GIS are required.

### Writing up field data

A day's worth of data from a pair of field workers will take four to six hours to 'write up'. This includes the downloading of GPS information, digitising of polygons (or preparing fair maps), writing up target notes, drawing profiles and logging of photographs. All target notes, descriptions and photographs should be clearly geo-referenced either to polygons or to known locations (e.g. a GPS waypoint). If a PC is not available to field workers, all data should be transposed onto paper and a neat map drawn and clearly labelled. It is essential that all the information is collated in such a way that it can be readily entered into a GIS at a later date. If producing a paper copy it is particularly important that polygon boundaries are made clear. Surveyors must keep up with the task of writing up as the survey progresses and sufficient personnel and time should be allowed for this on survey.

### Data collation and analysis

Where more than one field team has been entering data into a GIS and database, time must be allowed for amalgamation of data. The more thoroughly data collation is carried out following each field work session, the less arduous the task of producing the final maps and data output.

## Method

### Preparation

Good quality colour aerial photographs taken at low water of spring tides at a scale of 1:10,000 provide the best information for shore mapping. Photographs taken at a larger scale may not show enough detail to be useful. If the photographs are loaded into a GIS on a computer prior to the fieldwork, they can be printed out at any required scale for field annotation. Additional background maps (available from the Ordnance Survey), and grid lines can also be overlain prior to printing. The more information that can be made available to the field surveyor, the easier the job of locating one's position in the field becomes.

There are a number of methods for loading aerial photographs into a GIS system:

(1) scanning and registering

(2) scanning, warping (or rubber sheeting) and registering

(3) scanning and ortho-rectification

For each of the above methods, the photographs should be scanned (ideally at a resolution of 300dpi or higher) and registered (i.e. identify points on the photograph – sometimes called *control points* – and obtain the co-ordinates for the same point from a map). Registration is normally done using about 5 control points.

Warping (sometimes referred to as rubber sheeting) requires an additional software tool. By using additional control points, the aerial photograph is fitted more closely to the real map. 'Rubber sheeting' is a term used to describe the technique, as it is analogous to printing the aerial photograph on a sheet of rubber, and then using pins to hold each of the control points in the correct position. The end result is that all the control points are correctly located, and the photograph is stretched between these points. In practice it means that the further you are from a control point, the greater the inaccuracies.

The only truly accurate method for loading an aerial photograph into a GIS is through ortho-rectification. The inaccuracies may seem small, but they tend to be cumulative, especially if you are trying to 'mosaic together' a number of aerial photographs. Without ortho-rectification it becomes virtually impossible to line up neighbouring photographs. This again requires additional software such as OrthoPhoto by exeGesIS SDM Ltd. It also requires the digital terrain model (DTM), which can be purchased from the Ordnance Survey for about £50 for a 20 x 20km tile (at the time of writing). This is used to remove the relief displacement errors.

Colour maps for use in the field should then be printed at a scale of 1:5000 or greater (depending on the detail required by the survey). By printing them from a properly corrected set of aerial photographs, any area can be printed regardless of whether it was originally split between two or more photographs. It is useful to print grid lines on top of the aerial photographs. Problems of orientation on the shore can occur, for example, when working below cliffs or far from shore on sediment flats where land features cannot be seen. The availability of grid lines and a GPS that gives read-outs in OS co-ordinates can be invaluable in such instances.

Wyn *et al.* (2000) describe a technique of producing 'wire frames' by tracing recognisable features from aerial photographs prior to the field survey. This can be useful when copies of aerial photographs are not available for annotation in the field. Visible polygon boundaries are traced by laying a clear acetate sheet over an aerial photograph or by using a GIS. Other visible features, which will be useful for orientation in the field, can also be included, such as field boundaries, roads, groynes, streams, houses and access points. The wire frame map can then be transferred onto waterproof paper and annotated in the field with biotope information and polygon boundaries adjusted as required.

## Field recording

Prior to beginning any fieldwork, it is important that the whole survey team gets together to agree recording procedures and biotope identification. Biotope recording is not an exact science and biotopes in the National Classification (Connor *et al.* 1997) can vary visibly from region to region. A 'training session' may take most of one working tide but is essential in order to ensure consistency in recording between team pairs.

When taking aerial photographs into the field, recorders must match biological features with those identified from aerial photographs. These features are then labelled with dominant biotopes and their extents marked on the printed aerial photographs as polygons. It is important for later data handling that each polygon is given its unique field identification code (e.g. FB12).

In particular, on rocky shores, polygons may contain more than one biotope, e.g. algal/faunal dominated zones interspersed with rock pools, overhangs, gullies, etc. Guidelines for recording/mapping mixed biotopes are given in Foster-Smith and Bunker (1997); see Figure 1. Notes on subordinate biotopes in polygons together with any features of importance should also be recorded, together with positional information where possible (e.g. GPS waypoints). Profiles of shores or sketches of important features should be completed in field notebooks whenever a major change is encountered. These profiles are especially important to give information on zonation patterns on steep or vertical shores. It is important that estimates (or measurements) of horizontal and vertical scale should be included on all diagrams and that these should be geo-referenced.

If required, biotope boundaries and the positions of particular features, such as gullies, can be recorded precisely using differential GPS. This may be useful for recording changes of features such as intertidal *Zostera* beds. Biotope boundaries can be difficult to interpret from aerial photographs of sediment shores. It is important to make decisions over biotope boundaries in the field and complete polygon maps as fully as possible. Delaying difficult decisions simply results in further inaccuracies. As it is impossible to cover every square metre of shore, it is important to record how much of the shore area has been visited during the survey. If the GPS has a tracking function, it can be useful to show exactly where surveyors have been. The GPS tracks can later be downloaded to a PC with appropriate software. A map of tracks can then be produced which will give future surveyors a guide as to the intensity of survey undertaken to produce the field maps.

If a biotope is encountered which does not match the national biotope classification, full JNCC marine habitat and site forms should be completed. The data obtained should then be discussed with the JNCC's Marine Information Team.

Photography is an important adjunct to the field surveys. This gives visual information on the condition of the biotope against which gross change can be measured. A mixture of viewpoint and close-up photography is useful. Photographs can be scanned (alternatively a digital camera can be used) and images attached electronically to polygons (with the aid of appropriate software). Video is also a useful medium for recording and can be used as a visual notebook and as an aid to provide relocation information for features of interest. Video files can be incorporated into the GIS and geo-referenced if desired. This method was trialled during the monitoring of biotopes on shores oiled by the *Sea Empress* oil spill in Pembrokeshire; see Bunker and Bunker (1997) for further information on the use of video.

A distinction is made between *polygon attributes* and *target notes* depending upon the type of information and the way in which the notes are geo-referenced.

### *Polygon attributes*

Polygon attributes are information attached to a polygon and recorded as standard. This information would include (where relevant):

- dominant biotope(s);
- substrata and important modifying features;
- species/community information pertaining to the polygon, particularly if this represents a significant variation on the standard biotope description;
- rare species or species of conservation significance;
- information on the quality of the biotope, e.g. if it is scoured or perhaps a particularly good example;
- subsidiary biotopes, which are too small to be mapped individually, e.g. shallow coralline pools, which are widespread over the polygon;
- any other relevant information relating specifically to a particular polygon, e.g. any anthropogenic activities such as bait digging.

Additionally, some surveys may require specific fields for recording data such as the degree of oiling, bait digging or other anthropogenic effects that apply to the polygon.

These data will be stored in a spreadsheet or database linked directly to the polygons through the unique polygon ID reference code. Note that all these data are mappable either by creating a thematic map based on the polygons or as points taken as the centroid of the polyons.

### *Target notes*

Target notes contain information not collected as standard for the polygons, which can be located on the map. This information will be displayed as at least one separate layer within a GIS. The number of layers will be dictated by the nature of the data. The target notes may refer to points, lines or polygons, and it is good GIS practice to have separate layers for each of these data types. The information may also be separated by category (e.g. biological and anthropogenic). Although the creation of too many layers within a GIS may not be desirable, it is extremely difficult to disentangle different types of information once they have been amalgamated into a single layer.

The data may contain:

- information on biotopes smaller than 5 x 5m which cannot be regarded as typifying the whole polygon, e.g. a significant small pool or gully in a large polygon;
- information on impacts within a localised area of a polygon (but which can encompass more than one polygon);
- artificial substrata, e.g. sewage pipes which may be represented as lines that may cross more than one polygon;
- shore profiles showing zonation and biotope extents (especially important on steep or vertical shores);
- features outside the limits of the survey (dunes, land falls, etc);
- locations where photographs and /or video were recorded;
- location of sampling stations (e.g. where quadrats or sediment samples were recorded).

Note that the target notes might refer to very small features as point data (e.g. location of a photograph), or features that are large enough to encompass more than one polygon (e.g. a long sewer pipe). The positions of the target notes can be estimated visually or located more precisely using GPS; the method used and its accuracy must be recorded in the data file for future reference. All target notes must be geo-referenced to display on a map.

Often where there is a large area of shore to cover, it is not possible to visit every polygon and any map should make a distinction between those polygons actually visited and those mapped by extrapolation or using binoculars. The associated data file should include a field to indicate how the data were recorded (direct observation or extrapolation).

### Writing up field data

Ideally, surveyors should aim to transcribe field maps, target notes, etc. directly to a PC following the survey. The availability of powerful notebook PCs has made this option easily achievable for field survey teams. Failing this, a neat paper copy of all field survey data should be made. Whatever method is used, it is important that information is transcribed carefully and that target notes, photo logs and other information are cross-referenced both to each other and to the shore map (or GPS waypoints if appropriate). It can be useful to collate the information gathered every day by a team of field workers within MNCR or CCW Site Forms (especially if it is not being entered directly into a PC).

Fair maps should be prepared by drawing out the polygon boundaries, elucidated in the field from aerial photographs. This can be achieved either on a GIS (i.e. digitising the polygons) or by making a neat copy by hand. Either way the polygons should be numbered and labelled with biotopes. Polygon attribute and target note information should be referenced to the numbered polygons and/or waypoints from the GPS (on a PC this is achieved by creating data files which are either tagged to polygons or geo-referenced to waypoints). Photographs should be logged and also geo-referenced (any digital images being downloaded onto a PC). Sketches from field notebooks should be copied out in neat and geo-referenced (these can be scanned in at a later date and incorporated into the GIS if desired).

Any GPS waypoints should be accurately copied out on paper, entered, or downloaded directly onto the PC for display on maps.

Field teams may find it useful to write out the descriptions and target notes and transcribe shore profiles for stretches of coast on standard forms such as the MNCR Site Form or those produced for Phase 1 mapping by CCW (Wyn *et al.* 2000).

## Data analysis

All data should be entered into a database such as Recorder 2000. The GIS and associated database can be interrogated for required information. However, it is important that the requirements be decided upon prior to the survey and data entry.

## Accuracy testing

Independent checks need to be made at all stages to ensure accuracy.

## QA/QC

Photography is a useful supplementary recording method, for instance where examples of biotopes (particularly new, provisional biotopes) need to be referred to during the course of the survey to ensure consistency of recording. This is especially so when there are more than one pair of surveyors involved with the survey work. The use of digital cameras is recommended, as images are instantly available and can be readily downloaded, attributed to OS co-ordinates (geo-referenced) and then entered onto the GIS.

Where more than one field team is operating, it is important that agreement is reached on the naming of biotopes, target noting and other procedural matters before the survey begins. Agreeing the naming of biotopes between survey teams is especially important as there can be difficulties matching the habitats and communities seen in the field with the biotope classification. Training prior to a survey is essential and such procedures are covered in Wyn *et al.* (2000).

Within the context of monitoring it is important to ensure that changes observed are due to factors other than inaccurate recording or variability between workers and it is therefore important to embrace control methods. Completed biotope maps should be taken into the field and checked for accuracy; checks could be made on the identification of biotopes and species. Special attention should be paid to the marking of polygon boundaries. Where extrapolation has been used to complete areas of the photographs not surveyed, some of these areas should be checked.

Wyn *et al.* (2000) describe quality control methods adopted by CCW, where it is recommended that 5% of sites be checked in house and 2% by experienced external surveyors.

The accuracy of field maps will depend on a variety of factors; in particular, the quality of aerial photographs, accuracy of photo registration, intensity of survey, consistency in biotope identification, weather and tidal conditions during time of survey and whether differential or ordinary GPS is used.

# Data products

End products by necessity depend on study requirements. It is important to ensure that the GIS and associated database can be interrogated for required information prior to entering data. Commonly required products include printouts of biotope maps (Figure 1), together with data tables of associated information (e.g. target notes) and a written discussion. For monitoring purposes, precise details of the methodology will be required for future surveys.

Electronic copies of the maps, database, etc. are perhaps the most important data products.

# Cost and time

The costs of a particular project will depend on location, extent and detail of survey required, ease of access and many other factors depending on the specifications of the project. When in the field, rate of progress will depend not only on these factors but also the prevailing weather conditions, especially if boats are needed for access. It is essential in every survey to cost in time for training and agreement of procedures and biotopes by the field team. Wyn *et al.* (2000) provide a useful guide to estimating the time required to undertake fieldwork in a variety of situations (Table 1).

**Table 1** Examples of variations in survey speed on different shore types (from Wyn *et al.*, 2000)

| *Shore type* | *Survey method* | *Survey time (hrs) (4hrs/tide)* | *Site length (km)* | *Site area (km2)* | *km/hr* | *km2/hr* |
|---|---|---|---|---|---|---|
| Sandy shore | foot | 8 | 8.2 | 3.64 | 1.025 | 0.5 |
| Bedrock cliff | boat | 3 | 5.1 | 0.11 | 1.7 | 0.04 |
| Sandy mud inlet | foot | 8 | 4 | 2.23 | 0.5 | 03 |
| Thick mud estuary | boat and foot | 15 | 33.5 | 4.3 | 2.2 | 0.3 |
| Muddy gravel inlet | foot | 8 | 4.3 | 0.81 | 0.5 | 0.1 |
| Complex mixed shore | foot | 8.5 | 7 | 0.65 | 0.8 | 0.08 |
| Complex bedrock platform | foot | 7 | 3.6 | 0.6 | 0.5 | 0.08 |
| Complex shelving platform | boat and foot | 9 | 13 | 0.52 | 1.4 | 0.06 |

Wide rocky shores (such as those 200m wide found along much of the Northumberland coast) are very difficult to explore by foot and require more survey time than the narrow shores found around much of the Shetland Isles. A boat can be useful for wide rocky shores where one team records the lower shore while a land-based team records the middle and upper shore.

Table 2 provides a framework, which can be used as a guide to planning for costs and time to complete a project. This assumes the team involved has the necessary tools to carry out the job (see 'Equipment' above) together with one or more computers with GIS software.

**Table 2** A suggested framework to assist the planning of a mapping project

| *Item* | *Cost per unit* | *No. of units* | *Total* | *Notes* |
|---|---|---|---|---|
| Pre-survey | Desk rate for experienced staff | Estimate number of days to complete task | | Obtaining of maps and aerial photographs. Scanning and ortho-rectification of aerials together with preparation of the PC system for data entry and interrogation.<br><br>Printing out maps and aerial photographs for field use. General survey preparation. |
| Transport | Mileage cost | Estimate distances | | Two vehicles desirable, one to deposit a team, the other to leave at a pick-up point for after the survey. |
| Field team (worker 1) | Field day rate for experienced biologist | Estimate number of days to complete task | | A team of two would be a minimum. Most surveys use two pairs of surveyors. |
| Field team (worker 2) | Field day rate for person with mapping/GPS experience | Estimate number of days to complete task | | |
| Boat | Hire charge | Negotiate daily or weekly rate | | Does cost include fuel? Always try and view boat to ensure it is suitable for the job. |
| Accommodation and Food | Rate per day / week | | | Ensure adequate space available to spread out maps, photographs, etc. and instal PCs and printers. Self-catering can be an advantage. |

# Health and safety

Codes of safe conduct for shore and boat work must be followed at all times and risk assessments must be prepared for the specific locations where the study is being undertaken. The fieldwork often involves exploring coastlines not known to the surveyors. A proper risk assessment prior to fieldwork is essential, especially regarding access and tide times to prevent surveyors being stranded by a rising tide.

Appropriate field survey clothing and safety equipment should be carried, along with a VHF radio or mobile telephone, first aid kits, tide tables and hats and sunscreen (also immersion suits, life jackets and/or hard hats where appropriate).

Surveyors should always work in pairs and adopt lone-worker policies in case both surveyors become trapped or incapacitated (e.g. adhere to predetermined routes and agree details for rendezvous following the survey).

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Wyn, G and Cooke, A (2000) Application of Phase 1 intertidal survey techniques to monitoring. In: Sanderson, W G *et al*. (2000) *The establishment of an appropriate programme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998–1999 trials*, pp. 115–135. CCW Contract Science Report No: 380, Countryside Council for Wales, Bangor.

**Figure 1** Typical outputs from a biotope mapping exercise (from Bunker and Bunker, 1997; aerial photograph printed with permission from the Countryside Council for Wales)

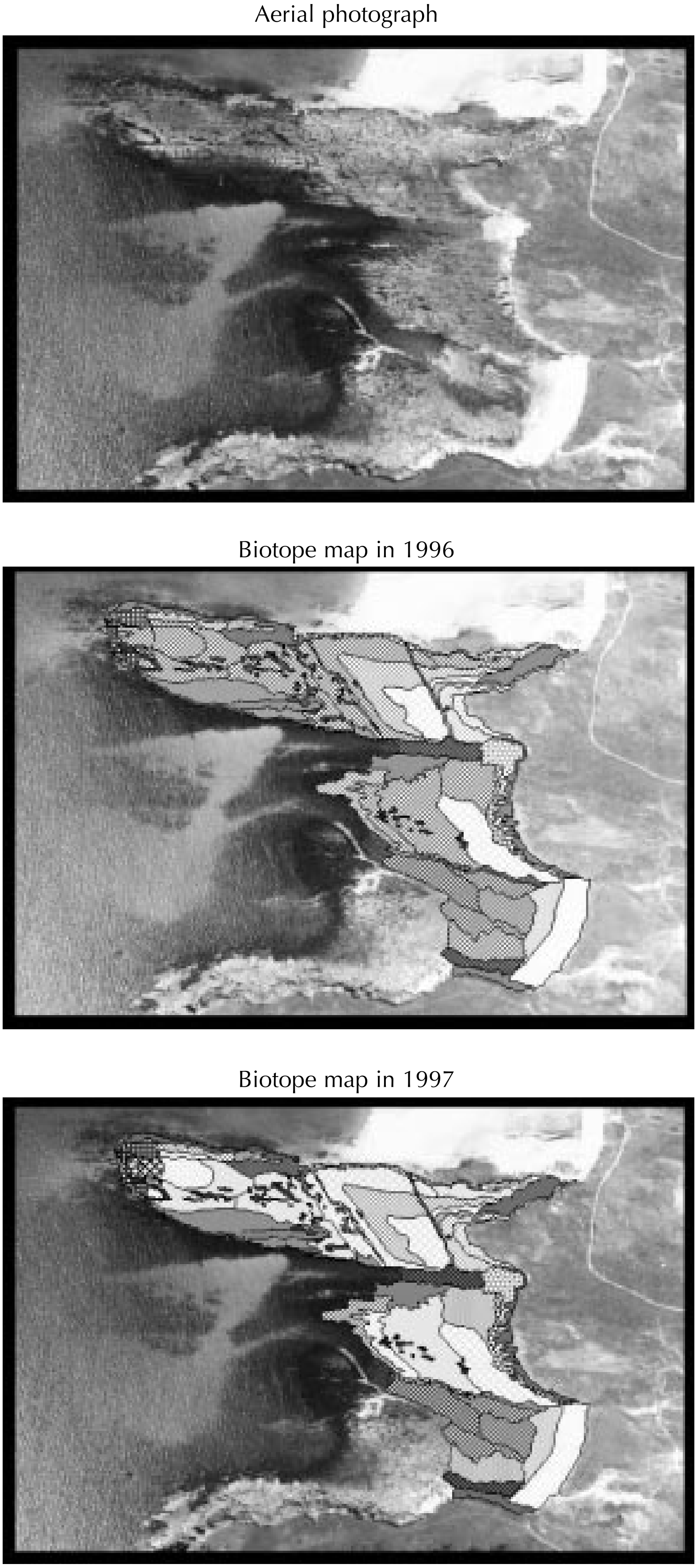
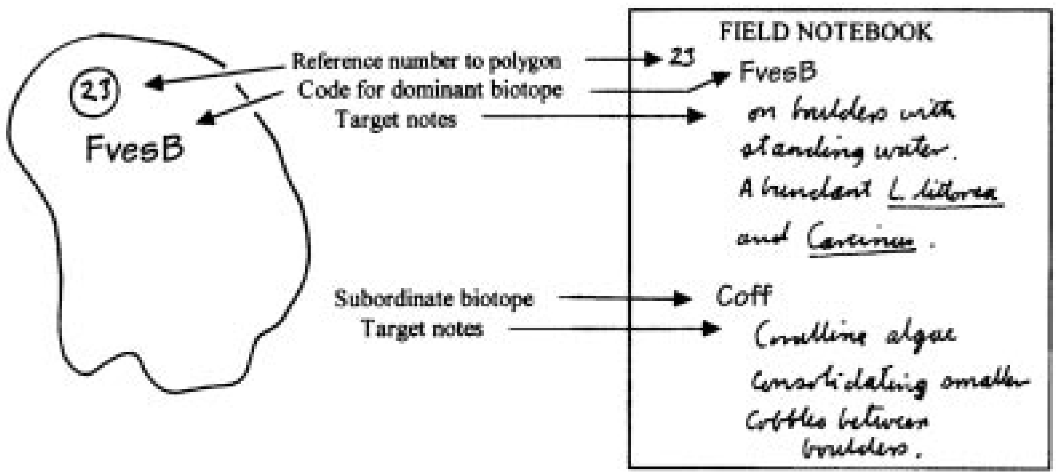


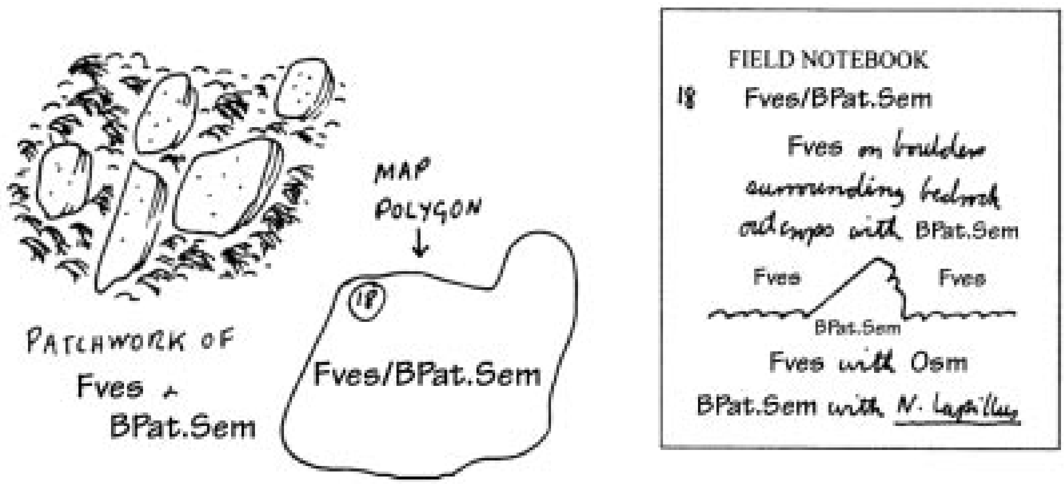
**Figure 2.** Different methods of recording and representing biotope mixes (after Foster-Smith and Bunker, 1997)

*A. Homogeneous areas (polygons) illustrating the format for recording biotope information as codes and target notes*

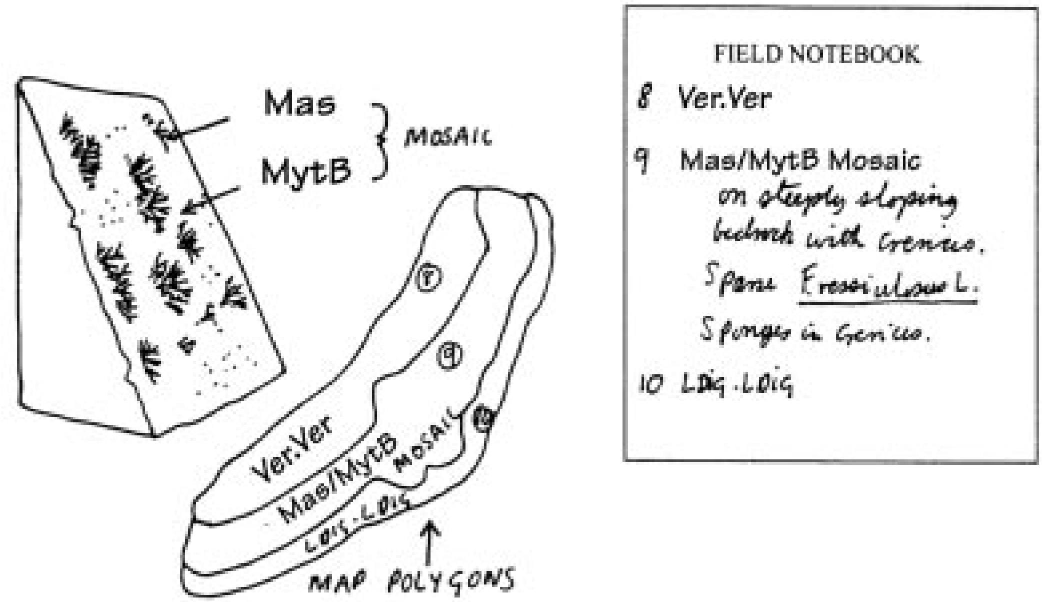



*B. Areas dominated by one biotope but with a major division in a key habitat feature and/or presence of subordinate biotope*

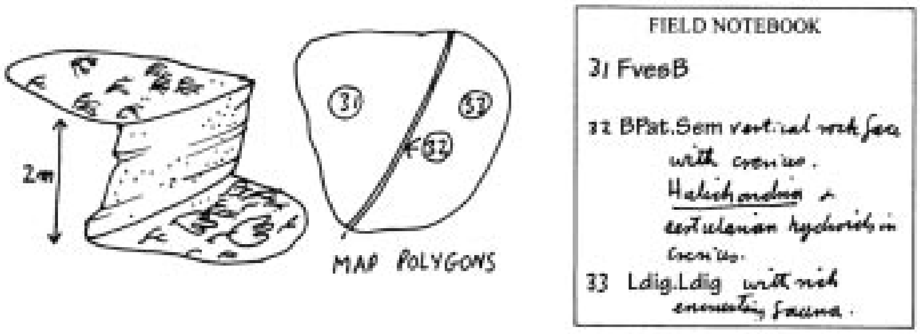
*C. Biotopes form a patchwork where each patch falls below the minimum mappable size and where there is no clear predominant biotope. The biotopes are likely to be distributed according to obvious structural differences in the habitat.*



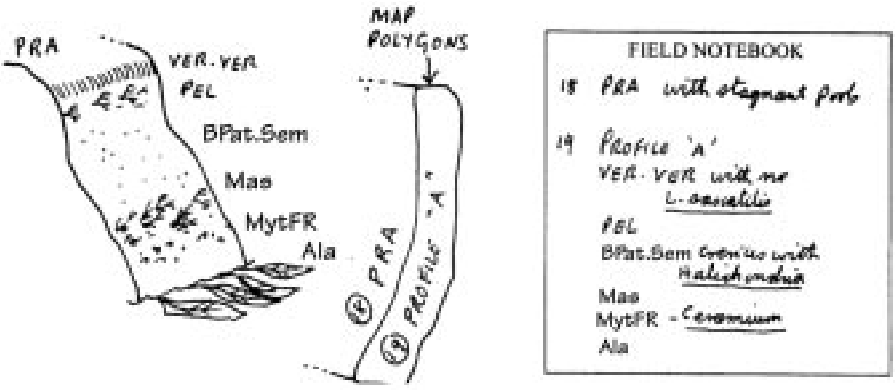
*D. Biotopes form a mosaic of small patches below 1m$^2$. Often, these mosaics are the result of biological interactions leading to changes in patch distribution over time and are not directly related to structural differences in the habitat.*



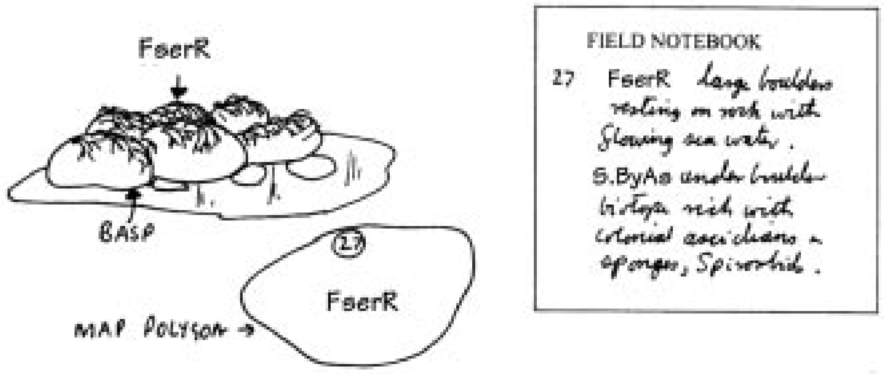
*E. Biotope forming a linear feature with no mappable width*




*F. Biotopes forming a zonation pattern where each biotope is a linear feature of no mappable width*




*G. Cryptic biotopes as a component of more conspicuous biotopes*



# Procedural Guideline 1-2
# Fixed viewpoint photography

Jon Moore[1]

## Background

Viewpoint photography involves taking photographs of a monitoring site, transect, biotope or other fixed area at intervals over time, at exactly the same viewpoint, to show visual changes. However, a number of potential pitfalls need to be avoided, and there are simple procedures that can help to produce more useful photographs. This guideline describes many of these features.

The surveillance method has been used extensively in an *ad hoc* and unsystematic fashion for many intertidal monitoring and surveillance programmes, but it can provide considerably more useful and impressive material if it is carried out systematically. It is used during the long-term annual rocky shore transect monitoring around the Sullom Voe oil terminal in Shetland (Moore *et al.* 1995), for which it provides very useful information to back-up semi-quantitative data which is also collected.

General advice on photography as a research tool is given by George (1980).

## Purpose

Viewpoint photographs are most useful as supporting information for a more quantitative monitoring or surveillance programme. In particular, they provide very valuable visual information which can be used to support or refute evidence from quantitative data; help to show whether changes identified from monitoring in a small area are representative of a larger area; and provide information (in the form of visual clues) about other features that were not recorded (either forgotten or not easily recorded quantitatively) at the time of the survey (e.g. the movement of boulders and cobbles, the presence of silt, the amount of space between the barnacles, etc.).

The method is also very valuable for rapid inspection surveys in between more detailed monitoring surveys and can provide a record to check when a change started to occur. The technique is particularly suitable for use by non-biologist or marine biologist staff including site wardens.

Some qualitative and semi-quantitative attributes can be recorded from viewpoint photographs. In particular:

- extent of a biotope, e.g. for an intertidal eelgrass bed or mussel bed
- semi-quantitative abundance of highly conspicuous species, e.g. ephemeral green algae

Viewpoint photographs are also extremely valuable as an easily interpretable medium, for showing to non-specialists when explaining features that have been identified by other data.

### Advantages

- non-destructive
- can provide information for large and small areas
- provides pictures – easier to interpret by anybody and can be more effective than data when explaining features to non-specialists
- can be carried out by non-biologists (e.g. local staff or volunteers)
- cheap and quick
- images are permanent (if stored properly) and can be interpreted at a later date

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### Disadvantages

- does not provide any reliable quantitative data
- cannot be used reliably for species identification
- of limited use on biotopes that are overlain by algae
- image quality is greatly dependent on the prevailing weather conditions at time of survey
- comparisons can provide misleading information if light conditions or image quality is variable
- will not replace *in situ* quantitative recording
- difficult to apply subtidally

## Logistics

Normal logistical planning required, as for any other intertidal survey. In particular, check tides, weather and site access.

### Equipment

#### *Key equipment*

- SLR camera with an appropriate lens. A standard (50mm) lens is generally best, but a wide angle (e.g. 35mm or 28mm) can be most useful in taking whole shore photographs. Whatever focal length is used, it should be fixed (i.e. not a zoom lens), so that the angle of the view is the same every time.
- Colour print or slide film (400 ASA usually most useful to give flexibility with light conditions). Colour prints have been found most useful for comparison.

#### *Other useful equipment*

- tripod – to get good stable images from a known fixed height (particularly in low light conditions)
- Polaroid camera and film – to take instant photographs which can then be annotated on site
- waterproof pens (fine tip)
- portable GPS navigator – to take aid position fixing
- access to good colour photocopier (with slide attachment if appropriate); or slide scanner and colour printer
- access to laminator

The polaroid prints are marked with the waterproof pen to show the precise location where the photographer is to stand, the location of sites for close-up photographs and any conspicuous objects or features to line-up for positioning.

### Personnel/time

#### *Personnel required*

- one capable photographer – experience at taking landscape photographs preferred
- one assistant – primarily for safety back-up (it's easy to fall over when you are walking along while looking through a camera lens!); can also be useful for pointing to important features in the photograph

#### *Best time of year*

Primary consideration is the amount of light, but there are no particular seasonal requirements. However, for intertidal viewpoint photography the time of low water spring tides may be a limitation during the winter months. Spring months are often best avoided because of barnacle spat settlement and other rapid changes in shore communities. Whatever time of year is chosen, repeat photography is best carried out at the same time.

Note: The repeat photography will also be much better if it is carried out at the same time of day as the initial survey, because the direction of lighting determines the position of shadows and the general appearance of the shore.

# Method

In conditions (of tidal height, weather, time of day) as similar as possible to those of any previous survey, return to the exact location from which photographs were taken previously and, using those photographs for reference, re-take the same views using the same focal length lens and film speed as previously.

## Initial survey

(1) First choose subjects and a viewpoint according to the objective of the study. This choice should not be rushed. Move around the site looking at it from different angles before choosing. On rocky shore sites photographs are typically taken with a view up the shore, down the shore, across the site and then of particular biotopes or areas of interest.
(2) Choose a lens of suitable focal length. If at all possible, use a standard 50mm lens. If you are using another lens, note the focal length used for each shot. Put the camera on a tripod if you find it easier or if light conditions require it.
(3) Try to ensure that important features which happen to be of similar colour, texture and shade will be distinguishable in the photo, because the 3D perspective you have when you are standing in the field will not be so obvious in the photograph (for example, a view of an overlapping series of rock ridges can look like a single piece of rock).
(4) Try to frame the photo in such a way that it will be easy to re-frame the same view on a future occasion; for instance, try to have distinguishable features in the foreground, background and at the edges of the view. Best of all, try to line up an object on the skyline with a sharp feature in the foreground. If you have more than one aid to re-framing in the photo it will help you to re-position yourself very quickly (and it will check that you have the correct focal length lens).
(5) If you think that it may be difficult to relocate the viewpoint, you may need to take a photograph of the place from which you took the viewpoint photograph. This is best done with a Polaroid camera, because you can then annotate the Polaroid photo on site (X marks the spot).
(6) Take photograph. Bracket exposures if you are not sure if all features will come out.
(7) It may help to locate important features (site markers, biotope boundaries, re-framing features, etc.) in the final photograph if you also take a Polaroid photograph of the view at the same time and then annotate it with a fine-tip waterproof pen. These can then be copied to the proper photograph after the film has been processed.
(8) Make any necessary notes, sketches and GPS position fixes to ensure that you can find the site again. A record of date and time is also a good idea (these will be recorded on the GPS).

## Processing

(1) Have the film developed and printed, then label all originals on the back as soon as possible. The label should include date, location, film number, and frame number. Do not use water soluble pens. Label and store negatives.
(2) Get a set of prints (standard 6” x 4” are normally adequate, but larger sizes can be useful) of all viewpoint photos that will be used in the field. Do not use originals in the field. Colour photocopies are often cheapest and easiest.
(3) Annotate prints to aid identification of important features (as in point 7 above). The prints can also be incorporated into detailed site location sheets with maps, grid references, site and methodological details, etc.
(4) Have these prints laminated or otherwise waterproofed.

### *Repeat survey*

(1) Plan the survey for, as near as possible, the same time of year (unless intentionally more frequent than annually),and the same time of day and tide as the initial survey.
(2) Use camera with same focal length lens.
(3) Locate general viewpoint position using all clues.
(4) Look through viewfinder and then check back and forwards between viewfinder and the annotated photograph to line up all features. Take care to get it right – a quick snap from ‘about the right place’ is not good enough. It can take some time to see the features on the rock that are shown in the photograph.
(5) Re-take the photograph and make a note of the frame number.

### *Processing (repeat survey)*

After the film has been developed and printed, label all prints on the back as soon as possible. Label should include date and location (and preferably film number, and frame number). Do not use water soluble pens. Label and store negatives and prints.

## Data analysis

Photographs can be displayed (or projected) side by side for easy comparison.

There are various methods of measuring the area of a feature in a photograph (e.g. using grids, point screens, computer image analysis), depending on the degree of accuracy and precision required.

Photographs can be used in presentations or reports for illustration.

## Accuracy testing

The only potential concern is for photographs to be taken from the wrong position. It is normally obvious if this occurs and accuracy testing is not considered necessary. If there is any doubt, have a suitably experienced and independent person view and assess the photographs.

## QA/QC

It is essential that photographs are taken from exactly the same position each time, using the same focal length lens. Good site location information and instructions for each viewpoint photography site, which anybody can understand, are therefore required. Sufficient time must be allowed for relocation of viewpoints.

It is difficult to cater for the weather conditions, but if good quality images are an important feature of the survey, it may be necessary to wait for suitable conditions before the viewpoint photography is carried out. The best conditions are bright diffuse light on a dry day. Very bright directional side lighting is often worse than low light and wet weather, because the contrast between shadows and highlights can make the photograph almost useless for comparison with images taken in other conditions.

Photographs and negatives must be fully and accurately labelled as soon as possible after the survey.

## Data products

The method will produce a collection of photographs (preferably prints and negatives) which need to be stored in a dry place, out of the sun.

## Cost and time

Camera hire rates can vary, but are often around £5/day for a standard land camera. Film cost, including processing, may be around £10 per 36-exposure film.

This method is normally used in conjunction with another more quantitative survey method. On this basis, a survey of a typical rocky shore site, with five or six viewpoint photographs, would require an additional 15–20 minutes on site for the photography (for the initial survey or a repeat survey).

Labelling the photographs, after they have been developed and printed, can take 30–45 minutes per film.

Comparison of photographs may only require a quick scan and a couple of notes, or a more detailed measurement of area.

## Health and safety

Appropriate safety procedures for shore surveys must be followed, especially with regard to protective clothing and careful use of tide tables, taking account of local conditions to avoid being cut off by the tide.

Photographic viewpoints must not be established at dangerous positions such as the edges of cliffs.

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# Procedural Guideline 1-3 Seabed mapping using acoustic ground discrimination interpreted with ground truthing

Bob Foster-Smith, SeaMap,[1] Craig Brown, CEFAS[2], Bill Meadows, CEFAS[2] and Ivor Rees, School of Ocean Sciences, University College of North Wales[3]

## Background

Acoustic ground discrimination systems (AGDS) are based on single beam echo-sounders and are designed to detect different substrata by their acoustic reflectance properties. An echo-sounder generates a short pulse of sound at a single frequency that travels through the water and rebounds off the seabed (Urick 1983; Mitson 1983).The echo is detected by the transducer which converts the acoustic energy into an electrical signal that is displayed on a screen. The transducer shapes the pulse of sound into an approximate cone directed towards the sea floor. The area ensonified[4] – known as the *footprint* – by the echo-sounder directly under the vessel is approximately circular, although in practice, echo-sounders produce many side-lobes that make the footprint a more complex shape. The area depends upon the diverging beam angle (angle of the apex of the cone of sound) and depth of the sea floor.

Sound waves travelling in the centre of this cone will hit the seabed first (assuming the seabed is level) and depth is measured from time taken for this returning sound energy to be detected by the transducer. The strength of the echo and the way it decays with time produces a complex signal whose shape depends to a large degree on the nature of the sea floor and this is the basis upon which echo-sounders have been used for sea floor classification (Orlowski 1984; Burns *et al.* 1985; Jackson and Briggs 1992; Keeton and Burle 1996). The extent to which sound is absorbed or reflected by the sea floor depends upon the hardness of the seabed: hard surfaces produce strong echoes whilst soft surfaces (and this may include rock substrata that are acoustically softened by overgrowth of biota) give a weaker signal return. The sound energy that spreads away from the centre of the cone produces a weaker echo. This wave energy takes slightly longer to reach the seabed because of the extra distance travelled, and this time lag increases with increasing angular distance away from the vertical axis of the transmission pulse. Rough surfaces will produce an echo that decays slowly, since sound spreading some distance from the vertical may reflect off inclined surfaces angled towards the transducer (a property termed 'backscatter') whilst flat surfaces will reflect sound away from the transducer. The decaying echo may also contain an element that depends on the reflectance of sound from subsurface features. This is particularly the case for low frequency echo-sounders where there is greater penetration through soft surface sediment. The shape of this returning pulse or first return forms the basis for AGDS systems that map acoustic seabed properties to physical seabed properties.

Additionally, there may be multiple echoes as the returning sound energy bounces off the water surface and rebounds from the sea floor a second (or third) time. The significance of the second echo (first multiple echo) for ground discrimination is debatable, but it has been considered to be more sensitive to hardness than the initial reflectance of the first echo (Chivers *et al.* 1990; Heald and Pace 1996).

Two proprietary AGDS have been used extensively for surveying biotopes – *RoxAnn*™ (Marine Micro Systems Ltd, Aberdeen) and *QTC-View*™ (Quester Tangent Corporation, Sydney, Canada). *Echo Plus* ™ (SEA Ltd, Bath) is a third system new on the market that is a dual frequency, digital system similar in

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3 Menai Bridge, Anglesey, Gwynedd LL59 5EY, UK.
4 Analogous to the term 'illuminated'.

principle to *RoxAnn*.

The *RoxAnn* system uses analogue signal processing hardware to select two elements from the echo and measure signal strength (in millivolts) integrated over the time (Burns *et al.* 1985; Chivers *et al.* 1990). The first selected segment of the echo is the decaying echo after the initial peak. This measure of time/strength of the decaying echo is termed 'Echo 1' (or 'E1') and is taken to be a measure of roughness of the ground. The beam width of the echo-sounder is important for E1 since a wide beam will give greater scope for measuring signal decay away from the perpendicular than a narrow beam. For this reason it is recommended that AGDS operate with a echo-sounder of moderate beam width (15–25°). The second segment is the whole of the first multiple echo and is measured by the *RoxAnn* processor as 'Echo 2' (or 'E2').

The two paired variables (E1 and E2) can be displayed on a Cartesian XY plot, and this is the basis of the *RoxAnn* real-time display as used in the data logging and display software *Microplot*™ and *RoxMap*™. Rectangular areas on the Cartesian plot can be marked out so that records lying within that section of the plot can be colour-coded and displayed on the track plot.

*QTC View* operates in a very different way to *RoxAnn*. The echo is converted from analogue to digital form and is then subjected to analysis using a large number of algorithms for wave-form analysis (Collins *et al.* 1996; Collins and McConnaghey 1998). The *QTC* choice of algorithms and the way they are applied to the echo is considered commercially sensitive. However, the second echo is not used. The system can be run in one of two settings: supervised or unsupervised mode.

In the supervised mode the system is designed to be calibrated (ground-truthed) by positioning the vessel over known ground types and a sample dataset collected. The exercise is repeated for different ground types and the combined datasets subjected to principal components analysis. The data are displayed on a three-dimensional plot of the first three principal components, termed '*Q space*'. The *Q* space is then divided up into regions that relate to the ground type classes by forming a catalogue. This catalogue can then be applied to subsequent survey data collected at the site to classify the tracks in real time. If new ground types are covered further ground truthing is necessary.

The unsupervised mode offers greater flexibility without the use of calibration. The signal is subjected to the same algorithms within the *QTC View* system, but all variables are logged for later principal components analysis to be applied to the complete dataset. The software package *QTC Impact* is then used to identify 'natural' clusters which are acoustically different, within the dataset, which can then be attributed to ground types as dictated by the field sample data. The clusters can be further split by running *Impact* again. This process of finding 'natural' clusters is termed 'unsupervised classification' and is covered in detail later under the section on classification procedures).

## Purpose

Since the purpose of survey based on remote sensing is to extrapolate from direct observations to unobserved areas, uncertainty is unavoidable. No remote survey will give detailed, precise and accurate information. Uncertainty may be high with AGDS surveys, but the adoption of realistic objectives for a survey can reduce uncertainty to acceptable levels. AGDS measure acoustic properties of the sea floor and do not directly measure sediment or biological characteristics. These must be interpreted from the acoustic data through the use of field sampling (such as videography, diver observations, physical sampling using grabs etc). As with all remote sensing systems, the extent to which AGDS can discriminate between biotopes (e.g. physical habitats and their associated benthic communities) is dependant on the spatial distribution and degree of disparity between adjacent biotopes. For example, it might be expected that AGDS will be able to detect the difference between a limited number of discrete biotopes with clearly defined faunistic/habitat boundaries, whereas a but large number of subtly different biotopes that merge into each other will be poorly discriminated using these systems.

With this in mind suitable objectives for AGDS surveys include:

- Very broad-scale survey of large areas to map the approximate distribution and extent of a limited range of broadly defined biotope types (no more than 15). This type of survey is useful for gathering information in areas where there is little available data, and broad-scale survey has been the most common use of AGDS.
- AGDS maps may stratify the selection of suitable sites for more detailed survey. AGDS surveys can identify areas where there is a greater likelihood of finding a particular biotope of interest and thus reducing subsequent survey effort and cost.
- Rapid repeat survey of a small number of broadly defined biotope types to assess gross change over time. Although uncertainty will undermine the significance of apparent changes between similar biotopes, it must be remembered that gross changes can and do occur.

- The survey of a small number of distinct biotopes: whilst this might be useful for monitoring changes in boundary, this specific application for monitoring may be very limited.

AGDS are of limited use where repeat surveys are required to assess small and subtle changes in biotope composition.

### Applicable to the following attributes

Generic attributes that could be addressed by AGDS surveys are:

- The geographic range, extent and number of major habitat types supporting features of interest within an SAC;
- The geographic range, extent and number of biotopes or biotope complexes present in an SAC; and
- The geographic range and extent of the important biotopes (such as rare, fragile or rich biotopes) within an SAC.

### Applicable to the following survey objectives

- Map and re-map the extent of major substratum features including major biotope complexes.
- Compile an inventory of biotopes or biotope complexes present in an SAC (including the extent of organisms with a distinctive acoustic signal such as kelp, sea grass, mussel beds and maerl).
- Map or re-map the area occupied by all or selected biotopes or biotope complexes in an SAC.

### Advantages

- AGDS are relatively inexpensive compared to other acoustic systems.
- The quantity of data produced is less than for many other acoustic systems and this facilitates data handling and analysis.
- The analysis of a single vertical beam for measuring sediment properties is more straightforward than for swath systems.
- AGDS can be deployed from a variety of vessels of opportunity.
- Large areas can be surveyed (although at low resolution – see below) quite rapidly.

### Disadvantages

- AGDS do not give a complete coverage of the sea floor since the data are essentially points directly under the survey vessel as it tracks over the survey area.
- The wide beam width results in large acoustic footprints in deep water.
- The quality of the data is prone to the effects of poor weather conditions, and changes in acoustic properties such as tide and suspended load, perhaps more so than other acoustic systems.

These first two issues mean that the resolution of AGDS is poor as compared to swath systems. Although close track spacing can increase resolution, it is unlikely that a survey will result in a resolution greater than about 25m.

## Equipment

The following list indicates the equipment required for AGDS data collection.

(1) A *vessel* suitable for work in the locality with adequate cabin space for electronic equipment. (Some survey and fisheries patrol vessels have the relevant equipment permanently fitted.) Small vessels are adequate for sheltered inshore waters, but a stable working platform is essential.
(2) *Power supply*. The power supply on boats cannot always be relied upon where, for example, the peculiarities of wiring systems can affect electronic equipment. Unless absolutely confident of the reliability of the vessel's power, it is prudent to rely on your own power supply (generator and/or batteries, plus an inverter for higher voltage). All operators should be aware of the electrical safety implications of using mains powered equipment in marine conditions.
(3) An *AGDS signal processor* (*RoxAnn, QTC* or similar).
(4) A c*omputer* with appropriate *data logging software*.

(5) A d*ifferential GPS.*[5] Although the vessel's system may provide suitable navigation data, it is often better to be self-reliant for two reasons. Firstly it will avoid problems interfacing unfamiliar systems, and secondly, it is then possible to position the antennae above the transducer as far as is possible to minimise heading errors.
(6) *Echo-sounder*. It is likely that each AGDS will have its own echo-sounder, although they can be adapted to different systems. If AGDS are to be deployed from vessels of opportunity then portable systems with dedicated echo-sounders are required. The choice of frequency and power will depend upon the working depths expected. Systems set for deep water (generally low frequency) will not work well in water less than about 3–5m deep and systems set for shallow water (generally high frequency) may return invalid readings much below 30m.
(7) A *means of deploying the transducer from the boat*. The usual method is to mount the transducer on a pole strapped to the side or the bow of the boat (scaffolding poles are ideal, being cheap, readily available and very rigid.) This often limits the vessel's speed although fairings may reduce aeration and drag. Care should be taken to stop air bubbles being drawn through the pipe-end whilst underway and interfering with the signal. A range of ratchet straps to pull the pole into the side of the boat and brace the top and lower end of the pole fore and aft is usually sufficient to keep the pole stable at working speed (typically 7–8 knots). The transducer should be at least 1m below the water level and twice this in open seas to reduce aeration. It should also be lower than the vessel's deepest hull structure to avoid multipath interference.
(8) *Field sampling equipment* (see later section).

## Personnel/time

Skilled and experienced operators are needed to run the AGDS and field sampling equipment. This is necessary to cope with any malfunctions, to ensure that the correct settings are used, and to increase the likelihood of detecting any spurious data being recorded. Numbers of operators will vary according to survey circumstances and whether 24-hour working is planned. On chartered boats where field sampling will also be undertaken, at least two experienced persons are advised.

Staff with good IT skills are needed for post-processing of data. They should also have sufficient understanding of sedimentology and marine ecosystems to use the most appropriate settings to derive the most suitable displays of the data.

## Method

These guidelines are based on more extensive technical reports than can be found on the SeaMap internet site.[6]

### Planning the survey

AGDS coverage is determined by track spacing and the way in which complex coastlines are surveyed. The intensity of tracking will depend upon the heterogeneity of the ground. Whilst this cannot be determined prior to a survey, inspection of hydrographic charts will give some indication of the nature of the ground likely to be encountered. Although a series of regularly spaced parallel tracks may be desirable for consistency in analysis, the need to concentrate survey effort where most needed in the limited time available may dictate that some sectors of the survey area will be more intensively tracked than others. The decision about tracking intensity may need to be made on survey, especially if poor weather reduces available survey time.

Real-time visualisation available through *Microplot*™, *RoxMap*™ or other proprietary logging software can be used to keep a check on ground variability, consistency between tracks and discrimination (with reference to field sampling). QTC operated in unsupervised mode cannot display this information. Surveyors can plan their tracking in such a way as to reduce problems for data analysis (ideally, one of the surveyors should also be involved with subsequent data analysis). Planned track pattern should take account of the following:

5 At the time of writing, selective availability has been switched off and an acceptable accuracy to within 5m is possible without the use of a differential system.

6 See: **http://www.ncl.ac.uk/seamap**

- Track spacing should be related to along-track variability. The aim should be to see patterns emerging between adjacent tracks. Where track variability is high, close tracks will be needed. Track spacing might vary over very large areas with different patterns of variability. Track orientation should allow for the possibility of missing linear track features formed by underlying geology or tidal transport mechanisms.
- Geographic coverage should be comprehensive at the maximum track spacing.
- Track spacing wider than 500m is likely to present problems when generating a coverage from the AGDS data and should be avoided if interpolation is required for data analysis (see later section).
- Tracks should extend beyond the main area of interest since interpolation is often poor around the outside of a data set.
- Ground is usually very variable close inshore, particularly where the shoreline is complex. Ideally the shoreline should be tracked as far inshore as the safety of the vessel permits. This is particularly important to avoid spurious interpolation of data around islands and headlands. Minimum operating depths do apply to AGDS systems especially QTC

## Maintaining data quality during field survey

Maintaining the quality of the data is vital. AGDS can give variable data because of changing sea conditions or internal variability in the AGDS itself. The effects on the data may not be obvious unless a careful check is kept during the survey. Unless this is done, dubious data may only come to light in subsequent post-survey analysis when there is no possibility of collecting new data. The following should be continually monitored:

- The echo-sounder screen itself provides valuable information on ground type that cannot be easily seen on the AGDS plot. A good log will help interpretation and reassure analysts that the AGDS data accords with the surveyor's impressions of ground type.
- The echo-sounder screen may also indicate if there is interference with other acoustic systems (normally shown as interference on the screen). Any potential interference should be eliminated and all personnel alerted to the problems caused by switching on other echo-sounders during a survey.
- Deteriorating sea conditions may create aeration under the transducer, interrupting the signals from the echo-sounder; erratic depths recorded by the AGDS are a clear symptom. Too many erratic depth readings will usually lead to all the data for that whole track being considered invalid. However, AGDS can work in quite rough sea conditions and this alone should not prevent the survey from continuing.
- Cross-tracks and/or some close parallel tracks should be run at times throughout a survey to check for consistency in the operation of the system.

If the surveyor has reason to suspect that the track data are inconsistent then attempts should be made to trace the cause. This may be due to aeration and lowering or altering the position of the transducer pole may help. Electrical connections between the transducer and the AGDS are particularly prone to stress and intermittent faults can give misleading data – all electrical connections that are regularly made during equipment set-up should be checked. If sea conditions have deteriorated, the survey should be suspended.

However, some variability is only temporary and may be due to very slow vessel speed (such as when the vessel stops for sampling) or rapid changes in direction. It is not advisable to stop recording the AGDS data since these records can easily be identified post-survey and removed from the data set. There is always the risk that the operator may forget to restart the recording resulting in a loss of data.

Variability between days is a more difficult issue to address. It is good practice to track over a patch of homogeneous ground at the start and finish of each day. This is only possible when the vessel uses the same port throughout the survey. If different sections of a large survey area are covered each day, then the sections should overlap and attempts should be made to ensure tracks coincide. These overlapping data can be compared for consistency.

## Choice of field sampling technique

The choice of sampling techniques must match the expected nature of the sea floor and the purpose of the survey. For example, if the main objective is to survey bedrock reefs it may be sufficient simply to record where sandy habitats occur from videography without the need to take sediment samples.

Drop-down or passively towed video systems are ideal for rapid sampling. Rapid sampling is important since successful analysis of the AGDS data depends upon the collection of a large number of field samples, accurately located on the acoustic map. Video permits the observation of conspicuous sea floor characteristics at a scale appropriate to the echo-sounder footprint. The position of the video system must be estimated. Therefore, it is best deployed for a short duration rather than for long tows. This will reduce the positional error (layback) caused by the relative movement of the sledge to the ship's position in tidal streams as more umbilical is paid out. The use of non-contact 'dunking' video systems drifting with the prevailing current can minimise these layback errors. Numerous short drops (point data) on homogeneous ground are far easier to post-process than fewer long tows covering a wide variety of habitats. However, short and carefully positioned tows can be useful to explore sharp transitions in acoustic ground types.

Although videography is ideal for biotopes that are primarily characterised by their epifauna and flora, it is also useful for determining surface features of sediment (sand waves, shell fragments and evidence of bioturbation or biogenic sand reefs). Thus, video is almost universally applicable to surveys except where visibility is likely to be extremely poor. However, sediment sampling methods must be used to validate sedimentary areas, particularly when the biotopes present are characterised by infauna. For example, a standard grab sampling programme can be run in conjunction with a remote survey.[7]

Side scan sonar can also be used as a tool for ground validation and areas of habitat type recognised from the traces can be used to interpret AGDS data.

## Selecting field sample stations

AGDS are designed to give real-time discrimination between habitats. Whilst it is strongly advised to use post-processing of the data for interpretation (see below), the real-time facility is very useful for gaining knowledge of the distribution of acoustic ground types during the survey. Such knowledge is essential for designing an efficient, stratified field sampling programme to validate the acoustic data. Surveyors should edit the real-time display (e.g. the arrangement of the boxes in E1/E2-space) to identify acoustic ground types which may be related to particular habitats or biotopes. In this way field sampling will have an element of prediction as the survey progresses. The following points should be considered when selecting sampling stations:

(1) The full range of acoustic ground types should be sampled (E1/E2-space for *RoxAnn* or Q-space for *QTC-View*).
(2) The samples should cover the geographic range of the survey.
(3) There should be at least 5 samples for each of the main habitat or biotopes (for each geographic region). Even where a surveyor may feel that a particular ground type can be very confidently predicted (e.g. kelp forest in shallow water on hard ground), these habitats should still be sampled a minimum number of times. Failure to do this will compromise subsequent analysis.
(4) If necessary, the survey effort may be focused on particular biotopes if real-time prediction of these biotopes is low.
(5) Stations should be located in areas where the acoustic data are consistent along tracks rather than in areas where the along track data are changeable. This will alleviate problems of wrongly attributing acoustic values to particular biotopes due to positional uncertainty.
(6) Field samples should lie on AGDS tracks so that they can be closely associated with real data rather than interpolated acoustic values.

## Data analysis

Editing track data in real-time either within the logging software (*RoxAnn* logged on *Microplot* or *RoxMap*) or in near real-time with the processing software provided with the AGDS (*QTC-View*) may be the limit to which data analysis needs to be taken. One example is where AGDS data are used primarily to stratify a field sampling programme. However, detailed post-survey analysis of the data is required where biotope maps must be derived from an interpretation of AGDS data linked with ground samples.

Data analysis is a vast subject and many routes can be taken through the process of data interpretation. The following account is by no means exhaustive and is intended to raise awareness of important issues that must be addressed. Data analysis has been divided into three sub-sections: (1) preliminary data treatment and data exploration; (2) interpolation, and; (3) classification.

### *Software requirements for data analysis and interpretation*

Specific software will be required to carry out the following recommended analytical techniques (apart from the usual statistical packages):

- *data filtering and exploration*: standard spreadsheet software (or database)
- *interpolation and statistical spatial analysis: Surfer*™ and *VerticalMapper*™ will perform interpolation and variogram analysis
- *classification*: image processing software such as *ERDAS Imagine*™ and *IDRISI*™ are suitable for classification
- *spatial analysis and map production*: geographic information systems such as *ArcInfo*™, *ArcView*™ and *MapInfo*™ provide the most appropriate software tools

7 See PG 3-9 'Grab sampling'

## *Preliminary data treatment and data exploration*

The purposes of this stage are:

- check that the data are of sufficient quality for further analysis and remove data that are considered dubious (known as *filtering*)
- explore the nature of the data and check for dependencies between variables that might compromise analysis, transforming data if required
- check for patterns of spatial correlation in the data that need to be considered when deciding the most appropriate route for further analysis
- standardise data prior to amalgamation of different data sets or to facilitate comparison between data sets
- correct depth data to chart datum (to account for tidal variation)
- derive other attributes that might be useful for interpretation (e.g. along-track variability, slope)

The raw AGDS data must first be exported from the data logging software in a format suitable for import into a spreadsheet (e.g. as comma-delimited text). These data will normally include geographic position (either as easting/northing or longitude/latitude), time, date, depth and AGDS parameters (E1and E2 for *RoxAnn* or the Q values (eigenvalues) for *QTC-View*).

Thereafter the following procedures are recommended:

(1) *Correcting depths to vertical chart datum, referenced to an appropriate local port*: recorded depth is tidally adjusted to chart datum by applying a correction, which is calculated from the tidal prediction program using the simplified harmonic method produced by the UK Hydrographic Office (Anon 1991). Corrections are applied at time intervals between 10–30 minutes. However, using 10-minute intervals eliminates steps in the depth track records that can be apparent if longer time intervals are used. This is particularly important for the construction of digital elevation models. It should be stressed that the resulting depths may not be very accurate and may conflict with the soundings on Admiralty hydrographic charts, which are naturally cautious in defining minimum depths. This must be expected since atmospheric conditions affect tides and, additionally, the nearest reference port may be some distance away. If accurate bathymetric data are required, it will be necessary to instal a local tide guage or use the elevation data provided by real-time kinematic GPS.[8]

(2) *Filtering data associated with low boat speed or erratic positions.* An estimate of boat speed can be calculated from the position data in sequential records (eastings and northings are most suitable). Sections of track should be highlighted where either there are large skips in apparent position due to GPS error, and/or there is little change in the position of the survey vessel. The distance between two consecutive points also shows where the vessel slows to a speed below the acceptable minimum for recording AGDS (about 1 metre per second). These calculations and the highlighting process can be automated via a macro. Highlighted records can then be checked to see if they should be deleted.

(3) *Filtering erratic depths*. Each depth record is compared to the average value of the two previous track points together with the two following points. Track points where a large difference (normally >5m) occurs are highlighted and inspected. If a point appears to be out of step with its neighbours, then it is deleted.

(4) *Scatterplots*. Scatterplots of E1/E2/depth or Q1/Q2/Q3/depth are useful:

To check for dependencies between variables. Weak relationships, given the overall variance in the data, might not be too serious for future analysis. But strong relationships (e.g. depth and another parameter) will dominate classification and careful selection of variables will be required. Note that E1 and E2 can be transformed to eliminate dependencies, but QTC data are already transformed through PCA.

To check for outliers that might be spurious. An especially useful procedure is to create scatterplots in a GIS (e.g. *MapInfo*) using non-earth co-ordinates, select outliers and then display these geographically. Outliers may occur on a particular track that is inconsistent with neighbouring or cross-tracks, or may be associated with ship manoeuvres.

Scatterplots are also useful for indicating if two data sets appear to be compatible prior to amalgamation.

(5) *Variogram*. This is a graphical technique for showing the degree of spatial correlation within the data. It shows how the similarity between values decreases as distance between points increases. A variogram illustrates the overall pattern of spatial correlation for the whole dataset and not local variation (Figure 1). It does not show very broad-scale spatial trends or local variations in spatial correlation. The variogram shows:

*Noise* (the variance within the minimum sampling distance): this should not be too large in relation

8 See PG 6-1 'dGPS'.

to the maximum variance of the data set. If it is, then the variability within the minimum point-to-point distance is so high that one point is independent of its near neighbours – in other words, no local patterns will be seen and interpolation is impossible.

The *range* (the lag distance to the sill): the range gives the maximum distance where some spatial correlation might be expected to be present. Whilst interpolation is possible over distances represented by the range, the interpolated data are not likely to be much better than the local average. If interpolation is required, the *search radius* (see below) should be the range equivalent to half the sill variance.

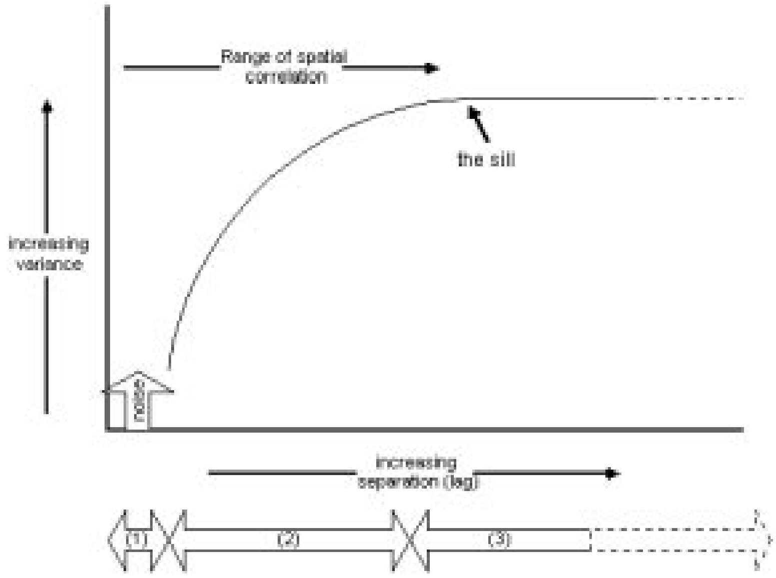


**Figure 1** A general form of the variogram that illustrates the points referred to in the text. The shape of the relationship between variance and lag distance illustrated is only one of many models that might be found in practice (see Burroughs and Donnell 1998), but is the general shape found with AGDS data. The graph starts at a minimum distance representing the maximum spatial resolution of the AGDS (1) and the variance below this distance is *noise* (also called the *nugget effect*). Variance may then rise quite steeply, initially over the range of spatial correlation, indicating that the strongest links between data are over short distances and correlation dwindles rapidly as distance increases. The point where the graph levels off (the *sill*) marks the maximum distance (2) over which spatial correlation can be detected and is called the *range*. However, the correlation is very weak at distances approaching the maximum range and a smaller working range for interpolation may be chosen. At distance greater than the range (3) no interpolation is possible.

## *Interpolation: point-to-area conversion*

Whilst it is possible to interpret track point data and show the results on a map, it is far easier to see spatial patterns in data if these are displayed as a continuous picture. Interpolation is a process of converting point data to areal coverage in which new values are estimated for locations where there are no track records on the basis of spatial patterns within the real data. The reader is referred to Burroughs and McDonnell (1998) for a detailed discussion of this subject. Interpolation might be considered for the following reasons:

- for cosmetic purposes: the maps look better. This is perfectly valid if it makes the maps more persuasive for management (as long as the maps do not misrepresent the data).
- to show broad patterns (i.e. possible error in the detail is acceptable if the interpolation clearly shows general patterns).
- spatial modelling: the interpolation process is used to generate knowledge about spatial patterns to generate testable hypotheses.

If none of these reasons applies, it is probably best to work with track data rather than an interpolated continuous coverage. If a continuous coverage is required, then the next step is to appraise the nature of the data. Note that interpolation using any form of distance weighted averaging cannot work for categorical data. This would apply to QTC View data which had been classified using QTC Impact. However, if the Q values (eigenvalues) are used for Q1, Q2 and Q3 then interpolation using these methods may be appropriate. There are other forms of interpolation based on nearest neighbour or Voroni polygons that may be more suitable for categorical data.

Assuming the data can be interpolated using some form of distance weighted averaging, is interpolation likely to be problematic? If there are many point data, interpolation will be successful no matter which interpolation model is used. If data are sparse, careful selection of interpolation methods (models and parameters) will be needed since the outcome will be sensitive to the choices made. The emphasis changes from filling in missing values with obvious estimated values to one of spatial modelling. In most AGDS surveys the situation is somewhere between the two extremes. It is important to have some idea of the problems interpolation might cause:

- Interpolation is robust when there is low variability along the track relative to track spacing, and there is a similarity between adjacent tracks. Normally:
  - the track spacing is well within half the range of the sill (see variogram); generally, track spacing should be less than 0.5km;
  - the nugget effect is small relative to the variance at the sill.
- Interpolation is likely to be problematic when there is high along-track variability relative to track spacing, or there are few obvious patterns that are consistently reflected in parallel tracks. Normally:
  - track spacing greater than the half-range distance;
  - the nugget effect is large relative to the sill;
  - in general, track spacing is greater than 1km.

Additional problems will arise if the data are not truly continuous and two or more data sets need to be amalgamated where it is uncertain if they are directly comparable.

*Interpolation method* If data can be interpolated, what sort of distance weighting should be used? Kriging is considered to give the mathematically optimal weighting, but is dependent upon choosing the correct model. *Inverse distance* gives acceptable results and allows greater choice of parameter settings that can suit particular situations and requirements.

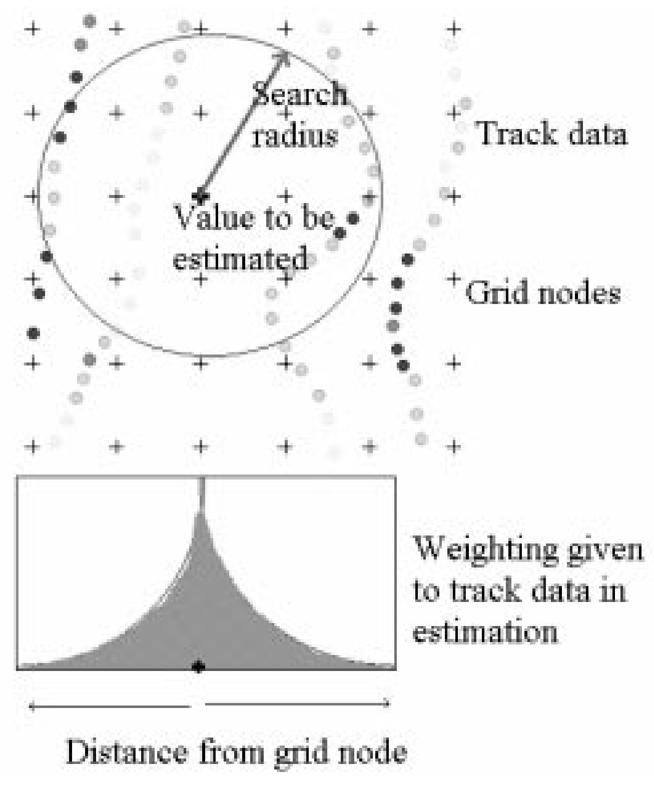


**Figure 2** A small section of track with grid superimposed, illustrating the main parameters to be set for interpolation. Interpolation replaces real data with values estimated at regular grid nodes. The grid spacing can be set by the analyst, which sets the minimum resolution (pixel size) for all images thereafter. The grid nodes are indicated by the crosses. Grid spacing is set so that the image files are not too large for processing nor so widely spaced that valuable local variation in the data is lost through averaging. The bold cross indicates the grid node for which an estimated value is to be calculated. A *search radius* is set to encompass data from different tracks (unless the radius is larger than the range justified by the variogram). The distance weighting used depends upon the interpolation algorithm chosen; inverse distance square weighting is shown in the box below the track data. However, not all data within that search radius need be included if the maximum number of data points is set at a small number. The search can also stipulate that data from different quadrants must be included so that the calculation is forced to take account of data from different tracks.

Distance weighting can be considered as ranging from heavily weighted towards the nearest data to no weighting (local average within search distance). In the extreme, weighting can be so heavily biased to the nearest point that it is effectively performing a nearest neighbour interpolation. Here are some choices along the weighting spectrum:

(1.) *Nearest neighbour*

Advantages: no values 'made up' so that classification will not be affected by unreal data; ensures that field samples that lie a short distance away from track data will be associated with real AGDS data for signature development.

Disadvantage: if interpolated over some distance away from data, gives a very blocky and crystalline look that is visually unacceptable.

(2.) *Inverse distance squared* (or power above 2 to give strong weighting to nearest data)

Advantages: interpolated values are faithful to nearest data and the averaging effect between tracks associated with weaker distance weighting is reduced: this is suitable if there are doubts about whether the data are truly continuous variables.

Disadvantage: can create noticeable distortion around data hot spots (isolated values substantially at variance with neighbouring values).

(3) *Inverse distance to a power between 1 and 2* (weak distance weighting)

Advantages: gives very smooth result where hot spots are averaged out; suitable for showing general trends especially where track spacing is wide and there is a reasonable expectation that the ground between is likely to be homogeneous or with gradual trends in values.

Disadvantage: smoothing may be at the expense of local variability (which might be significant); superimposing other variability measures might redress the smoothing effects somewhat.

*Interpolation to produce digital images* Perhaps one of the most compelling reasons for interpolation is that it opens up the use of proprietary image processing software for further analysis (Sotheran *et al.* 1997). A grid of interpolated values can be treated as a digital image where each grid node becomes a centroid of a pixel. Note that the same pixel arrangement is required for all images that are to be analysed together. That is, geographic boundaries, search and display radius and grid spacing need to be standardised. If the images are to be trimmed, this process must also be standardised.

## Classification

There are many ways in which AGDS data might be classified using the ground truth data ranging from univariate or bivariate analysis of continuous variables (e.g. silt content of sediments) to multivariate classification techniques.

### *Calibration*

The simplest form of classification is an extension of the real-time calibration as used in Microplot. E1/E2 space is divided up into rectangular (or other shaped) areas whose dimensions can be modified by experience. Although useful for real-time data exploration, it is not recommended for producing biotope maps.

### *Univariate/bivariate plots*

Variables, such as silt content, species counts, etc., can be plotted against E1 or E2 and the acoustic variables used to predict the variable. This can be extended to E1/E2 plots by plotting contours of silt content (for example) and then classifying track data by the contour plot. This approach can be applied to categorical data (e.g. biotopes) if the frequency of their occurrence is plotted in E1/E2-space and the results contoured as above.

### *Unsupervised classification*

Detecting 'natural' clusters in data and then assigning biotopes to these clusters is the basis behind unsupervised classification.

*RoxAnn* Data can be clustered, but there are not many variables available for multidimensional clustering. Clusters may appear in small data sets, but as the range of biotopes increases, the data resembles a 'cloud' without clear nodes and the division of the data cloud into classes therefore becomes somewhat arbitrary. Unsupervised classification is most useful as a guide to the collection of ground samples.

Once this information is available, supervised classification is preferable.

*QTC* *QTC View* and *QTC Impact* do use clustering although the raw parametric data is hidden from the analysts due to commercial confidentiality. The three Q values are plotted in Q space, and natural clusters of points within the 3-dimensional plot are identified and classified statistically under direction of the analyst (Figure 3). The decision to split and merge clusters is assisted by provision of statistical information of each cluster.

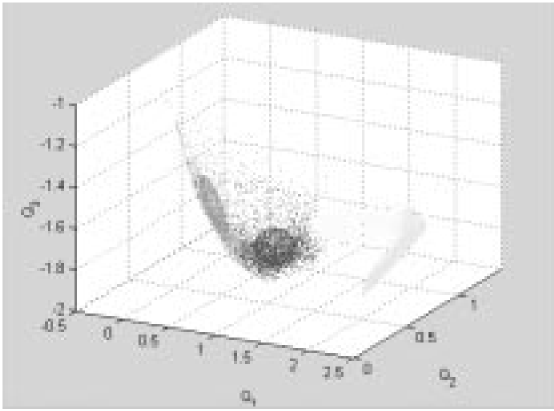


**Figure 3** An example of the three-dimensional display of QTC data classified into 5 clusters.

## *Supervised classification*

Supervised classification of the images is quite straightforward for *RoxAnn* data, assuming that the variables (which are standardised from 0–255) are independent. Supervised classification using *maximum likelihood* is a very convenient route for analysis since it is well supported by proprietary software, and generally gives good results. This method of classification can also be applied to QTC data, using the three Q values and depth in the classification procedure.

The main steps in supervised classification are:

(1) *Selecting training sites for the biotopes.* Training sites are usually digitised around areas of an image that are known to represent a particular biotope from direct observation. However, field samples in the sublittoral are mostly point data and the training sites are created by drawing a (circular) buffer zone around the points (or lines if the sample is a video tow, dredge, etc.). The buffer must be large enough to capture sufficient acoustic data to complete the next stage successfully, but not so large that data are wrongly attributed to the biotope.

(2) *Developing acoustic signatures for the biotope classes.* Supervised classification calculates, for each biotope class, an 'n' dimensional probability distribution based on the mean and standard deviation of each variable (E1, E2, depth, etc) from all the data included in the training sites. The probability distribution is calculated through a process of maximum likelihood.

(3) *Classifying the whole survey area.* Each pixel in the whole image is matched to the biotope signatures in turn and classified according to which biotope has the highest probability value. However, the actual probability values for each biotope are also accessible and can be used in their own right (if these are significantly above or below what might be expected by chance).

## *Classification of track data*

A distinction needs to be drawn between the use of interpolation for generating (1) continuous coverages and (2) digital raster images. If a decision is taken not to create a continuous coverage, digital images can still be created through interpolation so that image processing software can be applied to track data. The most straightforward way is to interpolate and classify in the usual manner, but to blank out and eliminate those parts of the image away from the tracks. Alternatively, if nearest neighbour or a large weighting to nearest real data is used combined with a very small search radius, then interpolation will simply reproduce the tracks as raster images with the pixels in the inter-track spaces having zero values. The latter method will create very large files because of the small grid size used even though the great majority of the pixels will contain zero values. The classification algorithms (unsupervised or supervised) are applied to these 'track images' to create a classified track image.

### *Bathymetric models*

In addition to the above products, the construction of 3-D bathymetric models is very useful for visualising the topography of the survey area and, if biotope maps are draped over the model, the relationship between bathymetry, topographic features and biotope distribution. These models can be created in the image processing packages and also in *Surfer*™ and *Vertical Mapper*™. Some extra precautions need to be taken with the bathymetric data for successful modelling. The model is very susceptible to spurious depth records and the raw data must be rigorously filtered. Points along the high and low water isobaths should also be digitised, given a nominal height value and incorporated into the model. Interpolation procedures may need to be specifically tailored to the creation of the model in that more averaging of the data may be required to smooth the model than is the case for image processing (i.e. weaker distance weighting coupled with a larger search radius).

# Accuracy testing

## Field log

A log must be maintained with details of the equipment set-up, the parameters which are used, any changes made during the survey, and the performance of the survey equipment. Although data logging systems allow notes to be entered electronically as waypoints, it is strongly advised that a separate written log be kept. A log is vital for tracing possible causes of variable performance discovered during subsequent data analysis and to ensure that repeat surveys can follow the original survey with confidence. The log should record:

(1) Details of equipment and power sources used and their position on the survey boat. Draft of the transducer and height of the GPS antennae.
(2) Settings selected on the echo-sounder (power and depth settings).
(3) Geodetic parameters, namely the co-ordinate system, its units and the datum set in the GPS (e.g. OSGB36; UTM zone 30; latitude/longitude in decimal degrees with WGS84).
(4) Position and time of any changes to the equipment settings, interruptions of power supply or GPS signal, problems encountered with equipment and remedial action taken.
(5) Sea conditions.
(6) Description, position, time and depth of any event (field sample, ground as observed on the echo-sounder, shoals of fish or other mid-water echoes on the echo-sounder screen). Description of field samples should detail sediment characteristics, topography and conspicuous species observed with an approximate assessment of abundance/cover. Although this information will be available from post-survey analysis of samples, this analysis may take place some time after a survey and a preliminary interpretation may be needed before the completion of the project. The written log also provides a valuable alternative account of field sampling that can be compared with the electronic log in the case of confused or lost data. Where possible metadata standards for data collection methods should be used.

## Analysis of field samples

Misclassification of the field data can undermine data interpretation and is a major source of uncertainty in interpretation. This is particularly important for interpretation of acoustic data since it is likely that the field records will be summarised as biotope classes for the purposes of data analysis (see above discussion on classification). The reader should refer to the relevant procedural guideline to ensure that the appropriate measures are taken to minimise misclassification.

## Data analysis

There are many ways that performance of the biotope mapping process can be assessed and the following questions form useful points for consideration:

- How internally consistent are the biotope maps with the ground samples used for classification?
- How well do maps predict biotopes as assessed against an external ground sample data set?
- How dependent is performance on survey design, particularly survey intensity? Where (in terms of confusion between biotopes and location within survey area) is uncertainty most acute?
- How consistent is the interpretation of different AGDS data sets for the same area?

An *error matrix* (from cross-tabulation between the classified biotope map and the field sample data) is a standard tool for assessing the performance of a map. Cross-tabulation is straightforward for digital images using GIS/image processing software (e.g. IDRISI™ or ERDAS™). Pixels in the buffer zone around the field samples are coded by biotope class and this image is overlain on the acoustic map (classified to the same codes). The pixels from each image are compared in a matrix and accuracy can be expressed as percent match, or other indices can be used (e.g. Kappa and Tau) that give probability of a match over and above chance. A similar cross-tabulation process can also be used to measure the similarity between two interpreted maps of the same area for comparing the results from repeat surveys.

Internal accuracy is a measure of the internal consistency between the field samples used in classification and the resulting biotope map. Thus it uses the same field sample data set for classification and accuracy assessment. External accuracy assessment uses a different set of field records from that used for classification and measures the predictive performance of a biotope map. Benthic samples for large survey areas are 'hard-won' and it is often difficult to avoid using all the data for classification of the acoustic images. This is, admittedly, unsatisfactory since it would be expected that internal accuracy would be higher than predictive accuracy. Dividing the field data set into two subgroups used for (a) classification and (b) external accuracy assessment is unsatisfactory since the subgroups will probably have too few samples per class and will not represent the whole survey area evenly (as intended by the surveyors). Thus, unless a separate field sampling exercise is planned specifically to test a map, it is probably advisable to use internal accuracy and regard the values as a measure of the relative performance of the survey. However, the accuracy measures can be surprising. Quite high internal accuracies can be achieved with only a small number of field samples if these have been selected from homogeneous acoustic ground since the signatures generated will not have the spread of values from a more extensive field data set.

Error matrices are also useful in pointing out the extent of confusion between biotopes with similar acoustic signatures, which are also often very similar in terms of their habitat and biota.

## Quality Control procedures

AGDS surveys are complex and involve a range of other sampling systems covered by other procedural guidelines. No universal approach can be adopted since the methodology will depend upon survey aims, the nature and extent of the survey area and the funds and time available. A well thought out project brief given to surveyors is essential.

Nevertheless, for any one area the adherence to the guidelines set out in the above sections will ensure that the data gathered will be of a high standard given the survey conditions. It is important to keep a record of the progress of the survey through planning, fieldwork (see 'Field log' above) and data analysis. This includes:

- the steps taken to ensure consistency of AGDS data during the survey
- all details of set-up conditions (equipment, GPS reference system);
- a record of data editing procedures adopted and proportion of data rejected. (NB: all raw data files must be archived in an unmodified format);
- data exploration and, in particular, justification for interpolation (e.g. variogram analysis);
- track plots and field sample locations for accurate re-location;
- the parameters used for interpolation;
- the parameters used to create digital images (e.g. min/max co-ordinates, value used for a *contrast stretch*);
- all measures adopted for classification accuracy assessment;
- all cartographic conventions: include details of source of coastline, projection and datum used, scale, date of survey, surveyors and data analysts.

If repeat surveys are to be compared, then they should follow the previous survey as closely as possible. Although the outcome of interpretation should be similar for different AGDS since analyses are independent and should stand alone, in practice the powers of discrimination will vary between systems and this will influence the final biotope map. It is desirable, therefore, that the same system (ideally the same instrument) should be used for repeat surveys.

## Data products

The final products of the AGDS survey are maps of the most likely distribution of biotopes (and/or habitats). The raster output from classification procedures should be converted into vector maps for cartographic presentation and export to the required GIS format. Maps can give the impression of being definitive when in fact they are only predictions based on the best available information and using justifiable analytical procedures. The final maps should be underpinned by other information (graphical and tabular) which gives clear indications as to their accuracy and the confidence with which the maps can be used. These supplementary products should be:

(1) Track plots of the edited data. The individual data points can be colour coded according to selected acoustic characteristics (e.g., E1 or E2, E1/E2 boxes, clustered division of Q-space). Track plots of bathymetry are also useful.

(2) Contoured bathymetric maps.

(3) Raster maps of E1 and E2, Q1,2 and 3.

(4) Positions of all field samples coded to biotope.

(5) Error matrices.

Electronic copies of these maps should be available in a GIS linked to the underlying data in spreadsheet or database.

## Cost and time

The speed with which a given area is surveyed will depend upon tracking intensity, itself dependent upon biotope heterogeneity and complexity of the shoreline. Time must be allowed for setting up equipment and problems arising as well as poor weather. It is unlikely that any survey will require less than 5 working days. The following are estimated costs for a week's field survey:

| *Stage* | *Time* | *Cost* |
|---|---|---|
| *Project management* | | |
| Personnel (incl. travel) | 2 days | £700 |
| *Field survey* | | |
| Equipment hire | 7 days | £600 |
| Vessel hire* | 5 days | £2500 |
| Travel/vehicle hire | 7 days | £250 |
| T & S for 2 surveyors | 7 days | £500 |
| Personnel | 7 days | £3500 |
| Field consumables | | £200 |
| *Analysis* | | |
| Preparation of AGDS data | 5 days | £1250 |
| Analysis of field samples** | 3 days | £750 |
| Classification (interpretation) | 5 days | £1250 |
| Preparation of maps | 3 days | £750 |
| Preparation of report | 5 days | £1250 |
| *Total* | | *£12,800* |

* For hire of a small craft. Costs will be much higher for larger survey vessels.

** Based on video samples. Other sampling involving specialist identification and sediment granuolometric analysis will incur supplementary costs.

## Health and safety

Appropriate safety equipment for boat work must be used, particularly life jackets and/or lifelines during sampling operations where the risk of falling overboard is higher. Consideration must be given to any risks posed by the use of electrical equipment in wet environments.

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# Procedural Guideline No. 1-4
# The application of sidescan sonar for seabed habitat mapping

Andrew J. Kenny,[1] Brian J. Todd[2] and Richard Cooke[3]

## Background

The aim of this guideline is to highlight those aspects of sidescan sonar configuration and operation that must be considered to ensure good quality data are obtained in the field. The procedure assumes the surveyor has some experience of using sidescan sonar, particularly in respect of maintenance, testing and operation and that the terms used in this guidance note will be familiar. However, in the first instance, the authors wish to highlight an important distinction between the principal acoustic mapping systems, at a non-technical level.

### Principal acoustic systems

In general, acoustic remote seabed mapping or sensing instruments may be classified into one of two types:

- broad beam swath systems (sidescan sonars); and
- narrow beam echo-sounders (AGDS).

The distinction between the two is very important as they look at the seabed in very different ways, and therefore the output requires very different interpretation. The broad beam swath systems may have single or multiple beams that exhibit the same beam geometry characteristics, i.e. the beam insonifies a wide swath of seabed due to its low grazing angle, but the beam is narrow in azimuth as shown in Figure 1. In order to achieve the low grazing angle the sonar has to be towed at a fixed altitude above the seabed and hence the sonar is not hull mounted. The advantage of this is that relatively large acoustic shadows are cast by relatively small objects protruding from the seabed (including changes in sediment composition such as gravel substrata). The acoustic geometry of the sonar footprint therefore makes the sidescan system most suitable for detecting small objects on the seabed and changes in bed roughness.

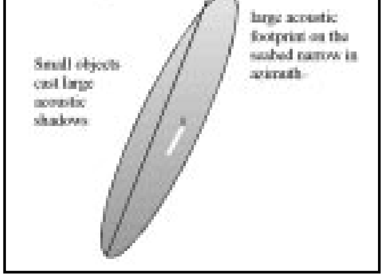


**Figure 1** Schematic of sidescan sonar

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The echo-sounder system may again be a single or multi-beam unit which, by definition, will be hull mounted in order to measure changes in bed level. To achieve good object detection capability the beam geometry must be narrow (which is the opposite of the sidescan system) with the sonar having a high sample rate. A schematic showing the beam geometry of a typical echo-sounder such as an AGDS is shown in Figure 2. It should be noted that the actual sonar lobes have very complex shapes which are seldom exactly the same between soundings owing to the subtle changes in the properties of the water from one location to the next. The technical attributes of AGDS are provided elsewhere in this handbook. The remaining sections will focus on the use of sidescan sonar.

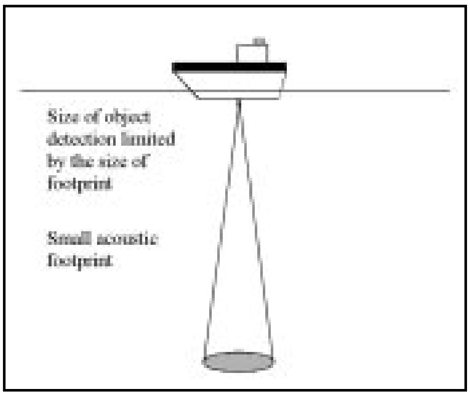


**Figure 2** Schematic of an echo-sounder

# Theory of sidescan sonar operation and purpose

Sidescan sonar has been defined as an acoustic imaging device used to provide wide-area, high resolution pictures of the seabed. The system typically consists of an underwater transducer connected via a cable to a shipboard recording device. In basic operation, the sidescan sonar recorder charges capacitors in the towfish through the cable. On command from the recorder the stored power is discharged through the transducers which in turn emit the acoustic signal. The emitting lobe of sonar energy (narrow in azimuth) has a beam geometry that insonifies a wide swath of the seabed particularly when operated at relatively low frequencies, e.g. <100kHz. Then over a very short period of time (from a few milliseconds up to one second) the returning echoes from the seafloor are received by the transducers, amplified on a time-varied gain curve and then transmitted up to the recording unit. Most of the technological advances in sidescan sonar relate to the control of the phase and amplitude of the emitting sonar signal and in the precise control of the time-varied gain applied to the return signals. The recorder further processes these signals (in the case of a non-digital transducer converting the analogue signal in to digital format), calculates the proper position for each signal in the final record (pixel by pixel) and then prints these echoes on electro-sensitive or thermal paper one scan, or line at a time.

Modern high (generally dual) frequency digital sidescan sonar devices offer very high resolution images of the seabed that can detect objects in the order of tens of centimetres at a range of up to 100m either side of the towfish (total swath width 200m), although the precise accuracy will depend on a number of factors. For example, the horizontal range between the transducer and the seabed is affected by the frequency of the signal and the grazing-angle of the signal to the bed which is itself determined by the altitude of the transducer above the sea floor. Some typical limits associated with sidescan sonar are as follows: operating at 117kHz under optimal seabed conditions and altitude above the bed, a range of 300m (600m swath) can be obtained and typically 150m at a frequency of 234kHz. Accuracy increases with decreasing range, for example, 0.1m accuracy is typically obtained with a range of 50m (100m swath) whereas 'only' 0.3m accuracy is obtained at a range of 150m. The sidescan sonar provides information on sediment texture, topography amd bedforms, and the low grazing angle of the sidescan sonar beam over the seabed makes it ideal for object detection.

In general, there is a trade-off between the area which can be mapped in a given time and the resolution or detectability of seabed features within the mapped area. For example, a sidescan system operating at 500kHz can potentially detect features measured in decimetres, but this can only be achieved along a narrow swath of about 75m per channel and therefore the typical area which can be mapped in an hour is relatively small. By contrast, the systems which operate a lower frequencies of around 50kHz have much greater range and can be towed at faster speeds which allows a greater area of seabed to be mapped in a given time (Table 1).

**Table 1** Object resolution versus range for two sidescan sonar systems

| *Range (m)* | *Spacing betweem soundings (m) @ 4knts* | *120kHz Sidescan 75° beam width* | *330kHz Sidescan 0.3° beam width* |
|---|---|---|---|
| 25 | *0.07* | 0.33m | 0.13m |
| 50 | *0.13* | 0.65m | 0.26m |
| 100 | *0.26* | 1.30m | 0.52m |
| 200 | *0.52* | 2.60m | 1.00m |
| 500 | *1.30* | 6.50m | n/a |

### Advantages

- Due to the relatively large swath produced by sidescan at lower frequencies it is possible to cover relatively large areas of the seabed in a relatively short period of time. For example, a system operating at 100kHz towed at a speed of 5 knots would allow about $3.5km^2/h^{-1}$ of seabed to be mapped at a resolution of about 1m (Kenny *et al.*, 2000).
- An almost photorealistic picture of the seabed can be generated as individual survey tracks are mosaiced together and like a photograph the raw acoustic data 'speaks for itself', which is why sidescan sonars are sometimes referred to as self-calibrating. For example, certain bedform features are instantly recognisable, such as sand ripples and rocky outcrops, before any ground truth samples are taken.
- The morphology of the features can be interpreted to reveal information on sediment transport pathways and the stability of the bed.
- The quality of the data are not affected by changes in the depth of water since the sonar fish is towed at a fixed height above the seabed at all times.

### Disadvantages

- The grey-scale (or signal amplitude) between swaths covering the same area of seabed is often noticeably different, particularly when the orientation of the sonar to the target feature varies. The variation in signal amplitude for the same area or type of seabed causes problems when trying to classify the sonograph, since ground truth samples (grabs and underwater cameras) may reveal the seabed to be composed of different sediments such as muds or muddy sands, but the difference between these is not easily identifiable on the sonograph.
- Target location using sidescan is complicated by the need to know where the fish is relative to the navigation system antennae. This has been solved by using a transmitter on the sonar which allows its position to be fixed exactly; however, this is not at present common practice. The more common approach is to calculate a layback of the towfish when using short cables and an equation for this is provided in the QA/QC section below.
- Large amounts of data are typically generated, for example a $19km^2$ survey generates about 500 megabytes of data in the form of *geotif* files (gridded at 0.2m), and at least 1 gigabyte of storage space should be available for each day of survey.
- The size of the data files also necessitates powerful computers. These have traditionally been (Unix) workstations, but increasingly dual-processor PCs are being used.

## Equipment

Like any sonar system used from a vessel at sea, the more dedicated the system is (i.e. it is configured for use on a single survey vessel and is used for the same type of operation between surveys) then the better quality of data. Systems which are 'off-the-shelf' for use on any survey vessel will not provide the same quality of data. The two configurations have been described below:

### Non-dedicated (off-the-shelf) configuration

The configuration of a typical sidescan sonar system is shown in Figure 3. It should be noted that with the advent of digital technology most sidescan sonar systems are now fully supported by proprietary software which allows the user to fine-tune parameters such as the time-varied gain whilst at sea. The inclusion of a computer to run both the system set-up and data post-processing software is now commonplace.

The last few years have seen a move by manufacturers from analogue to digital towfish for better quality data. In simple terms, in an analogue towfish, the energy returning to the towfish is converted in to millivolts, which is transferred along the tow cable to the recording device that converts the millivolts in to a digital value. The tow cable has several wires running through it (multi-core) and the data can suffer from slight degradation. A digital towfish however, converts the millivolt readings to digital values, which are transferred along a single coaxial cable to the recording device. This results in less data degradation as the data are transferred along the cable from the towfish to the recording device.

A vessel should be used that is of suitable size for the survey area. For shallow water surveys, a vessel with shallow draft, adequate cover for electronic equipment and a suitable power source should be used. It should also be big enough to deploy a sidescan sonar safely. For deeper water surveys the draft of the vessel is not an issue, but there should be enough deck space to accommodate a sidescan sonar cable winch.

It is often good practice to have a thermal recorder and digital acquisition and processing system interfaced together during data collection as this provides data backup and aids online quality assurance and control. For low budget surveys where only an overview of the seabed is required, a survey undertaken with only a thermal recorder will be sufficient. However, if more detailed examination of individual targets or mosaicing of the data are required, for example for seabed classification, a digital acquisition and processing system should be used. Particularly in shallow water, sidescan sonar data are adversely affected by poor sea conditions. To obtain good quality data it is recommended that data are not collected when the sea conditions are worse than sea state 4.

Apart from the vessel crew, a sidescan sonar system can be operated by one person trained to operate the systems involved. It is essential that the operator can determine the quality of the sidescan sonar data being collected on board the vessel and can determine that the correct amount of data has been collected from the correct place and that the navigation system is functioning correctly.

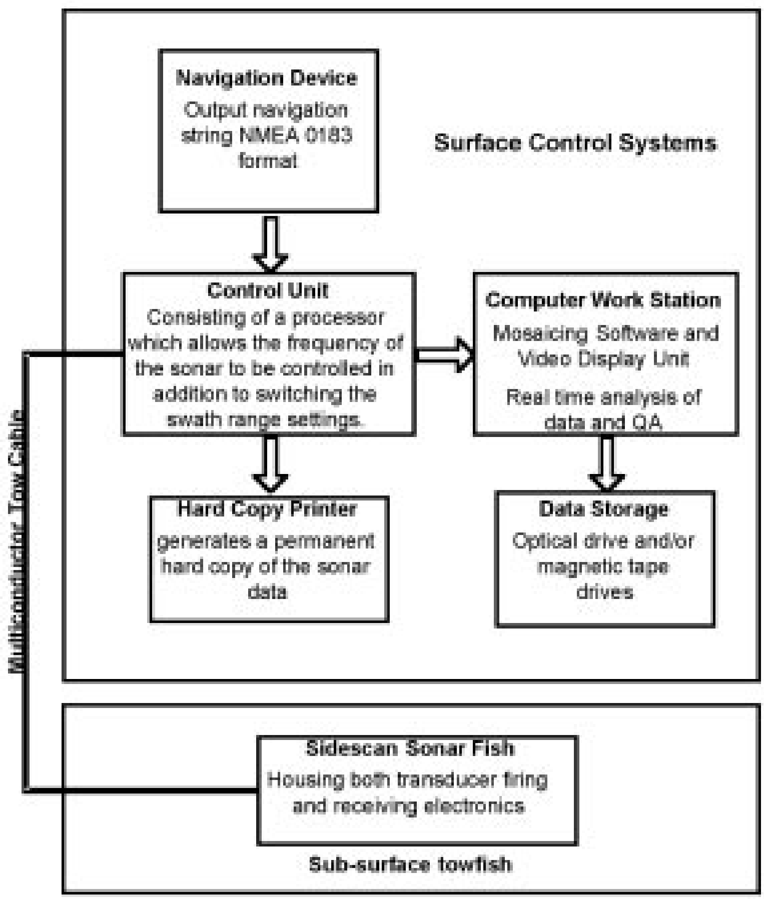


**Figure 3** Schematic diagram showing the configuration of a typical (off-the-shelf) sidescan sonar system

Specific items of a typical system are:

- Digital dual frequency sidescan sonar fish: the most commonly used are manufactured by Simrad, Kline, GeoAcoustics, EG & G and DataSonics (Figure 4).
- Depressor for the sonar; this is most useful for soft tow cables which tend to be neutrally buoyant (Figure 4).
- For inshore survey work (water depths <50m) a soft tow cable is suitable; this avoids the need for sophisticated winch systems with high slip ring specifications.
- Sonar firing control unit which may be integral with the sonograph plotter/printer and data storage system.
- Configuration and testing software installed on an appropriate computer.
- Data viewing and mosaicing software also installed on the computer.
- Survey vessel with dGPS and navigation software (e.g. Sexton, Hypack) to accurately follow planned survey lines.

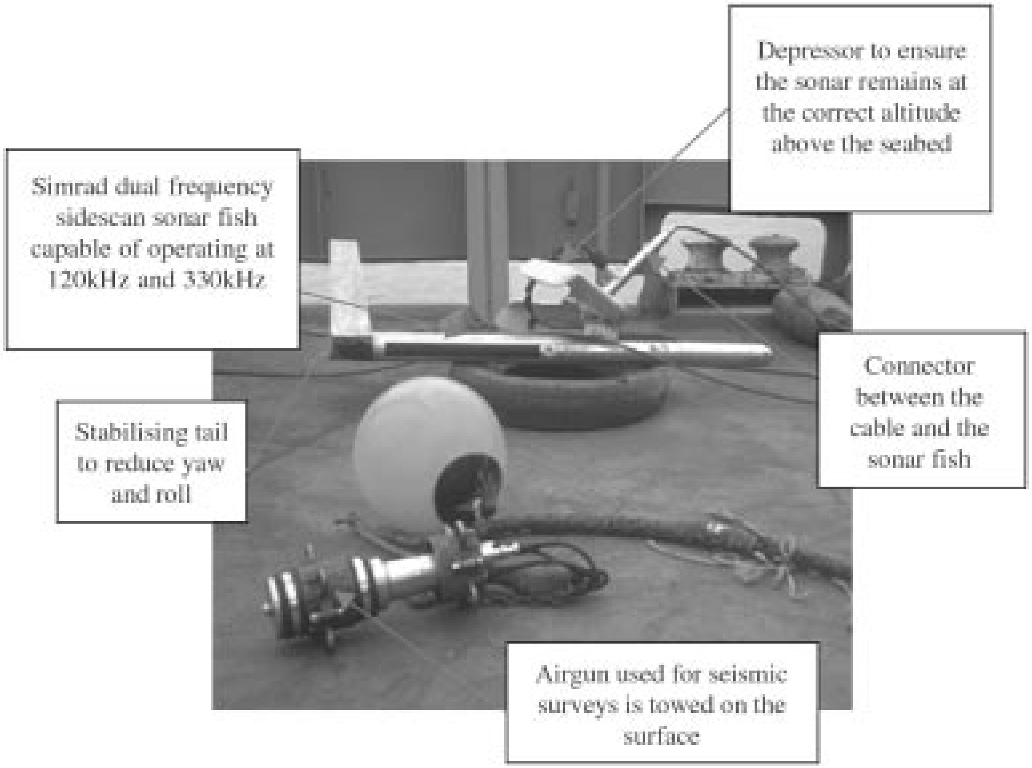


**Figure 4** Typical (off-the-shelf) sidescan sonar

## Dedicated configuration

There are a variety of sidescan sonar deployment geometries; the geometry described here is the neutrally-buoyant arrangement designed and used by the Geological Survey of Canada (Atlantic) for surveys on the continental shelf. As shown in Figure 5, a Simrad MS 992 dual-frequency sidescan sonar towfish is attached beneath a hydrodynamic buoyancy housing containing vinyl floats rated to a depth of 200m. A beacon mounted at the front of the plastic housing is the sidescan assembly component of the Trackpoint acoustic positioning system which provides range and bearing to the assembly from a transducer mounted beneath the ship's hull. This information is combined with depth data from the towfish by the shipboard navigation system, giving the latitude and longitude of the towfish. The sidescan towfish also transmits pitch and roll information. Accuracy in towfish position and attitude is necessary for correcting sidescan record distortion.

As illustrated in Figure 5, the neutrally-buoyant sidescan assembly is towed by an umbilical cable from the stern of the survey vessel. The umbilical cable is composed of two or more conductors and a Kevlar strength member, both housed in a double urethane waterproof sheath. From 10–20m from the sidescan assembly, a 120kg depressor towfish is attached to the armoured tow cable. This depressor towfish acts to isolate the sidescan system from the surface motion of the survey vessel, thus reducing sidescan assembly instability. The buoyancy package is weighted to be slightly buoyant and bow up. This results in the sidescan assembly tracking above (and behind) the depressor towfish, which is the optimum position to avoid sidescan collision with the seabed and to negate ship heave transmitted along the tow cable. A large-diameter cable block suspended from the A-frame on the stern of the survey vessel guides the tow cable to the 20 hp winch. Usually, about 600–800m of cable is available for deployment.

Two options are available for recording the sidescan system output. As illustrated in Figure 6, both a hard copy and digital version of the data are recorded by the Geological Survey of Canada. Commonly, two 11" grey scale thermal recorders are utilized, one for the 120kHz record and one for the 330kHz record. Simultaneously, the four channels of the digitised sidescan signal (port and starboard 120kHz and 330kHz) are logged in SEGY format, along with time, on digital Exabyte tape with a capacity of approximately 4 gigabytes. During post-cruise sidescan processing, the dGPS navigation data are merged with the sidescan data, based on time. Thus it is critical to synchronise the sidescan datalogger clock with the dGPS time and this is true of both dedicated and non-dedicated systems.

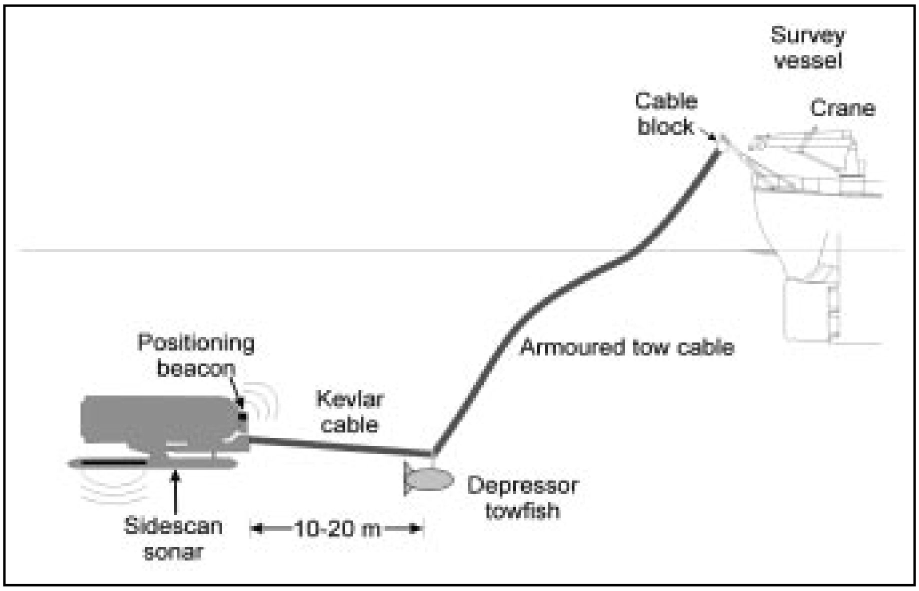


**Figure 5** Deployment of a neutrally-buoyant dedicated sidescan sonar system

# Operations at sea

## Testing

Before sidescan deployment, a rub test is done to determine the integrity of the system. The sidescan system is turned on with the gain set to maximum. The transducers are lightly rubbed by hand until a dark line appears on the paper record and/or on the monitor screen. In this manner, the system circuitry is checked and confirms that the port and starboard sidescan transducers are functioning properly. Detergent is brushed on the transducer faces to improve acoustic coupling to the water. To test that system seals are watertight and that the mechanical deployment systems are functioning properly, the towfish assembly is lowered into the water while the survey vessel is secured at the dock. The system is turned on and the record is inspected.

In addition a series of tests should be undertaken to calibrate instruments and to check equipment settings and interfacing – this is particularly relevant for non-dedicated systems. These checks may include the following:

- compass calibration
- acoustic underwater positioning system calibration
- navigation system check and calibration
- sidescan sonar navigation check (survey a known point in opposite directions)
- trial runs over the survey area to adjust gain settings; when data are recorded on thermal paper gain changes should be kept to a minimum

### System deployment

The dedicated systems tend to be more bulky than soft tow systems. In the case of the Canadian neutrally-buoyant sidescan the unit weighs about 85 kg in air, and deployment of this system from the stern of the survey vessel is a two-stage operation. A crane is used to swing the assembly over the stern (Figure 6). Once in the water, the Kevlar umbilical cable is paid out from the depressor towfish. The armoured tow cable passes from the sidescan winch through a large-diameter cable block suspended from the A-frame on the vessel's stern (Figure 6). This cable is used to hoist the depressor towfish from the deck, with the umbilical trailing over the rail, and deploy over the stern using the swinging A-frame. The system sinks slowly through the water column, so deployment is done at least a nautical mile from the start of the survey line. Retrieval of the sidescan system is the reverse of this process. Lifting loops attached to the umbilical enable the crane to hoist the system from the water.

For the soft tow system the towfish is gently lowered into the water by hand and the umbilical is paid out sufficiently to ensure that any drive-train noise is minimised and the altitude above the bed is suitable.

### System tuning (fish stability, height, position)

Fish stability is of paramount importance in reducing or eliminating artefacts in sidescan sonar records (see QA/QC section). Each of the four forms of towfish instability (heave, roll, pitch and yaw) produces characteristic artefacts, or distortions, on the sidescan record which can sometimes be misinterpreted as real data. Stability of the neutrally-buoyant sidescan system is maintained even when the sea state is unsafe for the survey vessel. Sidescan systems which do not decouple fish and ship motion to the same extent as the neutrally-buoyant system will be adversely affected even at relatively low sea states and this tends to be a problem of the non-dedicated systems.

### Survey design

The standard survey speed on most multiparameter surveys (i.e. sidescan, seismic, and other geophysical survey tools) is about 4 knots (7.4 km $hr^{-1}$). Note that 2.5 knots is the optimum survey speed for many high-resolution sidescan systems, providing an along-track horizontal resolution of 7cm. However, at this speed many survey vessels cannot maintain an accurate heading, and seabed coverage is slow, whereas the horizontal resolution at 4 knots is about 15cm. Enough cable is paid out to allow the sidescan towfish to fly at a height of between 10 and 20m off the seabed (generally 25% of the horizontal range setting). For benthic habitat mapping, short ranges are used (100m or less) which allow relatively small objects to be detected. For seabed reconnaissance, individual survey lines are collected over a broad area. In mosaic mode, a pattern of survey tracks is run at a specific line spacing. The line spacing is less than the swath width (i.e. twice the range) of the sonar so that range overlap occurs. This design ensures that the area of seabed being surveyed is completely insonified and that the loss of resolution at the outer limit of the range is compensated for. As a rule of thumb, in areas of relatively smooth seabed, a line spacing of between 75% and 50% of the swath width will provide the necessary overlap.

## Record interpretation

A basic understanding of how the sidescan record is generated is essential in order to understand how to interpret the record.

Figure 6 summarises how the intensity of the returning echoes is influenced by the shape and density of the seabed (or objects). The returning echoes from one pulse are displayed on the recorder as one single line, with light and dark portions of that line representing strong or weak echoes relative to time. There are many variables which will affect the sonar data, such as waves, currents, temperature and salinity gradients, and some examples of how specific sonar interference is manifested in the record are given in the QA/QC section.

Whilst there are efforts to make sidescan sonar interpretation an objective semi-automated process, the interpretation remains very much a qualitative analysis. As indicated in Figure 4 there are two important attributes of the seabed that will affect the intensity of grey-scale in the sonograph:

(1) The material properties of the substrata. This will determine the acoustic reflectivity of the seabed. For example, rock, cobbles and gravel are better reflectors than sand or mud and will therefore show up darker on the sonograph.

(2) The shape of the seafloor (or topography). Up slopes facing the towfish are better reflectors than down slopes.

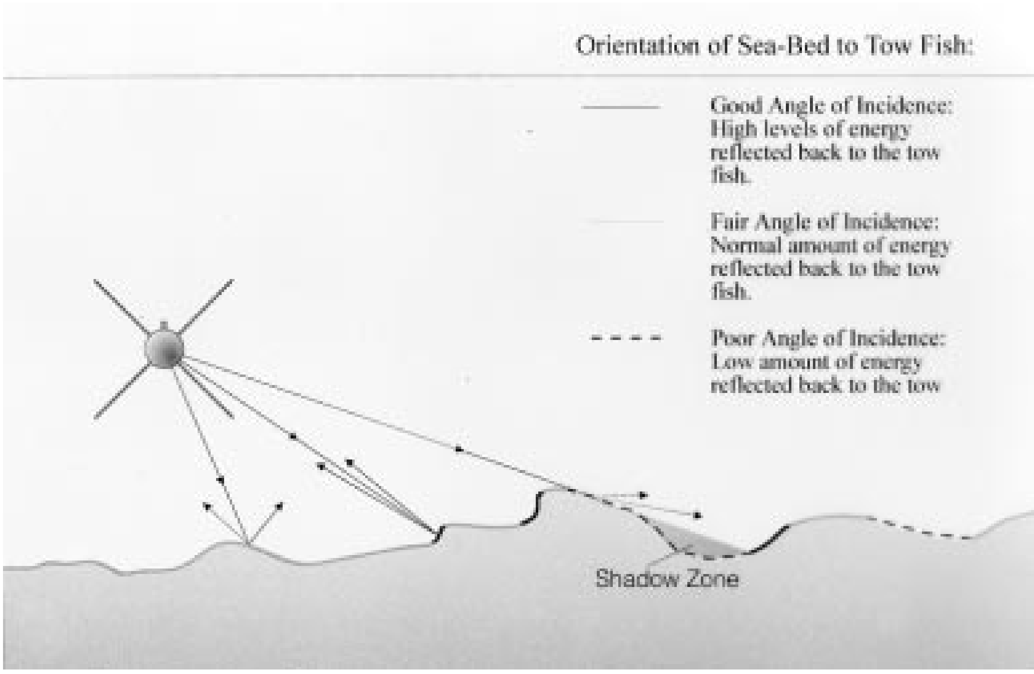


**Figure 6** Schematic of sidescan return echoes

Since material reflectors and topographical reflectors often produce the same result on the sonograph it is up to the operator to interpret the image carefully in order to determine the actual composition of the seabed. Shadows are the single most important feature of sidescan sonographs since they provide the three-dimensional quality to the two-dimensional image. Shadows are therefore of extreme importance and the interpreter relies on their position, shape and intensity to accurately interpret most sonar records.

The height of objects on the bed can also be determined from the record. For example, using the following equation the height of a target can be calculated:

$$H_t = \frac{(L_s \times H_f)}{R}$$

Where $H_t$ is the height of the target (m), $L_s$ is the length of shadow cast by the target (m), $H_f$ is the height of the fish above the seabed (m) and $R$ is the distance (m) along the hypotenuse between the towfish and the end of the shadow cast by the object.

In general, for data collected with an analogue thermal recorder only, features of interest should be plotted on a trackplot for the survey. The same features identified from data collected on adjacent survey lines should be compared to check that position calculations are correct. Any other data that may enhance the interpretation, such as field notes, bathymetry data, seismic data, sediment distribution information and Admiralty Charts should also be collated and compared with the sidescan sonar information. From this a plan of seabed features and/or sediment distribution can be drawn.

Data collected digitally should be played back several times until the optimum settings for gain and bottom track threshold have been determined to create a good sidescan sonar mosaic. The data should then be mosaiced, ensuring that correct slant-range correction and layback calculations are applied. Any features of particular interest identified can be magnified and further enhanced if required. Most sidescan sonar processing software will allow other information to be overlaid to enhance the sidescan sonar images and mosaics. It should also allow for annotation of the processed data so that objects and sediment types can be labelled and mapped out.

# QA/QC

Like any other type of acoustic system sidescan sonar is susceptible to interference from a number of sources, but with experience most of these can be recognised in the data. The sources of error to watch out for areas follows:

- Survey vessel drive train noise. This is less obvious than direct propeller noise and appears as faint regularly spaced dark lines in the record (Figure 7). The most common cause of this is when the sonar is too close to the vessel (typically <50m), and simply increasing the horizontal distance between the towfish and the vessel will often eliminate the noise.

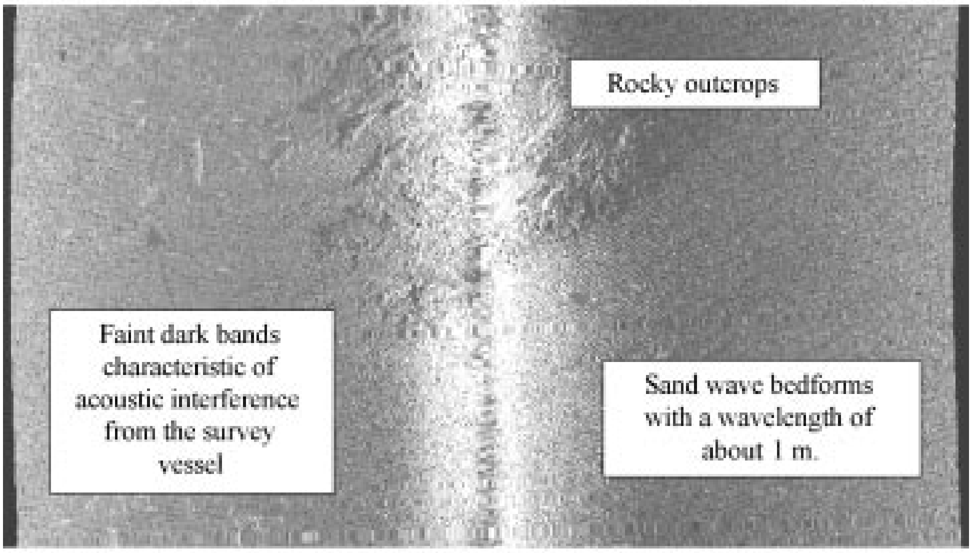


**Figure 7** Surface vessel drive-noise

- Navigation drop-out of signal will give rise to errors in the speed correction of the record causing distortions. Depending on the system this may be evidenced by areas of no data in the record or as interpolated bands as shown in Figure 8.

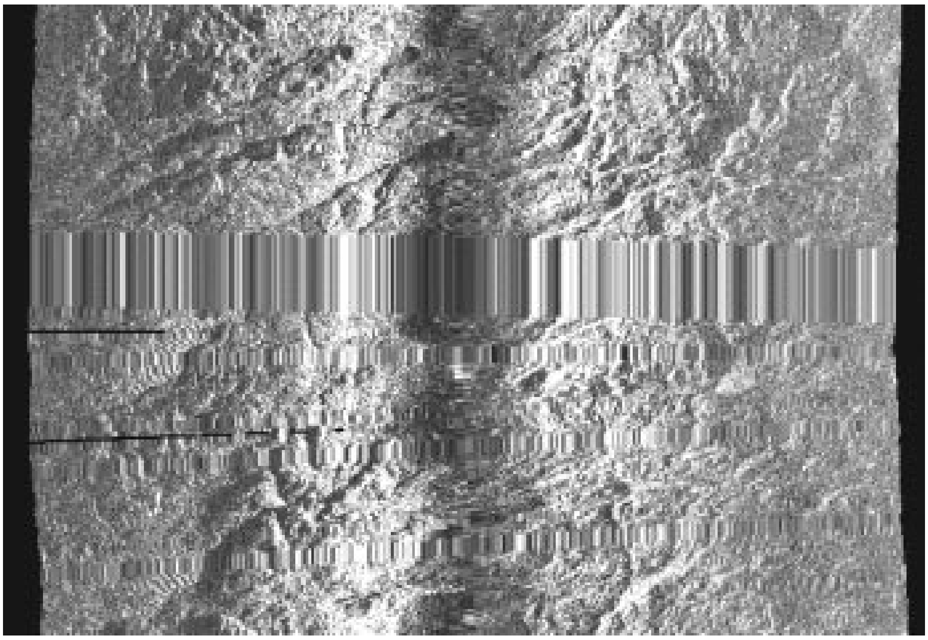

**Figure 8** Navigation drop-out

- Interference may also be caused by schools of fish or a porpoise, as illustrated in Figure 9, which shows the body undulations travelling in the direction of the sonar.

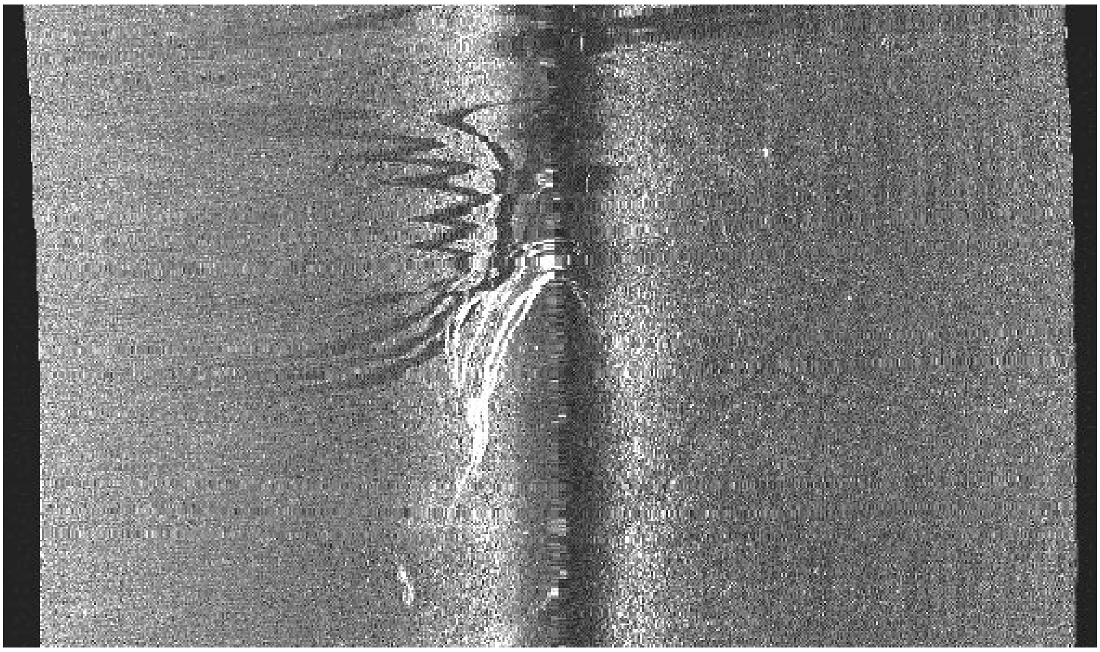

**Figure 9** Interference caused by a porpoise

Other significant effects are caused by changes in seawater temperature and waves. In Figure 10, wave effects are evident as dark banding across the sonograph; note how the effect is more apparent towards the centre line of the record. Banding due to acoustic interference tends to be more evident towards the edge of the sonograph.

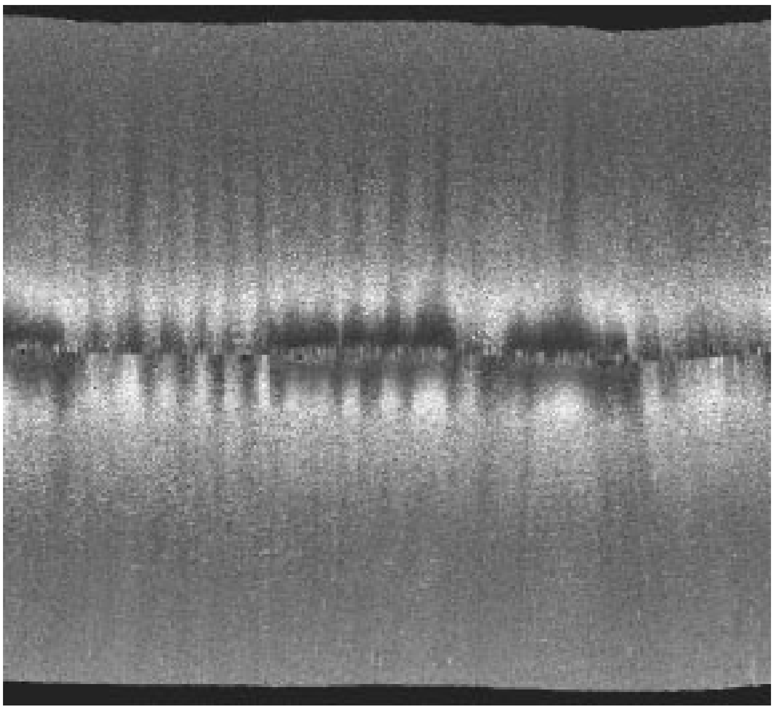

**Figure 10** Interference caused by heave on the towfish as a result of waves

For soft tow systems an estimate of towfish layback should also be calculated using the following equation:

$$L = 2\sqrt{(C^2 - D_f^{\,2})}$$

This does not take account of the catenary effect which lessens the lay back, but this becomes more of a problem for long cable deployments. In the equation, *L* is the layback, *C* is the amount of in-water cable and $D_f$ the depth of the towfish.

Good quality survey and data processing logs should be maintained throughout a sidescan sonar survey. All equipment settings and offsets used on the survey vessel should be logged. The survey logs should also include information such as the time of start and finish of each survey line and the vessel heading, even though these data are normally logged in the navigation software. These logs will allow the navigation data to be cross-checked and enable the data processor to correctly process the data and quickly find any faults.

## Data products

From thermal records a seabed feature and/or sediment distribution plan is typically produced. These should be annotated with information on the dimensions of targets such as sand waves. This may be augmented by images showing features of interest that have been scanned in to a computer and added to the plan(s).

Typical output from digitally collected data may include the following:

- mosaic of data annotated with features of interest, supplied as both a paper chart and in digital format correct for insertion into a GIS system (*GeoTiff* files)
- magnified and enhanced images of particular features of interest supplied both in paper and GIS compatible format
- plan of sediment type distribution supplied as a hard copy chart and in GIS compatible digital format.

## Health and safety

The survey vessel must be seaworthy and suitable for the type of survey work to be undertaken. The crew should be suitably qualified and familiar with sidescan sonar survey operations.

All personnel on the vessel should be made aware of the vessel safety procedures and should be aware of the dangers involved in sidescan sonar surveys in particular. Apart from normal dangers involved in being at sea on a vessel the personnel should be aware of the following:

- The towfish may become snagged on underwater structures, endangering any person near the tow cable and perhaps endangering the vessel itself.
- Most sidescan sonar systems use 110 or 240 volts mains systems, which can be dangerous if misused, particularly when in close proximity to water.
- Care must be taken when deploying and recovering a towfish from the water and personnel involved in this procedure should wear the correct safety gear.
- Some parts of a sidescan sonar system are heavy.

## References

Kenny, A *et al*. (2000) An overview of seabed mapping technologies in the context of marine habitat classification. ICES Annual Science Conference September 2000: Theme session on classification and mapping of marine habitats. Paper CM 2000/T:10.

### Sources of further information

Open Seas Instrumentation Incorporated: **www.openseas.com**
Theory of interferometric sonar: **www.submetrix.so.uk**
Handbook of seafloor sonar imagery: **www.soc.soton.ac.uk/chd/bridge/research/interp.html**
Multiparameter approach to nearshore seabed mapping: **www.pgc.nrcan.gc.ca/marine/intro.htm**

## Acknowledgements

The neutrally-buoyant sidescan sonar system was designed and built by personnel of the Geological Survey of Canada (Atlantic). We thank Austin Boyce, Borden Chapman and Tony Atkinson for their assistance in preparing this material. The system is commercially available from Open Seas Instrumentation Incorporated (www.openseas.com) as the STABS™ (Sidescan Towed Acoustic Body System).

# Procedural Guideline No. 2-2 Sediment profile imagery

Brendan O'Connor[1]

## Background

Sediment Profile Imagery, or SPI, is an innovative and cost-efficient method of surveying and/or monitoring marine aquatic environments with a view to establishing the environmental status of these habitats or as part of a site inventory study. The traditional method of sediment sample collection and subsequent laboratory analysis is time-consuming and expensive and the time taken to return the data is slow.

SPI is based on single lens reflex (SLR) camera photography and computer-based image analysis which greatly accelerates the data acquisition. The camera system consists of a wedge-shaped prism with a plexiglas face plate; light is provided by an internal strobe (Figure 1). The back of the prism has a mirror mounted at a 45 degree angle to reflect the profile of the sediment-water interface up to the camera, which is mounted horizontally on the top of the prism. The prism is filled with distilled water, and because the object to be photographed is directly against the face plate, turbidity of the ambient seawater is never a limiting factor.

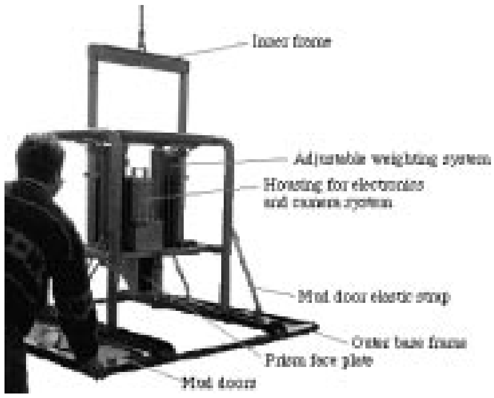


**Figure 1** A remote operated SPI system

The camera prism is mounted on an assembly that can be moved up and down by producing tension or slack on the winch wire. As the camera is lowered, tension on the winch wire keeps the prism in the 'up' position until the support frame hits the bottom. At this point the tension on the winch wire is reduced causing the inner frame to move to the 'down' position, penetrating the undisturbed sediment water interface. The upper 25cm of the seafloor, as seen in profile, is then photographed in high resolution with a film camera. To this basic system, it is possible to add an additional camera which also photographs the sediment surface before the prism penetrates the sediment.

After each image is taken, the camera is raised two or three metres off the bottom and redeployed for taking another image ('sample'). Typically, a number of replicate images are taken at each station within a period of about five minutes. An array of other measurement devices may also be attached to the frame to efficiently obtain information about water column properties (e.g. salinity, temperature, oxygen).

## Purpose

- to identify different seabed types and redox status (in relation to organic enrichment gradients)
- to identify sediment type and bed forms
- to identify habitat quality (in relation to physical disturbance and deoxygention)

1 Aqua-Fact International Services Limited, 12 Kilkerrin Park, Liosbaun Road, Galway, Ireland.

### Advantages

- rapid deployment whether by diver or boat
- permanent images of the sea bed profile
- no physical sample analysis required
- turn-around to report very rapid

### Disadvantages

- only works on mud or muddy sand sediments without subsurface obstructions
- samples not available for identification of fauna or sediment particle size (ground truthing or quantitative analysis)
- sediment may smear on faceplate and make interpretation difficult
- equipment may flood

## Logistics

### Equipment required

*Sediment profile camera*: This can be diver held or remotely operated on a frame lowered from a boat. Ideally, the surface of the sediment should also be photographed using a separate camera (by the diver) or a camera mounted on the remotely-operated frame before it touches the seabed.
*Survey vessel*: A vessel with lifting equipment is required, preferably an A-frame at the stern, with suitable winch gear.

### Personnel

- full diving team if diver operated
- appropriate boat and crew

## Method

### Survey brief

Deploy the SPI camera to penetrate the sediment, ideally to a minimum of two-thirds the height of the face plate but not above the top of the face plate (Figure 2). Take three separate (replicate) images at the required stations (stations along a transect, locations in an area). If over- or under-penetration is noted from the first deployment, the weights should be adjusted accordingly.

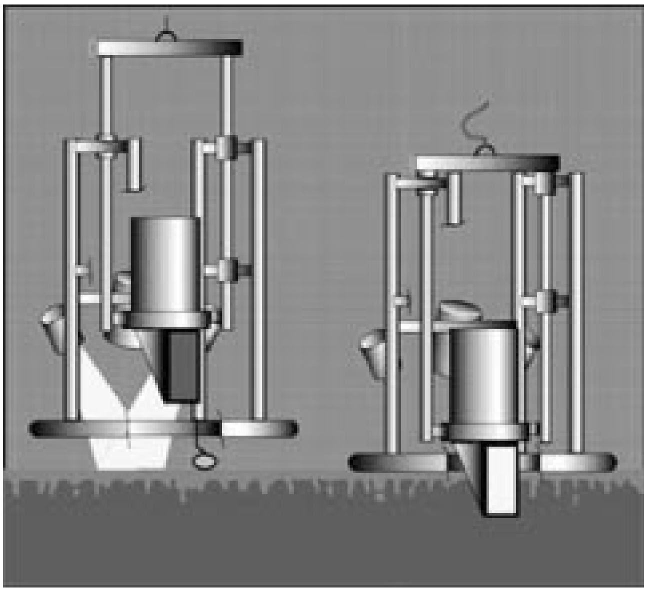

**Figure 2** Drawing of SPI. *Left*: a lead first hits the bottom and triggers a camera which takes a photo of the undisturbed sediment surface. *Right*: the prism penetrates the sediment and a profile image of the sediment is being taken.[2]

## Field

Usually three penetrations are used per sample station to obtain a mean depth for the redox discontinuity layer. This also makes it possible to obtain information on heterogeneity so that simple statistics can be performed (mean and standard deviation for depth of penetration, number of gas vesicles present, mean redox discontinuity depth).

## Laboratory

SPI technology can readily quantify over 20 physical, chemical and biological parameters, including: sediment grain size; prism penetration; surface pelletal layer; sediment surface relief; mud clasts; redox area; redox contrast; current apparent redox boundary; relict redox boundaries; methane gas vesicles; apparent faunal dominants; voids; burrows; surface features (e.g. worm tubes, epifauna, shell); dredged material; microbial aggregations; and successional stage.

2 Image and caption taken from **http://www.marecol.gu.se/projengl/hansnilssonpen.html** – Hans Nilsson, Gothenburg University.

## Data analysis

**Figure 3** In this image there is a high abundance of burrowing marine worms, most likely Capitellid Polychaetes like *Capitella capitata or Malacoceros fuliginosus.* These opportunistic worms thrive in high organic loading conditions and their burrowing action can often reintroduce oxygen into depleted sediments.

Photographs are analysed to extract the depth of penetration, redox discontinuity level and voids (number and size of vesicles, presence and absences). Improved interpretation of photographs can be obtained by using computerised image analysis (digitisation and enhancement). The exact analyses will depend on the type of information required. More detailed descriptions are presented at **http://www.aquafact.ie/SPI2.html** and **http://www.courses.vcu.edu/ENG-esh/diaz/diaz_services.htm**.

## Accuracy

Depends on number of replicates, qualitative assessment to phi value possible. Species identification, however, is very limited.

## Time required

### Field

About 30 stations a day from a boat. A diver could sample 10 stations with 3 images at each, along a transect.

### Laboratory

Each enhanced image takes approximately 5 minutes to analyse.

## Health and safety

All appropriate requirements for diving or boat-based remote sampling. No additional safety requirements are necessary.

## References/further reading

Germano, J D (1983) High resolution sediment profiling with REMOTS camera system. *Sea* Technolog,y **24(12)**, 35–41.

Grizzle, R E and Penniman, C A (1991) Effects of organic enrichment on estuarine macrofaunal benthos: a comparison of sediment profile imaging and traditional methods. *Marine Ecology Progress Series*, **74**, 249–262.

Nilsson, H C and Rosenberg, R (1997) Benthic habitat quality assessment of an oxygen stressed fjord by surface and sediment profile images. *Journal of Marine Systems*, **11**, 249–264.

O'Connor, B D S, Costelloe, J, Keegan, B F and Rhoads, D C (1989) The use of REMOTS technology in monitoring coastal enrichment resulting from mariculture. *Marine Pollution Bulletin*, **20***(8)*, 384–390.

Rhoads, D C and Germano, J D (1982) Characterisation of organism-sediment relations using sediment profile imaging: an efficient method of remote ecological monitoring of the seafloor (REMOTS system). *Marine Ecology Progress Series*, **8**, 115–128.

Rumohr, H and Schomann, H (1992) REMOTS sediment profiles around an exploratory drilling rig in the southern North Sea. *Marine Ecology Progress Series*, **91**, 303–311.

### Address for further information

Aqua-Fact International Services Limited, 12 Kilkerrin Park, Liosbaun Road, Galway, Ireland. Tel: +353 91 756812/756813; Fax: +353 91 756888; e-mail: **aquafact@iol.ie**

For a description of the equipment and its deployment, see **http://www.courses.vcu.edu/ENG-esh/diaz/diaz_services.htm**

# Procedural Guideline No. 2-3 Undertaking a physical survey of littoral and sublittoral sea caves

Caroline Turnbull, Joint Nature Conservation Committee[1]

## Background

Sea caves are listed on Annex I of the Habitats Directive and SACs have been designated around the British Isles citing them as features. Both intertidal and subtidal habitats need to be monitored and assessed in order to report to the European Commission on the condition of the feature. Assessment and monitoring of the dimensions of the feature are a key attribute in achieving this and provide a structure by which to arrange biological survey data.

## Purpose

(1) To provide detailed sketch maps which can be used to relocate the features in subsequent years for monitoring biological attributes.
(2) To provide an accurate scale diagram of each individual cave to provide a backdrop for the mapping of biological attributes.

## Logistics

### Equipment

*General*

- pitons
- two fibreglass or metal measuring tapes
- calibrated compass (not a sighting compass)
- waterproof paper
- day-glow tags
- white paint
- hard hats with chin strap
- head lamp + two extra reliable light sources
- sturdy clothes and shoes
- GPS unit
- clinometer
- levelling equipment, e.g. theodolite or cross staff
- elbow- and knee-pads – recommended

*Specific to sublittoral caves:*
- standard SCUBA equipment
- line and reel
- surface marker buoys

1 Monkstone House, City Road, Peterborough. PE1 1UA

### Personnel

Minimum of two people for surveying of whom at least one must be able to use a compass confidently. Caves must never be entered alone. The drafting of diagrams needs only one person.

## Method

The following methods are taken from Environmental and Resource Technology Ltd (2000).

### Marking the location

Draw a clear sketch of the location of the cave in relation to its surroundings. Take two bearings from the cave to two separate fixed positions to help with relocation. Take a GPS reading if possible and record the co-ordinates and the projection they are given in. Note the position of the cave on an Ordnance Survey map and take a note of the grid reference. If appropriate, mark the entrance to the cave with a small dash of white or fluorescent paint. A submerged cave once located may be marked with a buoy but this should only be left unattended when it is judged safe to do so and you are returning within the same day. It is not recommended that buoys are left for long periods since they can be a hazard to maritime traffic.

### Establishing reference lines

Cave walls are referred to side 1 (left side when looking into the cave) and side 2 (right side when looking into the cave).

Each reference line should be fixed in the side wall of the cave as close to the floor as possible. Hammer pitons into crevices, or drill a hole and then fix a piton using a rawlplug. Start the first reference line as close to the cave entrance as is convenient on side 1. Attach a measuring tape to the first piton and unwind it towards the rear of the cave keeping it close to the wall and taut. Where the wall changes direction (known as a node) attach pitons and affix the tape to them to aid it in keeping close to the wall. To minimise the impact on the environment, only place pitons at nodes when they are needed to hold the tape in. Place the reference line down the length of side 2 in the same way and join both tapes at a common node at the back of the cave if the cavity terminates. Mark the pitons with day-glow tags to aid relocation – these must be removable at the end of the survey. The pitons should remain if possible to aid with subsequent surveying work.

#### *Recording cave dimensions*

- Along both sides, starting at node 1, take and record a compass bearing from each node to the next. Also record the distance in metres of each node along the marker tape. Take bearings to the nearest degree.
- Measure cave widths from side 1 only. From each node on side 1, measure and note the distance and bearing across the floor to a recorded point on side 2 (either a node or a noted distance along the tape).
- At each node on both sides, measure and record the height from the floor to the reference line.
- At each node, measure (if possible) or estimate the vertical distance from the floor to the maximum ceiling height.
- Draw a plan view of the floor indicating the position of the reference line tapes, nodes and pitons. Also note major substratum types and discontinuities along the floor on the same plan view.
- On both sides describe the wall profile from floor to maximum height in terms of inclination, i.e. vertical, sloping or overhanging, with estimated heights and clinometer measurements.
- At intertidal sites, determine the height of the cave on the shore (to side 1, piton 1, or to the surface of a rock pool in the entrance) by levelling. Also draw a profile of the cave floor by levelling inside the cave.

For further information please refer to Environmental and Resource Technology Ltd (2000) or Ellis (1988).

# Data analysis

A plan view and side 1 and side 2 elevations of caves can be drawn from the dimensions and compass bearings taken during fieldwork (Figures 1 and 2 for examples). In addition, the length to width and length to height ratios can be calculated, which give an indication of the overall form or proportions of the cave.

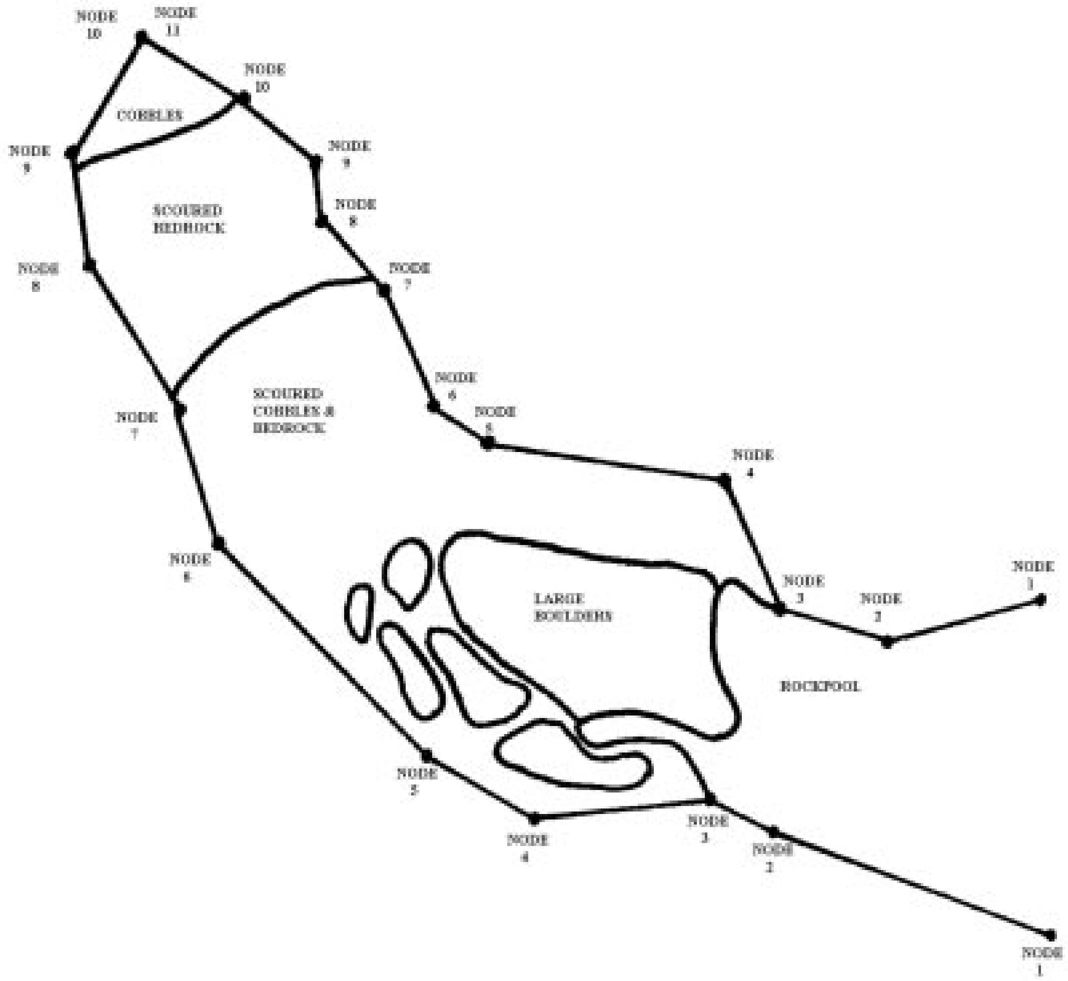


**Figure 1** Plan view of a sample cave showing the labelling of nodes and substrate types

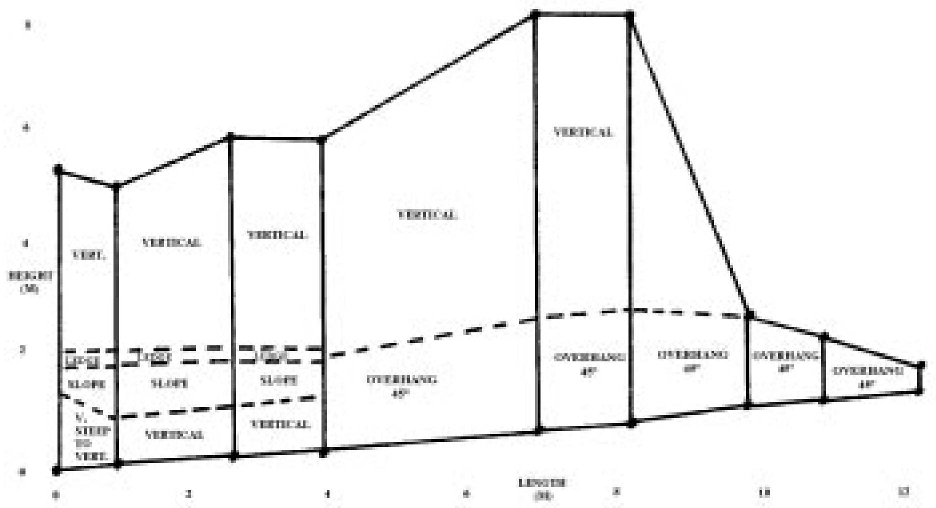


**Figure 2** Sample diagram of a cave wall showing changes in elevation and placement of nodes

## Accuracy testing

When possible, drawings should be validated by a co-worker with an understanding of the methodology.

## QA/QC

Check before leaving for survey work that there are sufficient pitons and length of measuring tape for a range of cave sizes and complexities. Also ensure that all other relevant equipment is present and in working order.

Use local guides or detailed maps to find the correct location of a cave before commencing surveying. This is especially important for sublittoral caves which can be hard to find without specialist local knowledge

The location of the cave should be recorded along with the projection or geographical coordinates used, e.g. OS grid or latitude and longitude. All locational information should be stored in a safe place with shared access so as to aid returning surveyors in subsequent years.

When laying the reference line ensure that the measuring tape is kept taught and does not stretch, so as to maximise the accuracy of the measurements.

It is worth noting that the minimum survey standards required by the British Cave Research Association and the Australian Speleological Federation are a survey using a compass and tape traverse, direction recording with a calibrated compass, vertical angles recorded with a calibrated Abney level or similar clinometer, and distances measured using metallic or fibreglass tape or tacheometry. This is especially important if details of the survey are to be disseminated for wider use than purely monitoring work.

Always specify which units the cave will be measured in – they should be SI units, i.e. length in metres or centimetres and plane angles in degrees. A suitable scale should be used and noted on the diagram. The ratio of 1:200 is regarded as the common standard scale by speleological groups.

Ensure that drawings and measurements are correctly transposed from field notes and that the positions of the nodes are accurately recorded.

## Data products

- plan and elevation views of caves
- records of substrates present
- cave length to height and length to width ratios

Cave dimensions can be entered into cave surveying software which can generate 3D images of caves. For further information please refer to the following websites:
**http://members.aol.com/caverdave/CPHome.html** – Cave Plot homepage
**http://therion.homepage.com/** – Therion homepage
**http://www.survex.com/** – the Survex Project

# Cost and time

Individual surveys should only take half a day to execute and require teams of at least two people for both littoral and sublittoral caves. Equipment for surveys may require some investment to provide the more technical pieces such as a clinometer or theodolite. There are also boat costs and diving equipment to be considered when surveying sublittoral caves.

The checking, verifying and drafting of cave plans should only take a few hours so long as the individual is familiar with interpreting compass bearings and able to scale the measurements correctly. The task should not require specialist staff unless there is a substantial cave complex with many changes in inclination, etc.

# Health and safety

Personnel working in caves must never work alone and must wear appropriate safety equipment as outlined in the equipment section. Caves are dangerous, and those surveyed for monitoring purposes are unlikely to have been made safe by local authorities. Therefore, care must be taken when entering a cave for the first time and note taken of overhead hazards and the possibility of falling rock.

In addition to this, littoral sea caves are likely to have slippery rock surfaces due to the presence of algae, and extra care must be taken when moving around. Considerable care must particularly be taken in remote areas where tidal immersion could occur before emergency assistance arrives. Field staff should carry a radio/mobile telephone to ensure the emergency services are notified promptly.

Surveying of sublittoral sea caves will involve SCUBA diving techniques. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[2] and must follow the Scientific and Archaeological Approved Code of Practice.[3] Divers may require specific training in cave-diving procedures to ensure their safety when surveying caves.

# References

Environmental and Resource Technology Ltd (2000) *Establishing a monitoring programme on caves in Berwickshire and north Northumberland cSAC.* Unpublished report to the UK Marine SACs project. English Nature, Peterborough.

## Further reading

Ellis, B (1988) *An introduction to cave surveying.* British Cave Research Association.

## Related websites

**http://www.bcra.org.uk** – British Cave Research Association
**http://www.bcra.org.uk/csg** – British Cave Research Association cave surveying group
**http://rubens.its.unimelb.edu.au/~pgm/asf/stdsurv.html** – Australian Speleological Federation Cave Survey and Map Standards
**http://www.sat.dundee.ac.uk/~arb/speleo/spfseminar96/survey.html** – Expedition surveying guide

2 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7 See: **http://www.hse.gov.uk/spd/spddivex.htm**

3 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997.Approved Code of Practice and Guidance - L107. HSE Books 1998. ISBN 0 7176 1498 0. See: **http://www.hse.gov.uk/spd/spdacop.htm - a**

# Procedural Guideline No. 3-1
# *In situ* intertidal biotope recording

Gabrielle Wyn and Paul Brazier, Countryside Council for Wales[1]

## Background

CCW has been engaged in a programme of survey and mapping of biotopes in the intertidal zone around Wales since 1996. This programme was initially stimulated by the EC Habitats Directive SAC designation requirements , since implementation of the directive in the UK requires that appropriate adjacent intertidal land must be notified as a Site of Special Scientific Interest (SSSI) before it can be included as part of an SAC.

Monitoring and surveillance using intertidal mapping techniques on rocky shores was trialed in Pembrokeshire following the *Sea Empress* oil spill (Bunker and Bunker 1997). In this work, biotopes were described spatially and boundaries determined. Bunker (1998) concluded that although intertidal Phase 1 mapping was not originally designed for surveillance or monitoring, the mapping and recording of observations on biotopes can have a useful role in surveillance and, additionally, in the planning of monitoring strategies.

The resolution of intertidal mapping (on which this procedural guideline is based) lies between Phase 1 terrestrial mapping (JNCC 1993) and Marine Nature Conservation Review (MNCR) Phase 2 marine survey methodologies (Hiscock 1996). During intertidal mapping, surveyors walk along the shore in order to identify and map the extent and distribution of biotopes.[2] Biotope identification is carried out in the field and, in addition, species lists are taken where necessary. The technique has been developed to enable rapid survey of the coastline (average 0.17km$^2$/hr for a pair of surveyors).

The survey technique outlined below was developed as part of the UK Marine SACS Project and tested in the Mawddach Estuary, west Wales. Biotopes were identified at designated sampling points laid out in a 200m grid over the site because of the inherent problems associated with repeatable boundary determination in those communities. The scale of the grid was set so that all the major biotopes in the estuary (those biotopes that make up a substantial proportion of the site and are important to the feature) would be visited five times, and all the minor biotopes (those biotopes that are locally rare or, though otherwise important, are not adequately covered by the grid) were visited twice.

## Purpose

The strategy outlined here has been designed to provide a means of measuring certain attributes, with consideration of the scale and resolution at which Phase 1 survey can be achieved. The grid sampling strategy provides sufficient distributional information on biotopes to be able to draw conclusions about the following:

- distribution of selected biotopes/biotope types throughout a site
- relative proportion of selected biotopes/biotope types throughout a site
- presence/absence of selected biotopes/biotope types throughout a site

### Advantages

- a rapid method for monitoring certain attributes of a site
- no expensive or specialist survey equipment required

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2 A fuller description of this methodology can be found in the *CCW Handbook for Marine Intertidal Phase 1 Survey and Mapping* (Wyn *et al.* 2000), and summarised in Procedural guideline 1-1.

- an inexpensive and straightforward method for monitoring certain attributes of a site representing a fraction of the costs of more detailed Phase 2 survey
- no expensive post-survey species identification and data analysis required
- no assumptions made about the accuracy with which biotope boundaries are marked or about the stability of biotope boundaries over time

### Disadvantages

- resolution of *in situ* recording may be inadequate for some monitoring objectives
- no quantitative samples taken that can be re-examined at a later date
- depending on the monitoring objectives and survey strategy, some habitats or biotopes may be overlooked without initial, more detailed baseline survey of the monitoring area
- no map with accurate boundaries can be drawn from the data

## Equipment

The following are required in the field:

- clipboard
- map of site with grid points and their co-ordinates marked
- waterproof survey forms, rubber and sharpener
- Ordnance Survey map
- laminated MNCR biotope manual
- collecting equipment for voucher specimens (small pots and labels)
- camera (weather-proof)
- safety equipment including mobile phone, PPE (including a dry suit), first aid kit, and flares
- tide tables
- spade and 0.5mm mesh sieve for sediment shores
- differential/non-differential GPS

Further equipment required for post-survey analysis includes simple word-processing and spreadsheet software packages.

### Personnel/time

*The minimum survey team requirements are for:*

- two staff (for safety reasons); of whom
- both need to be experienced intertidal surveyors familiar with the application of the biotope classification to the intended survey locality.

## Method

An evenly spaced grid of sampling stations is set up across the site from high water springs down to low water springs; this process is a simple operation for a Geographical Information System. If an existing biotope map is a available, the grid can be scaled to allow for at least five sampling stations on each of the major intertidal biotopes (from Connor *et al.* 1997).

Prior to the survey a risk assessment is completed, information is gathered on times and height of tides, and a map and table of the locations of the grid sample stations on the site are prepared. Access points, land ownership and local knowledge of the conditions on the site must also be collated.

The survey should begin at least two hours before spring tide low water (daylight permitting). This provides a sufficiently long time in which to work. The actual route taken across a site depends upon the topography and the tidal regime that exists at that site. Each intended grid sample station is located

3 See Procedural guideline 6-1.

using a differential Geographic Positioning System (GPS) accurate to within 1 metre.[3] The sample station number, GPS position, habitat and biotope details are recorded on a standard pro forma for each sample station. Different habitat types are surveyed as follows:

- *Sediment biotopes*. These are sampled within $1m^2$ of the grid station and sieved *in situ*. This involves collecting two spade loads (approximately $0.02m^2$) of sediment, dug to a depth of 20–25cm and sieved through a 0.5mm mesh sieve. At some sample stations it may be necessary to repeat where infauna are scarce. Species present and their abundance are recorded. Specimens are taken of species that are considered important to identify the biotope and not identified in the field. These are subsequently identified in the laboratory. For conspicuous species such as bivalves and *Arenicola marina*, it is straightforward to count the number of individuals per $m^2$. For bivalves such as *Macoma balthica* this will involve digging over $1m^2$ (or $0.1m^2$ if there are high densities). The presence of *Cerastoderma edule* can be gauged by dragging the tip of a spade through the surface of the sand and 'feeling' the shells immediately below the surface. For *Mya arenaria* and *Scrobicularia plana* surface siphon holes per $m^2$ are counted. For *A. marina* surface casts per $m^2$ are counted.
- *Rock and mixed biotopes*. The species found and their abundance are recorded within $1m^2$ of the sample station and a biotope code assigned using the Marine Biotope Classification for Britain and Ireland.[4]
- *Saltmarsh grid points*. Grid points falling within higher and pioneer saltmarsh communities are sampled in one of two ways. If the $1m^2$ around the sample station contains more than 5% cover of saltmarsh plants then it is classed as saltmarsh and the epifauna/floral species, their abundance and percentage cover are recorded but the sediment infauna are not sampled. If, however, the $1m^2$ contains less than 5% cover of saltmarsh plants the infauna and surface species are recorded as for other sediment biotopes. In all cases, the abundance and % cover of saltmarsh species is recorded. The distinction above is necessary in order to ensure consistency of recording in a time series, i.e. 'saltmarsh' is still the same entity from one monitoring episode to another. There does not appear to be clear guidance on this within the NVC classification for coastal vegetation communities (Rodwell 2000).
- *Submerged sample stations*. Due to the dynamic nature of a site, the channel position within it may change over time. This means that some sampling stations from a previous year may be submerged or visa versa. Grid sample stations falling within the river channel are not sampled and account must be made for this during subsequent analysis of the data.

Additional information of the more widely dispersed species and habitat details are recorded from a 5m radius around each sample station. Some sample stations may initially be located in areas of small-scale heterogeneity. On such occasions, biotope features are recorded as usual, from within a 5m radius of the sample station, but are restricted to the specific biotope present at the exact centre of the sample station. For example, a grid sample station located on a 1m wide strip of sheltered littoral rock with *Pelvetia canaliculata* (SLR.Pel) would involve a search 5m either side of the station for additional species but not above in the lichen zone and not below in the *Fucus vesiculosus* zone. Similarly, this system of recording was applied to areas of sediment with steep profiles, where biotopes were arranged linearly and changed within small spatial scales (e.g. saltmarsh channel banks).

The following points should be taken into account during survey:

- Monitoring of sediment sample stations should not be carried out in or immediately after heavy rain due to the loss of surface features.
- A sufficiently large volume of sediment should be sieved to adequately characterise the biotope. This is important to account for the more dispersed but diagnostic infauna.
- The survey should be carried out between April and October and during periods of spring low tides.
- Surveyors should familiarise themselves with all intertidal and sublittoral fringe biotopes and especially with those previously recorded from the site.
- Estuary sediments are prone to disturbance by erosion and deposition, sometimes in direct response to human activities. If a sample station is too disturbed or unstable then it will be unsuitable for biotope identification and should be recorded as such.
- Further sample stations may have to be added to ensure that there are sufficient numbers of both the major and minor biotopes chosen for a site in order to achieve monitoring objectives. Sampling may need to be stratified to adequately represent the biotopes to be monitored.
- For monitoring sediment biotopes, infaunal species collected in the sieve should be recorded as actual or estimated numbers, not as abundances which are less precise.

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4 Using the most recent version: Connor et al. (1997) at the time of printing

- The impact of sampling should be considered in the sampling strategy. Good practice is to fill in holes at sediment sample stations to minimise the impact from monitoring. Additional considerations must be made for sensitive or limited habitats such as saline lagoons.
- For inter-survey consistency, the same version of the national biotope classification must be used to avoid 'translational' difficulties between Phase 1 datasets in a monitoring time series.
- For more precise identification of biotopes at a particular site, it is advisable that the survey team clarify the key habitat and species characteristics of each biotope within the specific site in order to improve the differentiation of biotopes. This can be done by writing an additional (location specific) paragraph in the biotope description that explains local variation of the character of the biotope from the national character.

## Data analysis

The analyses that are completed will be specific to the objectives of the monitoring programme, but would be expected to include a measure of the different proportions of biotopes or biotope types and an account of changes found across a time series.

## Accuracy

Survey results should always be produced with as much accuracy and consistency as time and resources will allow. If there is a detailed and accurate baseline map of the site, then the accuracy of an intertidal biotope survey can be validated against this at the time of preparation of the baseline data. Inaccuracies during surveys should be presented and discussed in full in the survey report and the validity of the results assessed in view of them.

## QA/QC

When planning any survey, it is vital to include provision for quality control (QC). QC depends upon ensuring good survey technique and standards through training and quality assurance procedures. Good survey technique relies on accurate identification of species and biotopes, precise orientation skills, attention to detail and thorough survey preparation.

Verification of species identification with the specimen collection and biotopes identified on the shore must be carried out to ensure the quality of the data.

To ensure consistency, surveys (in whole or part) should be repeated periodically. This procedure can be used to identify aspects for improvement as well as providing an understanding of the limits of the methodology. Initially, repeat surveys should be done frequently to ensure consistency and accuracy between surveyors and to remove any problems associated with a new survey method. Once survey teams are fully experienced, a proportion of their work should be checked: about 5% of sites in-house and 2% by experienced external surveyors.

## Data products

Data products are likely to be datasets held on database or GIS, according to the monitoring objectives.

## Cost and time

The survey of the Mawddach estuary in 1999 required a mean effort of 7.5 person-minutes per station in contrast to 48.9 person-minutes per station for a quantitative survey using cores.[5] The following costing/timing was incurred during the survey of 141 sample grid points in the Mawddach estuary.

5 Wyn *et al.* (2000)

Initial Phase 1 survey: 30 person days
Methodology and specification development: 5 person days
**Survey on foot: 32 person days (2 persons x 16 days)**
**Additional boathandler: 1 person day**
**Survey preparation: 1 person day**
**Survey write up: 10 person days**
**Total 44 person days** (excluding the development and initial phase 1)

## Health and safety

Due to the dangers of working in the marine environment and the amount of data to be gathered, surveyors should always work in pairs. The lone worker policy should be adhered to in order to provide additional backup should both surveyors become trapped or incapacitated. Risk assessments should be prepared for each location to be surveyed in order to account for local conditions.[6]

In addition, safety manuals issued by the UK government conservation agencies provide advice and recommendations for shore survey work, as well as for dealing with wild and domestic animals; information is also provided about first aid for sunburn, heat exhaustion and hypothermia.

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6 Example risk assessments for intertidal survey are provided in Wyn *et al.* (2000).

# Procedural Guideline No. 3-2 *In situ* survey of intertidal biotopes using abundance scales and checklists at exact locations (ACE surveys)

Keith Hiscock, MarLIN[1]

## Background

This method is adapted from standard Marine Nature Conservation Review procedures (Connor and Hiscock 1996).

## Purpose

To provide as accurate an estimate as possible of the abundance and species richness of intertidal biotopes at exact locations. It is applicable to the following attributes.

Surveys that record the abundance of species at particular locations will be appropriate to assessing quality in terms of species richness and the abundance of species. A generic attribute is the maintenance or increase in species richness in the biotope and/or abundance of key (rare, fragile, declining or representative) species in biotopes, subject to natural change.

This method can also establish or re-establish the species that are present in biotopes at a site, including their abundance.

### Advantages

Records are obtained rapidly and, if significant change is suggested, a check can be undertaken immediately for possible reasons. More species can be discerned *in situ* than by video or photographs. The records are sufficiently detailed to analyse against other biotope records in order to assess species richness or the presence of unusual features or rare/scarce species using the MNCR database.

### Disadvantages

Abundance scale results are not amenable to statistical analysis. Worker variability can be high using this technique. There is no video film (but there may be still photographs) to check back to if change is suggested and results need validation.

## Logistics

### Equipment

- appropriate transport and safety equipment
- checklist of species to be searched for and recorded with indication of abundance scale to be used for each

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- 'crib notes' or sketches to assist identification of 'difficult' species
- abundance scale.
- writing boards
- spade and fork (for sediment shores)
- collection equipment (reference specimens)
- camera (for site location pictures, illustrative recording or checking of records)
- digital camera (if features are to be identified on photographs for relocation but not permanently marked)
- hand-held GPS for location of site

### Personnel

Experienced marine biologists able to identify the conspicuous species likely to be present (separate botanist and zoologist advisable where plants and animals are present).

## Method

### Baseline survey or repeat monitoring

Locate survey stations according to the key site attributes which have been identified and/or to represent the main biotopes present. At the precisely located survey station(s)[2] record the type of shore substratum present and the abundance of all conspicuous species but ensure that especial attention is paid to those on the check list[3] including recording estimates of density or percentage cover where possible.

### Inspection survey

Inspection surveys are a rapid check allowing several sites to be assessed in the course of one low tide period. Locate the survey station precisely. Check the species present and their abundance against the results of the baseline or previous monitoring survey. If any species appear to be present in greater or lesser abundance or are not previously recorded, carefully estimate their percentage cover or density and abundance.

### Field techniques

The site must be marked or capable of easy identification (for instance, a particular overhang or boulder can be identified from a photograph). Marking can be temporary and included in location photographs (chalk marks, tape measure laid on a transect, etc.) or permanent (for instance, drill holes in the rock, metal studs embedded in plastic plugs or resin – but not protruding bolts which may be dangerous to walkers). If the field recorder cannot identify a species, discretion can be used in collecting a small sample or photographs can be taken. The field recorder should estimate density or percentage cover of taxa in the field rather than try to remember the abundance scale. The abundance scale to be used for each species must be indicated on the checklist. Repeat photographs must be taken from the same angle of the same area as the first survey.

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2 This will be an Ordnance Survey six-figure grid reference for the site supported by photographs and sketches of the shore as required to show exact location of each survey station. On rock, the survey site must be located exactly and this might require marking (see below). The area of rock to be included must be stated (for instance, 'in a rectangular area 5m either side and 1m below the marker hole on the shore'). On sediment shores, a dGPS might be required or transit marks on shore features (not usable in misty conditions). A survey brief might be, for instance: 'Record the abundance of epifauna over $10m^2$ (3.16 x 3.16m) and infauna by digging over at least $1m^2$ from the muddy sand avoiding areas of standing water. Use a riddle to sieve sediments from digging-over.'

3 These will be key or characteristic species or species of particular conservation importance. For instance, in the littoral fringe on a rocky shore, *Pelvetia canaliculata, Lichina confinis, Verrucaria maura, Chthamalus stellatus, Elminius modestus, Lasaea rubra, Patella vulgata, Melarhaphe neritoides, Littorina neglecta* and *Littorina saxatilis* might be checklist species – none are rare or unusual or of particular marine natural heritage importance although increased abundance of *Chthamalus stellatus* might suggest warmer conditions. Including *Lasaea rubra*, which is <2mm in size, ensures that it is properly searched for. On a lower shore sandflat, there might be a special requirement to search for rare or unusual species such as the sea urchin *Spatangus purpureus*, and so on.

### Laboratory techniques

Identify specimens and transcribe notes to record abundance of conspicuous species on MNCR recording forms. Note actual records of density or percentage cover if taken. Process photographs to check species identification and abundance against completed forms if necessary.

## Data analysis

Enter data, including digital photographs, into an appropriate database, e.g. Recorder 2000. Compare the data with that from previous visits. Consider if differences suggested are likely to be real. All differences of more than one abundance grade should be significant if care has been taken to exclude worker inaccuracies. If data are entered during the field survey directly into the database, comparison with previous records and with other locations can be undertaken immediately. The abundance scale must include specific reference to each species included in ACE survey at a location.

## Accuracy testing

Trials have shown that, if the field worker does not concentrate hard to estimate density or percentage cover, considerable differences (± two abundance categories) can result. Some differences of interpretation also occur, particularly with regard to percentage cover, and careful reading of the abundance scale instructions are required. Species may not be spotted or recorded unless the field worker is aided by a checklist (produced from previous survey of the same site). Rare species are often observed by chance and comparison of records may suggest spurious differences in presence between visits.

## QA/QC

- At the start of a survey, comparative exercises to calibrate worker variability in both identification and estimating abundance are to be undertaken.
- All of the species to be recorded must be indicated on the abundance scale.
- Re-survey to be undertaken at the same time of year as the initial survey.
- Quadrats are to be used to aid accuracy of estimating density.
- Recording is to be backed up with photographs.

## Data products

- Database records of abundance scale ratings for conspicuous species and those of conservation importance.
- Photographs of survey locations.
- Records of survey points with co-ordinates[4] and associated notes.

## Cost and time

### Fieldwork

About 15 minutes per station. Surveys might record from one site on the falling tide and one on the rising tide so that workers might be at sites for four hours per tide.

4 Recorded using dGPS – see Procedural Guideline 6-1.

### Laboratory

Depends on how many specimens require identification but results should be written-up on the same day as the survey.

## Health and safety

- Particular care is to be taken to avoid being cut off by the tide.
- Work should not be undertaken alone.
- Risk assessments must be addressed for the specific locations where survey is being undertaken.

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# Procedural Guideline No. 3-3
# *In situ* survey of subtidal (epibiota) biotopes and species using diving techniques

Rohan Holt and Bill Sanderson, Countryside Council for Wales[1]

## Background

These methods are adapted from standard Marine Nature Conservation Review procedures (Connor and Hiscock 1996) and methods developed during monitoring trials in 1998–1999 (Sanderson *et al.* 2000).

In order for data to be analysed over a time series and to monitor biotope/species richness, it is considered necessary to account for or standardise recording effort because the number of biotopes/species recorded will be linked to effort (see species–effort curves, e.g. Hawkins and Hartnoll 1980). Similar rules apply to counting individuals of one species. Effort recording through, for example, timed swims is too inexact because divers would see more or less depending on the visibility, and swim at different speeds and travel differing distances depending on fitness and any prevailing current at the time.

Effort limitation has previously been utilised by divers for benthic survey for recording species (e.g. see Wilson 1994). Here, a modified version of a technique used by Wilson (1994) is described (Figure 1) that has a number of applications relevant to biotope and species monitoring and/or surveillance.

## Purpose

- identification of biotopes
- gathering data to describe biotopes/biotope composition
- determination of an index of biotope richness within a defined area
- determination of an index of species richness from within a defined area
- describing the extent and distribution of biotopes
- describing the extent and distribution of species
- describing the extent and distribution of other seabed features (e.g. burrows)

Note that a combination of the above can be nested within one survey. For example, the primary aim may be to gauge biotope richness within an area, but with suitable adjustments to the methodology, the data can also provide biotope descriptions, species richness and biotope distribution.

## Logistics

### Equipment

- Appropriate transport – inflatable boats or RIBs (Rigid-hulled Inflatable Boats) are adequate for most diving operations.
- Diving equipment and safety equipment (e.g. full diving kit, surface marker buoys, nitrox breathing gas if appropriate).

1 Plas Penrhos, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ, Wales.

- Position locating equipment and/or notes (e.g. dGPS co-ordinates and transit marks).
- Checklist of species (e.g. MNCR form[2]) and abundance scales.
- Writing boards (perhaps with waterproofed checklist, abundance scales and guidance notes attached).
- Collecting equipment for reference specimens (plastic bags, lidded buckets, fine net).
- Stills camera/video camera to supplement written records.
- Seabed guide ropes, 'roll-out transect' equipment or similar for effort-limited survey technique (Figure 1). The pole is designed to measure a fixed transect width and therefore, in combination with the fixed distance travelled, limit the area surveyed. In field trials in North Wales the guide pole length was chosen to be 3m because the visibility was unlikely ever to be worse than 1.5m (each diver would need to be able to survey the area on one side of the pole). Visibility could therefore be eliminated as a major source of variance over a time-series of data. The actual length of the transect should be based on previous experience and survey at the site. In Pen Llyn cSAC, for example, previous studies (Brazier *et al.* 1999a; Bunker 1999) suggested the total intended survey area of 150m$^2$ (50 x 3m) would be sufficient to record adequately at least one biotope (probably two).

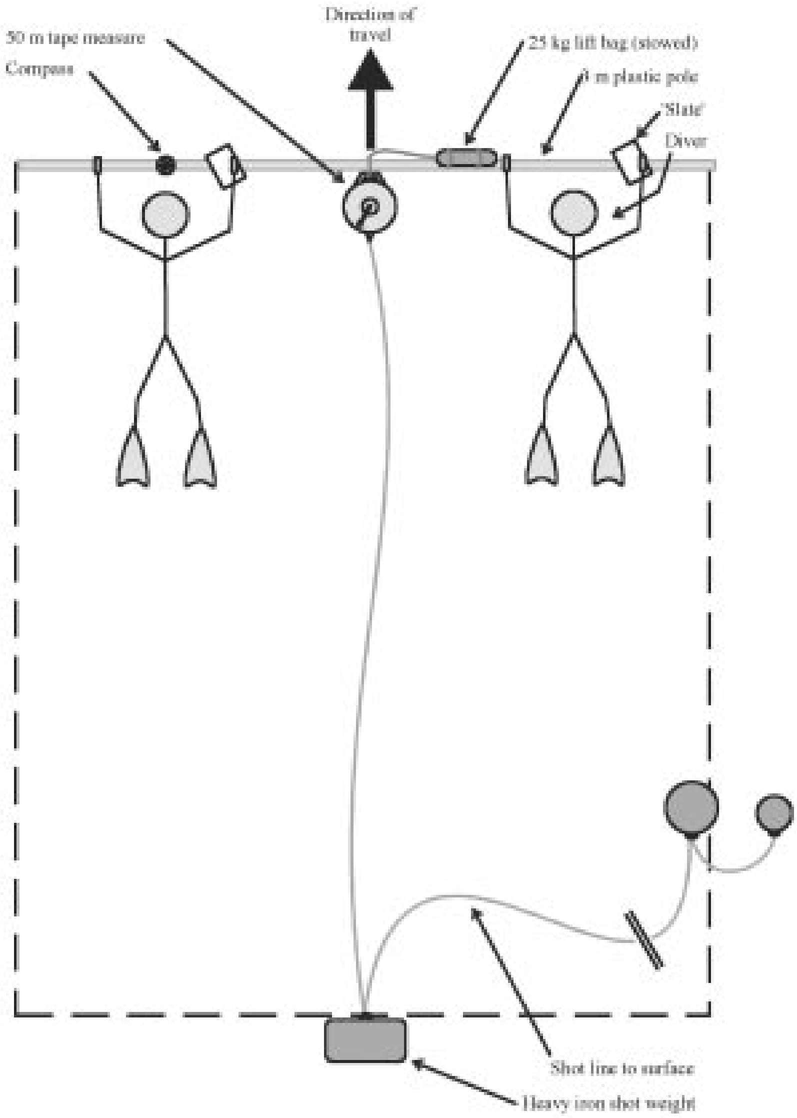


**Figure 1** An effort-limited diver survey technique – the box enclosed by the dotted lines represents the area surveyed.

## Personnel

All divers to be fully qualified (see 'Health and safety') with appropriate experience in biological recording. Minimum team size three in benign conditions; normally four for most survey situations.

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2 A copy may be downloaded from: **http://www.jncc.gov.uk/**

### Best time of year for sampling

Calm conditions, reasonably clear water (suggest 1.5–2m minimum underwater visibility), and little or no current are ideal, although not always practicable or attainable at all locations. The best times of year for suitable conditions tend to be spring, summer and autumn on open coasts (although consider the impact of springtime plankton blooms in some locations). Strongly tide-swept areas should be surveyed at the time of slack water – the duration of which is normally (but not always) longest during neap tides.

The timing of a survey should also consider seasonal changes in the benthos. For example, hydroids and bryozoans may be heavily grazed late in the summer and red algae may be obscured by growth of epiphytes. Repeat surveys as part of a time-series data set should be collected at the same time of year.

## Method

### Site location

This depends on the main purpose of the monitoring exercise. Sites may be chosen to target particular habitat types (e.g. by referring to charts or AGDS or sidescan survey maps) or chosen via a random/semi-random (stratified random) technique, for example, as part of a sampling strategy to investigate biotope richness.

GPS/DGPS co-ordinates are normally used to locate previously unmarked sites at sea. A buoy attached to a weighted shotline, supplemented with a small anchor, should be used in order to deliver the divers as close as possible to an unmarked seabed location, particularly where currents and/or deep water are anticipated. Exact location/relocation of a subtidal site far away from surface features (e.g. the shoreline) is not possible without deploying permanent markers and guidelines (see site marking PG) and therefore is not normally considered practicable for this type of survey.

### Diving survey

See Figure 1.

A pair of divers descend the shotline down which the tape and guide pole have already been deployed (see also Figure 4).

The divers then begin surveying as they reel out the tape from a pole travelling in a straight line. A compass fixed to the centre of one side of the transect pole can be used to assist in 'hands-free' navigation (Figure 1).

Species and abundances are recorded *in situ* using standard recording protocols (see Hiscock 1996). The level of detail to be recorded by the divers must be decided before they start the survey. For example, they can limit recording to the most conspicuous and characterising features of a biotope, or even count single species within the boundary of the transect. This may be particularly important for saving time, to ensure that even the deep sites are surveyed completely. It may be appropriate to develop a checklist of species to assist recording.

If recording biotope richness the divers will have to make judgements on where one biotope ends and the next one begins (and when they are in 'transition zones') and also make decisions on whether they are surveying from within a definable biotope. This decision is aided by applying a simple rule: only record biotopes that exceed a minimum area (e.g. biotopes that cover less than $5m^2$ are disregarded). This avoids creating 'new' biotope records for small features such as the epifauna found on a few scattered boulders (although their presence can be noted) or when a transition occurs in the last metre of a transect.

On completion of the transect the pole and line are sent to the surface using a 25 kg lifting bag/marker inflated by the divers. The divers are then free to make their ascent utilising their own surface marker buoy (Figure 2).

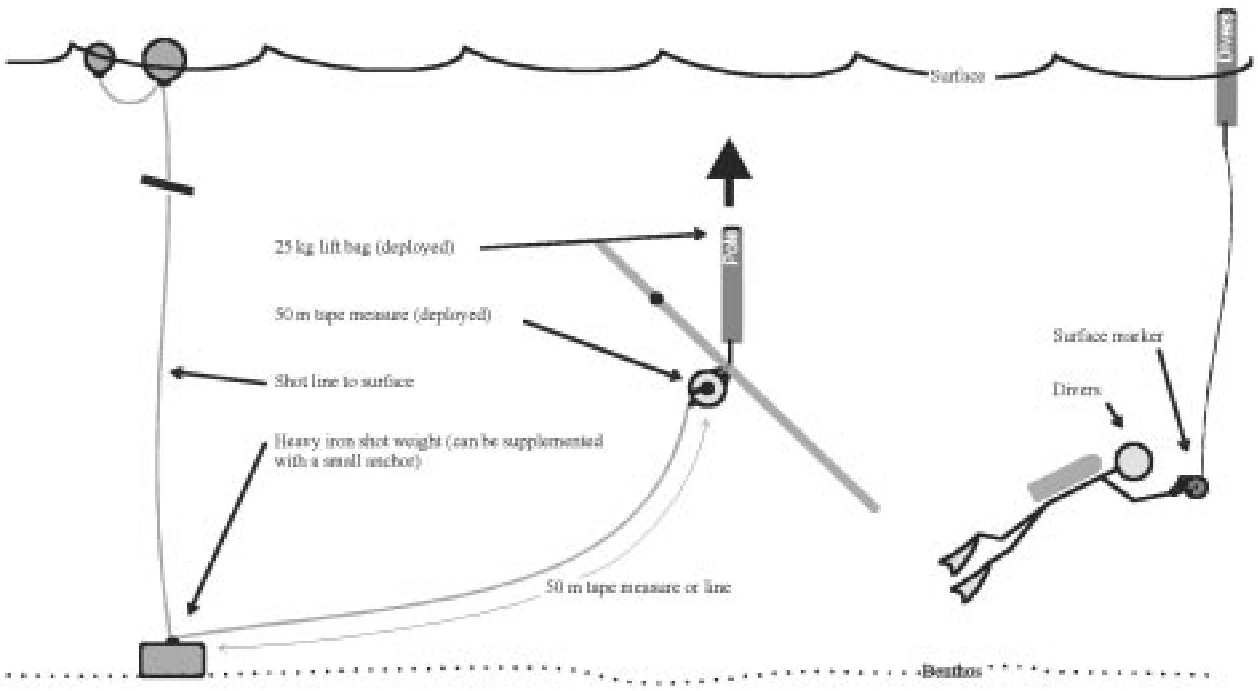


**Figure 2** Recovery of the transect equipment

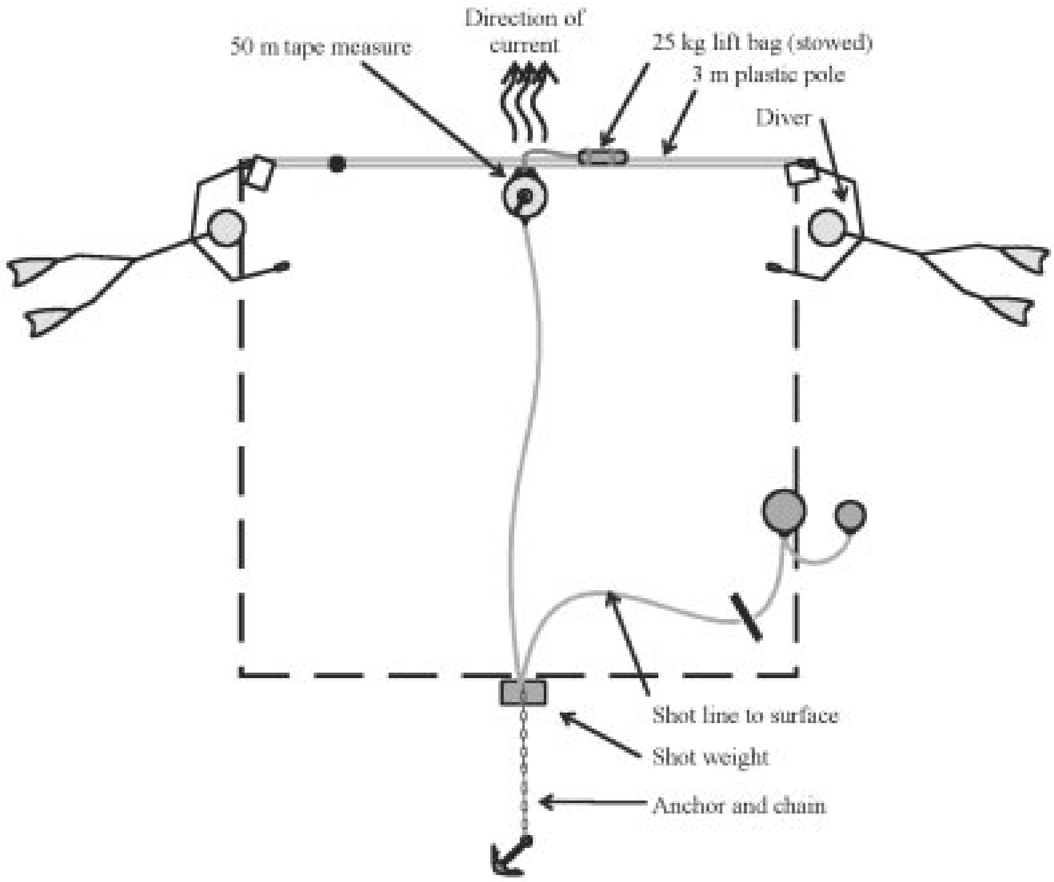


**Figure 3** The effort limited transect modified for tideswept conditions

A variation of this method could be used in moderate tidal streams, whereby the divers hold on to the ends of the pole and face each other. Providing the current is not too strong to prevent the divers maintaining station on the seabed when required, records can by made as the current carries the divers over the seabed (Figure 3). A small anchor is used to supplement the shot weight and therefore prevent the divers dislodging the shot from its intended position (Figure 4).

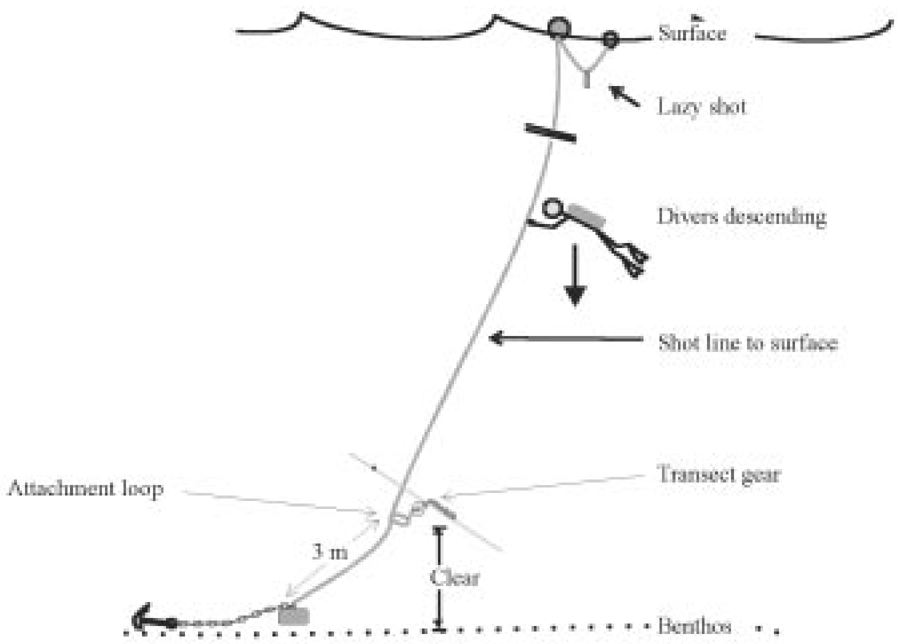


**Figure 4** Modified deployment of the effort-limited survey technique

# Data analysis

Data can be transferred to standard recording forms (e.g. the MNCR forms – Connor and Hiscock 1996) and later entered into a database (e.g. the MNCR database – MacDonald and Mills 1996, or Recorder 2000).

# Accuracy testing

Biotopes assigned in the field should be carefully re-examined by an experienced operator to ensure that all biotopes have been correctly assigned to the national classification (Connor *et al.* 1997) and/or a regional classification.[3] It may be necessary to adapt the national biotope descriptions to fully reflect their representation within an SAC to overcome any ambiguities between biotopes, and thereby improve the accuracy of sample assignments.

# QA/QC

The subjective element of abundance scale data can lead to inter-recorder variability and therefore are not appropriate for species monitoring/surveillance, even if the survey method has been effort limited in some way (Hiscock 1988).

Where the objective of a transect survey is to record sufficient information to *identify* biotopes present (and not necessarily describe or create biotope descriptions), specimen collection and recording of minor components of the fauna and flora will not be necessary (but can be conducted if time allows). However, specimen collections will be necessary when detailed records are required and when 'new' species or species difficult to identify *in situ* are encountered.

Expert knowledge is required (see Connor and Hiscock 1996) if the aim of the survey is to identify all conspicuous macrofauna. However, surveillance and monitoring surveys, depending on their aim, do not necessarily require every species to be identified. Less taxonomic expertise is required if the aims are simplified so that the surveyor needs only to record a few species. For example, a relatively inexperienced surveyor (although nonetheless an experienced diver) can be quickly trained to identify a few key species of sponge, alga or ascidian (e.g. using the checklist idea described by Hiscock 1998).

3 A regional classification must have explicit links to the National Biotope Classification.

Photography and video techniques can be used as a back-up to the data recorded in situ. However, taking pictures can distract a diver from the aim of the survey unless time limits are not an issue (rarely the case).

It is necessary to minimise inter-worker variation in recording techniques and taxonomic identification to improve the quality control of records. Methods for reducing such variation include bespoke training/familiarisation sessions prior to the field recording, clearly defining the recording procedures (via a Standard Operating Procedure) and/or using standardised biotope descriptions or species check-lists.

# Data products

Biotope survey data will be in the form of MNCR Phase 2 recording forms compatible with the MNCR database. Abundance is expressed as semi-quantitative abundance scales.

Data collected in other formats, such as counts of individual organisms, can be expressed as counts per $m^2$, actual counts, percentage cover or frequency (see Section 5 in the Monitoring Handbook for the pros and cons of each). Such data are more amenable to statistical analysis and tests than abundance scale data.

# Cost and time

## Cost

The costs of a dive team can vary depending on expertise and whether in-house or contract staff are used. The minimum team size required for most diving operations is four. The current daily rate (Autumn 2000) for an experienced diving marine biologist contractor is approximately £150–300 per day. Other costs to be taken into account are transport (vehicle and boat fuel, boat hire/charter or purchase), equipment (diving equipment and breathing gas) and time taken to train staff to carry out the proposed task (whether the training is in diving techniques or identification skills).

## Time

A four-person diving team can normally complete four to six transect surveys in one day depending on depth, duration of slack water, if required, and the time taken to make adequate records on the seabed. A 50m x 3m transect over a simple uniform seabed with only a few species to record may take around 20–40 minutes, whereas it may take over 90 minutes to search for an inconspicuous alga. Ideally the objectives and methodology should be adjusted to allow the full transect to be completed within the no-stop time of the maximum depth likely to be encountered.

# Health and safety

Diving survey is limited by physiological demands on the diver's body (a function of time and depth) and the risks associated with contracting decompression illness (the 'bends'). Current working practices within the country agencies limit divers to three dives per day (unless working in exceptionally shallow water ~ <6 m – see Holt 1998). All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[4] and must follow the Scientific and Archaeological Approved Code of Practice.[5]

All small boat use should comply with existing codes of practice and each diving operation or project will require a site-specific risk assessment.

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4 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7
See: **http://www.hse.gov.uk/spd/spddivex.htm**

5 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997.Approved Code of Practice and Guidance - L107. HSE Books 1998. ISBN 0 7176 1498 0.
See: **http://www.hse.gov.uk/spd/spdacop.htm - a**

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# Procedural Guideline No. 3-5 Identifying biotopes using video recordings

Rohan Holt and Bill Sanderson, Countryside Council for Wales[1]

## Background

Drop-down video recording techniques have been used in a variety of applications (Sanderson *et. al.* 2000) and are appropriate for the identification of seabed habitats/biotopes when multiple deployment has priority over the requirement for fine detail. The technique could be described as 'semi-remote'; the operator of the video camera and recording equipment does have a limited amount of choice over where the camera is directed and what footage is recorded compared to a 'blind' remote technique such as grab sampling or towed video. As the operator has considerable influence over what is recorded he or she must have an appropriate knowledge of benthic communities and a sound understanding of the aims of the survey. The deployment protocol should take into account the variable nature of the seabed but at the same time set minimum requirements for obtaining footage with a combination of images using the camera held both close to the seabed and suspended a few metres above it for each habitat/biotope. It is also advisable, when establishing a programme of monitoring using drop-down video, to ground-truth the video records by either incorporating information from existing *in situ* survey data (through reference to regional or local biotopes) or conducting targeted *in situ* surveys at a similar time of year.

## Purpose

To deploy video equipment to record sequences of video to identify biotopes or populations of conspicuous species.

### Advantages

- Records are obtained rapidly and are stored in a permanent format that can be reviewed whenever required.
- Video images have a wide variety of uses outside the primary aim of the survey, e.g. selected still images for illustrative purposes or for producing educational and training material.

### Disadvantages

Certain groups of species, such as hydroids, bryozoans and fine algae, are particularly difficult to identify from video records (hence the need for ground truthing or prior *in situ* survey and local biotope descriptions). Similarly other cryptic species, such as *Sabellaria spinulosa* and species that are best identified *in situ* by their touch (e.g. some of the sand-coated ascidians) are also missed by video unless good close-up images are obtained. This can lead to misidentification of biotopes unless appropriate measures are taken, such as using experienced surveyors who are familiar with the local area to score video footage.

## Applicable to the monitoring of the following attributes

- evaluating biotope richness (i.e. number of biotopes)

1 Plas Penrhos, Ffordd Penrhos, Bangor, Gwynedd, LL57 2LQ.

- detecting the presence of certain biotopes
- estimation of the extent of certain biotopes (as represented along a transect, for example)
- presence of conspicuous (key) species

### Applicable to the following survey objectives

- inventory of seabed biotopes within a near-shore area
- reconnaissance survey prior to deployment of other methodologies
- ground truth AGDS information
- estimating the distribution and extent of habitats
- estimating the distribution and extent of biotopes (primarily epifauna)
- supplement *in situ* diving surveys by targeting specific habitats or biotopes
- making observations beyond the depth limits of normal scuba diving
- estimating biotope richness within a specified area

## Logistics

### Equipment

An overview of a typical drop-down video system is shown in Figure 1.

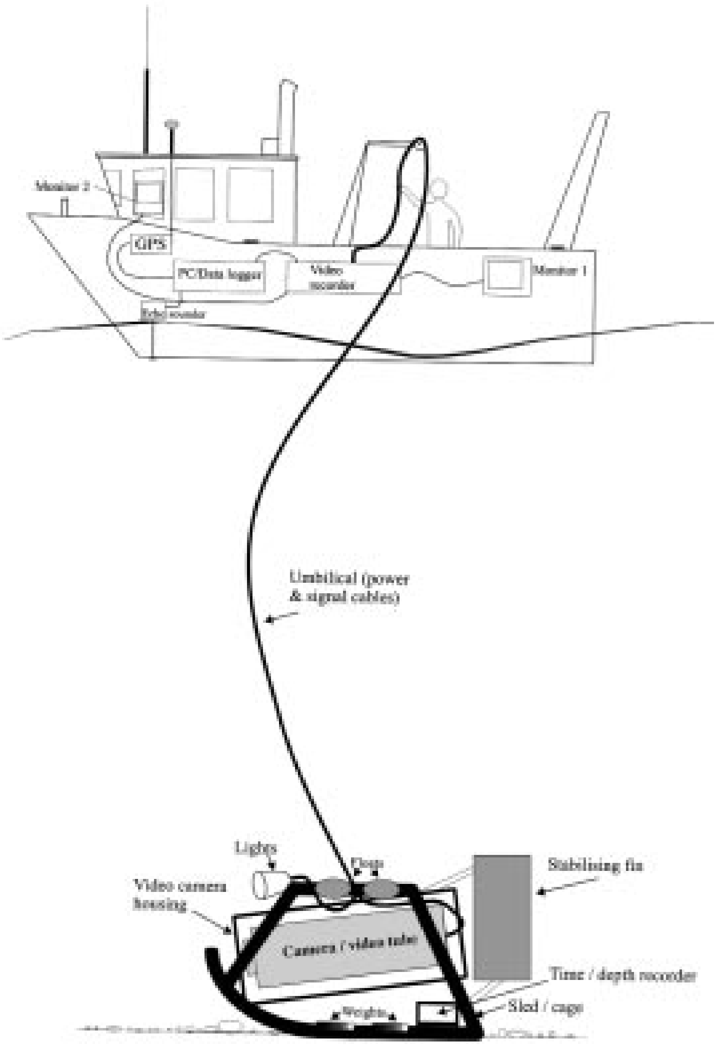


**Figure 1** The main components of a drop-down video system (not drawn to scale – the camera and sled are shown at ~6x relative size)

## Video format

The choice of recording medium is as important as the choice of video camera equipment, since this has most bearing over post-processing capabilities. There are many different formats of video recording media available at present. The more recently developed digital video systems designed for the domestic market (e.g. mini-DV or digital 8) or professional Digital S far out-perform older systems, such as Hi8, video 8, VHS and SVHS when considering the functions that are required to carefully review biological information on video. The higher cost and larger physical size of professional broadcast quality analogue and digital systems make them less suited for drop-down underwater use. The 'best' systems (in terms of value for money and image clarity and utility) available at present record digital information onto a variety of media including tape, laser disc (writeable digital video discs – DVD) or integrated hard drive. With magnetic tape recording media some degradation of the information on the tape can occur over time and therefore it would be unwise to plan archiving digital images on tape alone. Information stored on laser disc, providing the discs are protected from physical damage, should last indefinitely.

Digital images, in whatever medium, allow the viewer to freeze-frame, play in reverse, slow motion or a frame at a time backwards and forwards, and 'grab' video-stills without most of the distortion, flickering and 'noise' commonly experienced with analogue systems. The rate of image capture will cope with moving images at low light levels, although blurring will occur if the subject or camera moves too quickly.

Video footage can be played from a videotape recorder/player or camera. Whatever system is used the person reviewing the video recording requires as much control over the speed and direction of play of the tape as possible. Digital images can be viewed on a domestic TV (with an SVHS-in socket if possible) or run through a computer or editing suite for simultaneous image-grabbing or editing. Simple and relatively low-cost editing suites are now available that can cope with extracting video clips and stills or making back-up copies of tape sequences.

## Video camera

Digital video camcorder and professional broadcast quality video camera technology is moving ahead so quickly that the primary limiting factor for deployment of a drop-down system is obtaining an 'off-the-shelf' underwater housing that will fit a 'state-of-the-art' camera. There are ready made complete drop-down systems available, for example the 'Fishman' series of drop-down cameras and mini-ROVs (remote operated vehicles) made by Q.I. Inc. in Japan (**http://www.qi-inc.com**). Providing these are sufficiently rugged for the conditions likely to be encountered, such systems feature camera pan and tilt options that provide the user with greater control over where the camera is aimed.

The features found on the Sony VX1000 digital colour camcorder (DCC) used by CCW are shown in Table 1. Such features worked well in trials around the North Wales coast (Sanderson *et. al.*2000) and are considered the minimum requirement for a system.

**Table 1** Video camera requirements

| *Features* | |
|---|---|
| Tape format | mini-DV |
| CCD | 800 pixel |
| Min. illumination | 4 lux |
| Optical zoom | x 15 |
| Digital zoom | x 60 |
| Weight | 770g |
| Power consumption | 5W |
| Operating time | 325 min |
| Audio recording | 12/16 bit |
| DV output | IEEE 1394 (Firewire) |

A camera with an infra-red (IR) remote control facility can be utilised for surface control of the main camera functions via an umbilical. By building an infra-red sensor into the surface console the control signals can be converted into RS485 data format, thus allowing control signals to be passed via data wires in the umbilical. Electronics at the camera end of the umbilical convert the electrical signals back to IR pulses.

### Lighting

Even in brightly lit, clear, shallow water, colour at the red end of the spectrum is filtered out leaving all images with a blue or green-blue cast. Small inconspicuous species such as fine filamentous algae or well-camouflaged species blend with their background unless artificial lighting is employed.

Colour-balanced quartz halogen lamps or high-intensity dispersion lights provide the principal illumination source for the camera. Two or more lights should be attached to the camera housing or its supporting frame in such a way as to provide even lighting in the majority of the field of view. Most lighting systems can be run from batteries mounted on the video camera housing or frame but far better 'burn-time' is obtained by using a low voltage direct current supply from the surface via the main umbilical.

### Underwater housing

For drop-down use the ability to control the camera via signals sent down the umbilical is very important. Indeed, a simple drop-down system need consist of little more than a fixed-focus housed camera tube (i.e. lens and image capturing electronics) on the end of a cable with the power supply and recording facility on the surface. Therefore the specification for a housing can be fairly simple if it is to be 'made-to-measure'. A simple housing could comprise a hollow cylinder with mounting brackets to hold the camcorder, a lens system in addition to that of the camera (normally to widen the angle of view) and control rods/switches to operate the primary camera functions (on/off, record, pause, etc.). There is no requirement for being able to clearly see the viewfinder *in situ* (if using a camcorder) and therefore the back of the housing can simply act as an attachment point for the umbilical.

There are also many makes of underwater video housing on the market, many of which are reasonably easily adapted to working as a drop-down system. Some of the popular models already incorporate connectors for external umbilical cables. Please refer to the end of this guideline for websites where these products are available.

### Sled design

The housing and lights should be securely mounted in a framework that both protects them from damage and orientates them to view the seabed when supported by the umbilical. The frame must afford the camera an uninterrupted view but at the same time protect the housing and absorb shock if in collision with underwater obstructions. The video housing and lighting brackets should allow positioning at a variety of angles so that the camera is pitched nose-down to get a close-up view when the frame is resting on the seabed. The frame should have sled-like runners to allow the frame to be dragged smoothly across the seabed, and also a tail fin to orientate the camera to the direction of travel and reduce yaw when suspended in mid-water. Unlike towed camera equipment the frame must also be light enough to deploy by hand, because the ability to react to features underwater as they appear on screen at the surface is fundamental to successful filming. Ideally the frame needs to be constructed from corrosion-resistant stainless steel. The attitude that the frame adopts underwater may require trimming with buoyancy cells (e.g. solid foam or small solid buoys) or small bolt-on lead weights to optimise the field of view.

### The umbilical

Any system that requires images to be viewed in real time requires an umbilical. An umbilical is essentially a waterproof multi-core cable for transmitting power to the lights and camera, and passing control signals to the camera and video signals from the camera back to the surface. Waterproof connectors are required at both ends and at junctions in the cable.

The length and weight of the cable are the main factors limiting the maximum depth of deployment. Video housings can be made to withstand the pressure at a depth of hundreds of metres but manually hauling more than 80m of umbilical can create difficulties, although more expensive lightweight fibre-optic cables are more easily handled than conventional cables. The longer the cable the more drag is exerted on it and the greater the signal strength required to and from the camera (see manufacturers' specifications). For a system that is deployed manually the cable must also bear the combined weight of the camera and sled, although a strong point with a reinforced section of cable should form the attachment to the sled so that no strain is placed on the electrical connections. Most sea conditions will prevent a perfectly perpendicular deployment and therefore more cable is required than the depth of water below the boat. The system used in the CCW's surveys had an umbilical of 100m length, but this was difficult to use at depths greater than 60–70m. As a 'rule of thumb' allow 1.5–2 times the cable length to water depth in calm conditions and up to three times more in tidal conditions.

### *Peripherals*

Real-time viewing is necessary for most drop-down applications. A monitor should be positioned so that both the helmsman and the person handling the umbilical have an adequate view, although in some cases an auxiliary output might be necessary for a secondary viewing monitor if the working positions of the members of the team are separated. Monitors tend to be difficult to view in strong daylight and will require some form of shading (and waterproofing) if used in an open boat.

Equipment used on the boat should be mounted in a splash-proof console if the boat is open to the weather. All electrical power must be suitably fused and protected. High voltage supplies must have earth leakage circuit breakers and a sea earth must be used. Power to the whole system can come from multiple twelve-volt DC portable batteries (lead-acid rechargeable batteries), a small portable generator or from the boat's own 12 volt supply (via an inverter for any equipment, such as a PC or video recorder, requiring voltages higher than the boat's supply).

### *Geo-reference capability*

The utility of the video record can be greatly enhanced if the exact location (depth, time and position) of the camera is known. Geographic co-ordinates (from dGPS data) can be recorded simultaneously with depth readings from an echo-sounder and logged by a PC. If this information can be superimposed onto VHS videotape via an external interface the viewer can effectively geo-reference each frame, although attempts to superimpose positional information onto digital video during monitoring trials have so far been unsuccessful (Sanderson *et al.* 2000).

In order for data to be analysed over a time series and to monitor biotope richness, for example, it is necessary to be able to account for or standardise recording effort because the number of biotopes recorded will be linked to effort (see species–effort curves, e.g. Hawkins and Hartnoll 1980). Continuous tracking of the camera's whereabouts on the seabed using dGPS allows the user to restrict recording to a pre-determined distance. Based on previous experience of diving, effort-limited survey (e.g. Brazier *et al.* 1999a; Bunker 1999, Sanderson *et al.* 2000), a total survey area of $150m^2$ (50 x 3m) was found to be sufficient for divers to adequately record at least one biotope (probably two) in the tide-swept reefs of Pen Llyn a'r Sarnau. This method, adapted to suit the deployment of a drop-down system, required the deployment of the drop-down camera over a distance of 100m steered in a straight line. This suited the scale of heterogeneity present on this particular site.

In practice this can be achieved by setting a waypoint on the dGPS (which can be a pre-determined buoyed position, for example, chosen at random from within a desired survey area) when the seabed comes into view on the video screen. The boat can then be steered or allowed to drift in a straight line away from the waypoint until 100m has been covered as shown on the DGPS ('distance to waypoint'). If distance over the seabed can in some way be superimposed on the video tape or synchronised with logged positions over time, effort limitation can also be achieved by randomly selecting sections of seabed footage from longer runs.

Alternative measures for recording depth should be considered, particularly if working in shallow water and/or over rugged terrain where the boat's echo-sounder transducer might not be perpendicularly above the camera. A digital time and depth recorder (e.g. an electronic dive timer) mounted in one corner of the camera's view could be a simple but effective way of overcoming this problem, although this will partially obscure the field of view. Alternatively, the camera and the data logged by a dive timer/time-depth recorder (with a computer download facility) attached to the camera frame can be synchronised post-deployment.

### *Boat requirements*

Drop-down video equipment can be adapted for deployment from a wide variety of vessels. The following should be considered when choosing an appropriate boat:

- Is it capable of manoeuvring in shallow restricted waters or wherever the equipment is to be deployed?
- Does the boat have a power supply for running the drop-down equipment? If not, can batteries or a generator be adequately housed on board?
- Is there suitable dry cabin space or is the boat open to the elements?
- Is there a position on board where the sled and video can be easily deployed without long drops to the sea surface or danger from entangling the umbilical with other equipment/propellers etc?
- Can the helmsman and video operator both see the video image in real-time?
- Does the vessel carry sufficient safety equipment and comply with current workboat codes of practice?

### Personnel

A drop-down video survey 'team' should comprise three people: a helmsman, someone to deploy the video and a third to aid with navigation, take field notes, control the video recorder and assist with deployment and retrieval of the umbilical, sled and camera. It is distinctly advantageous (if not essential) that the person deploying the video is reasonably familiar with the benthic communities in the area so that he/she can react to the presence of inconspicuous, unusual or diagnostic features.

## Method

### Deployment of the drop-down equipment

(1) Plan to deploy the drop-down video equipment at or near to slack water if in a tide-swept area and consider carefully how the prevailing wind and tidal flow might influence the direction of travel during deployment. Manoeuvrability of the support vessel will be dictated by its size, engine type, etc., and trying to hold station or move in a straight line might be impractical at certain stages of the tide or if the wind direction is, for example, blowing onshore.

(2) The video recorder, camcorder, GPS/dGPS and data logger/PC all have internal clocks. It necessary to synchronise all time-keeping devices to real time (= GPS time) so that any records made with a time reference attached (whether hand-written or automatically logged) can be easily cross-referenced without having to add or subtract confusing correction factors.

(3) Prior to each deployment the video camera, lights and videotape recorder should all be tested and working to ensure all electrical connections are sound and the recording facility is functioning. Note that some video lights cannot be switched on for more than a minute or so as they overheat when out of water. This is also the best time to label the leader section of each video run with specific information about the site, date, time and operator. A simple 'clapperboard' with the relevant information written in black on a white background held in front of the camera for about five to ten seconds should suffice.

(4) Once the boat is on site (and perhaps anchored if only a small area of seabed is to be investigated) the video is set to record and the camera frame lowered overboard by hand and the cable paid out until the seabed comes into view. If the boat is moving, perhaps drifting with the tide or wind or under power, the operator must then respond to sometimes sudden changes in the seabed profile and raise or lower the equipment to keep the seabed in sight.

(5) To record sufficient detail to characterise epibenthic biotopes a combination of wide-angle and close-up views of the seabed are required, preferably with sufficient pauses to gain good 'still' pictures. This can be achieved by devising a flexible protocol to suit the prevailing conditions. For example, the camera can be 'flown' at half a metre or so above the seabed for ten seconds then lowered to touch bottom where, if stationary, it can focus on objects immediately in front of the lens for five seconds. Repeated cycles of 'hops' along the seabed should record sufficient detail of both the smaller inconspicuous species as well as more widely distributed larger species. An experienced operator in co-ordination with the helmsman may also be able to target and home in, to a limited degree, on new or unusual species. The temptation to repeatedly home in on large, bright and colourful species, such as dahlia anemones *Urticina felina*, should be avoided (Figure 2). Such species are usually readily identified from a quick glance, whereas less conspicuous species can easily be overlooked.

(6) Kelp forest biotopes can be surveyed by slight modification of the above technique (Figure 2). There is an obvious danger of entangling the equipment, but careful deployment in calm conditions should provide adequate views of the canopy, kelp stipes and understory substratum. To penetrate the canopy the camera system must be dropped vertically into the kelp, allowed to record images for a few seconds then extracted vertically again without dragging the camera sideways.

(7) Once the required distance or time sequence has been completed the camera is retrieved. The duration of each deployment can either be pre-determined (see effort-limitation paragraph) or can be dependent on the length of videotape or duration of the battery, particularly if the recording occurs in a housed video camera rather than at the surface.

(8) A handwritten field log should be kept of times and positions of deployment. Even if GPS positions and depths are being logged automatically, basic details of the start and finish of each particular run and how these data correspond to the videotape sequence must be recorded. This guards against loss of electronic data; a very real possibility when dealing with delicate electronic instrumentation on board a constantly moving vessel in a humid salt water environment.

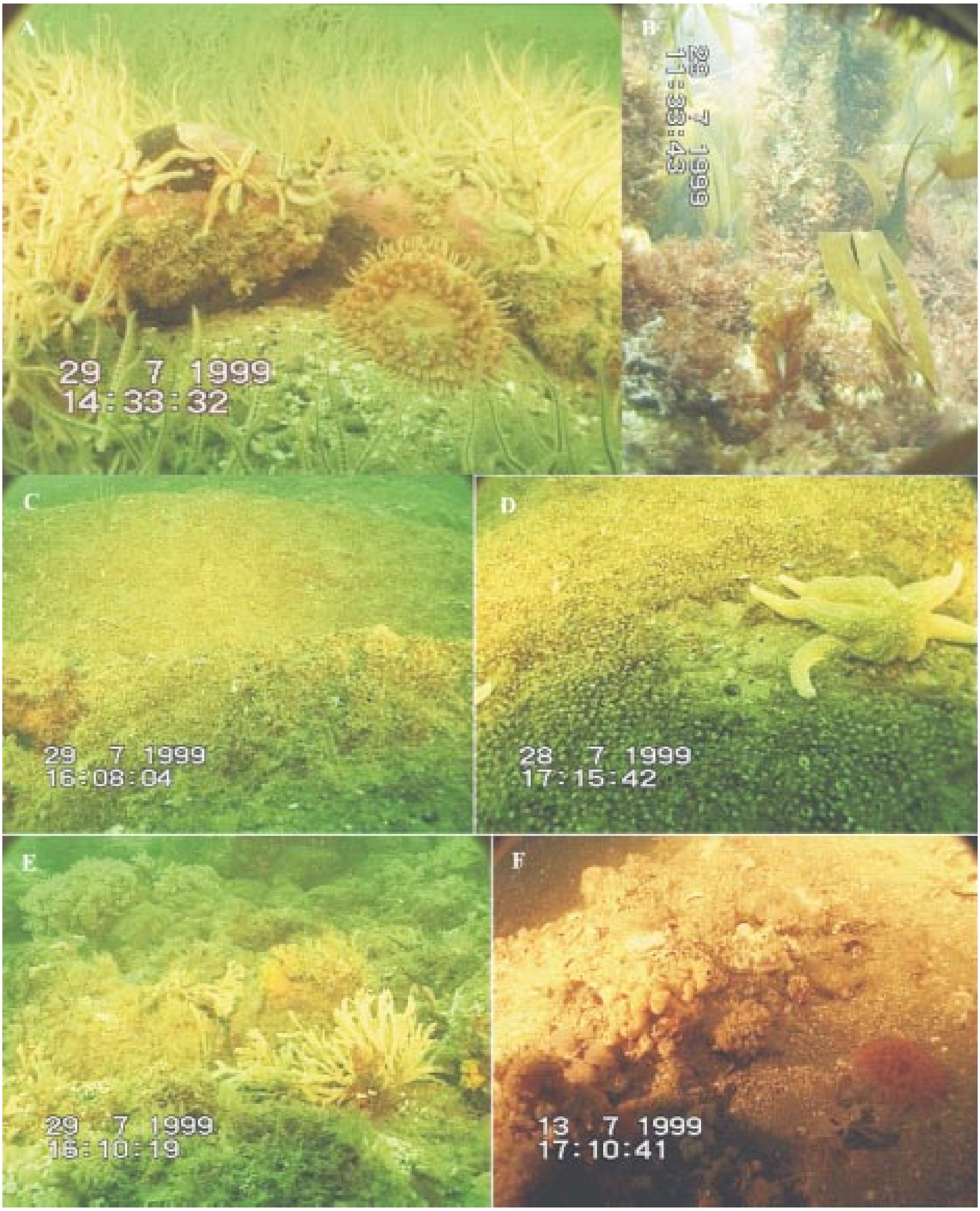


**Figure 2** Video stills taken from Pen Llyn monitoring trials. (A) Conspicuous species such as *Urticina felina* and brittlestars *Ophiothrix fragilis* are easily recognised at a glance, although the viewer is tempted to concentrate on them. (B) The camera can be lowered below the kelp canopy (in this case the camera has landed on its side). (C) With the camera held above the seabed, the extent of this mussel *Musculus discors* biotope can be seen. (D) A closer view of the mussel's siphons in the *Musculus discors* biotope is recorded by landing the camera on the seabed. (E) Many of the turf-forming bryozoan species can be identified from this image with practice. (F) Blurred images of these colonial ascidians make them difficult to identify – the camera was travelling quickly with the tide.

# Data analysis

## Post processing of video

(1) Tapes are scored using freeze-frame, slow motion or standard play speed as required to identify as many species as possible and estimate their abundance (using MNCR SACFOR abundance scales; Hiscock 1996). Each video clip should be viewed by a biologist, preferably with prior experience of identifying species both *in situ* and off video recordings. Estimates of abundance are made by eye using the relative sizes of known features/species to gauge the size of the field of view. Notes should be made on standardised recording sheets (e.g. SNH's video log sheets or Nature Conservation Review (MNCR) recording forms).

(2) Once a complete run has been scored, the data are organised into biotopes (or habitat types if the characterising epifauna/flora could not be identified). For the purposes of an effort-limited drop-down survey methodology a biotope can be defined as having a total lower size limit: $5m^2$ was found to be a workable limit (Sanderson *et al.* 2000) below which the data were not distinguished from the surrounding larger biotope. Sparse or scattered features, such as boulders on sediment plains, were only counted as separate biotopes if their total cumulative area exceeded $5m^2$ although their presence should be noted.

(3) Biotopes recorded from the video are then compared and matched, if possible, with descriptions in the national classification (Connor *et al.* 1997). In many cases a 'perfect fit' with the national biotope descriptions will not be found. It will therefore be necessary, particularly for monitoring purposes, to refer to local or regional biotope descriptions that emphasise the key species and habitat features. It may be necessary to review the footage again to search for 'clues' of characterising species that are particularly inconspicuous on video images. This applies particularly to encrusting species such as ascidians and small mussels (e.g. *Musculus discors*) and fine species such as hydroids, bryozoans and small algae (Figure 2).

## Accuracy testing

Field trials (both diving and drop-down video recording) have shown that in a limited number of cases there are difficulties encountered in appropriately attributing records to biotopes in the national classification (Connor *et al.* 1997). It was concluded that there were three principal reasons for these discrepancies that the recorder should be aware of:

(1) The workers did not examine all of the possible biotope options in the manual.

(2) Difficulties arise in the accurate and repeatable allocation of records to national biotope descriptions. National biotopes are, by their nature, nationally 'normalised' in order to account for biogeographic variations in the component species over their range. For this reason it would be highly desirable to match survey descriptions to more tightly described regional descriptions of national biotopes.

(3) The presence of mosaics of biotopes (e.g. vertical and horizontal surfaces that support two biotopes).

# QA/QC

## Minimum sampling and data analysis requirements

### *Effort limitation*

Drop-down video surveys can be adapted to effort-limit deployments to a distance of, for example, 100m steered in a straight-line over the seabed. This distance was chosen to suite the scale of heterogeneity present on a particular area in North Wales (Sanderson *et al.* 2000) and can be adjusted as required to suite different locations. The greatest accuracy in deploying the equipment in straight lines over a known distance is achieved by allowing the boat to drift with wind and/or tide – perhaps from a pre-determined start point, although not aiming for a pre-determined end point. Attempts to power the boat between two chosen points (starting at one buoy and aiming for another) often resulted in curved runs covering more than 100m of seabed.

The number of drop-down samples required for an area and the pattern of deployment will have to be considered as part of the overall monitoring strategy.

### *Best time of year to undertake sampling*

The best time for collecting video footage is usually related to ensuring the best likelihood of calm conditions and clear water. Although summer is usually the best time for calm seas, the best water clarity may be more specifically late summer or early spring (either side of spring and summer plankton blooms) and during neap tides. Comparative/time series studies should consider how different communities might appear at different times of year as turfs of plants and animals mature – some biotopes may be more easily identified during certain seasons.

### *Quality assurance measures*

- Guidance and training in the recognition of critical components of a biotope is necessary for anyone involved in conducting drop-down surveys or the post-processing phase. Footage from earlier surveys in the same area can be utilised for such purposes to improve familiarity with 'local biotopes'.
- Regional descriptions of national biotopes created through analysis of data from within the survey area (if available) will significantly contribute to the quality assurance of identifying biotopes from video records.
- A second opinion should be sought on the identification of a selection of biotopes (suggest 10% of the records should be double-checked), particularly those outside the specialisation of the person responsible for reviewing the tapes. Significant and consistent discrepancies between two workers must be resolved, perhaps through re-working of local biotope descriptions.
- A reference library of video clips and stills showing variations of confirmed biotopes should be included as part of a regional classification and added to as more information is collected during future survey programmes.

# Data products

- video recordings plus written record of content of each videotape
- still images (taken from video) to illustrate biotope descriptions
- position co-ordinates from dGPS related to time code on video and depth readings from echo-sounder or time-depth recording device (electronic files)
- field notes
- list of biotopes at given positions

# Cost and time

## Time required

### *Field*

Between 10 and 25 deployments can be achieved in a single day, although this is highly variable depending on depth, travel distance between sites, complexity of the sites, duration of slack water if required and duration of the power supply. Effort-limited 100m deployments can take approximately 10–20 minutes (to include the time taken to deploy and retrieve the video equipment), although more time is required to deploy and retrieve buoys if they are used to mark a site.

### *Post-processing*

As a rule of thumb, the time taken to score tapes is usually about two to three times the real-time length of the video footage.

### *Data analysis*

Habitat records can be matched by eye with existing biotope records, 'local' biotope descriptions from the same area or descriptions in the sublittoral biotope manual (Connor *et al.* 1997). Further viewing of video clips may be required to confirm the identification of a selection of biotopes.

### Equipment and survey costs

There are two main ways of calculating the cost of carrying out drop-down video surveys:

Option 1: where the survey is carried out using 'in-house' staff and equipment

Option 2: where the survey is contracted out to a ready-equipped survey company

The following table lists the items of equipment required for carrying out a drop-down video survey. The cost values given are estimates based on the cheaper end of the market – more sophisticated systems are available at higher costs.

**Table 2** Items required and approximate costs (in Autumn 2000) for a drop-down video survey

| *Extent* | *Items* | *Approximate cost* |
|---|---|---|
| Option 1# | Video camera* | >£1.5K |
| | Underwater video housing + umbilical* | >£2.5K |
| | Video lights* | >£1.5K |
| | Frame or sled* | >£500 |
| | Surface monitor* | £300 (x 2?) |
| | Video tape recorder (backup or instead of in-camera recording) | >£500 |
| | dGPS* | >£500 |
| | Echo-sounder (usually part of boat) | >£300 |
| | Time-depth logger | ~£250 |
| | Laptop PC (data logging) | >£1K |
| | Boat* hire or… | ~£250 per day |
| | Boat purchase | ~>£30K |
| | Power source – batteries | ~£200 |
| | Power source – generator | ~>£1.5K |
| | Playback facility – e.g. TV and high-end video player (can link camcorder directly to TV) | ~>£2K |
| | Ready-made drop-down systems (submersible camera, cable and surface monitor) | Start at ~£3K for basic system |
| Option 2 | External contract for survey company (including reporting, videotapes and field survey) | ~£220 per 100m transect (based on CCW information – Sanderson et al. 2000)** |

# Many of the Option 1 items can be hired.

* Essential items.

** For an organisation committed to regular drop-down video surveys it is substantially cheaper, in terms of cost per site surveyed (just over £120 per transect), to carry out the survey using in-house staff and equipment. The calculation takes into account estimates of staff time, overheads and equipment based on a comparative study carried out by CCW (Sanderson *et al.* 2000) although costs per site surveyed will vary considerably at different locations around the country.

## Health and safety

- Seagoing scientific work should comply with all rules and safety recommendations in force regarding safety at sea and boat use.
- High voltage equipment should be treated with great care in a seawater environment. Circuit breakers

earth connections (to seawater in this case) and measures to protect electrical equipment from coming into contact with seawater and the operators should be used where appropriate.
- Electrical equipment should not be handled with wet hands.
- The weight of the drop-down equipment should be considered with regard to safe manual handling practices.
- There is a risk of falling overboard when handling the drop-down camera – life jackets to be worn!
- There is a risk of snagging the umbilical and trapping the camera on underwater obstructions such as rocks, wreckage and lines. A buoy should be fitted to the surface end of the umbilical should the need arise to ditch it overboard.
- Avoid operating the gear in strong tides or rough weather, or whenever total control of the boat and camera is not possible at all times.

# References

Connor, D W, Dalkin, M J, Hill, T O, Holt, R H F, and Sanderson, W G (1997) *Marine Nature Conservation Review: marine biotope classification for Britain and Ireland. Volume 2. Sublittoral biotopes. Version 97.06.* JNCC Report No. 230. Joint Nature Conservation Committee, Peterborough.

Hiscock, K (ed.) (1996) *Marine Nature Conservation Review: Rationale and methods.* Coasts and seas of the United Kingdom. MNCR series. Joint Nature Conservation Committee, Peterborough.

Sanderson, W G, Holt, R H F, Kay, L, Wyn, G and McMath (eds) (2000) *The establishment of an appropriate prgramme of monitoring for the condition of SAC features on Pen Llyn a'r Sarnau: 1998–1999 trials.* Countryside Council for Wales, Contract Science Report No. 380. Countryside Council for Wales, Bangor.

## Useful websites

**http://www.cameratech.com/Products/Light-Motion-Housing2.html**

**http://www.videoquip.co.uk/underwat.html**

**http://www.amphibico.com**

**http://www.sli.unimelb.edu.au/research/mer/Irene_AMSA/index.html**

# Procedural Guideline No. 3-6 Quantitative sampling of intertidal sediment species using cores

Matt Dalkin[1] and Brian Barnett[2]

## Background

Core sampling of sediments is a well-established technique for obtaining quantitative data on infauna for analysis. The technique has been well used in the past, particularly on estuarine intertidal sediments, and a large amount of historical data is available for many of these areas in the UK. The advantages of using cores are that they provide quantitative results of a given precision and may provide a common standard for comparison between a number of data sets. The major disadvantage to the technique is that the collection and subsequent analysis of the samples can be very time-consuming and therefore costly.

This protocol has been adapted from those outlined in an Environment Agency internal report (Barnett 1993) and the MNCR Rationale and Methods (Hiscock 1996) in addition to the texts of Baker and Wolff (1987) and Holme and McIntyre (1984).

## Purpose

### Applicable to the following attributes

Core sampling will be appropriate for attributes concerning quality in terms of species richness and the abundance of species. Generic attributes are:

- Maintain or increase the species richness in the biotope and/or abundance of key species in biotopes.
- Maintain or increase the quantity of particular species of conservation importance.

### Applicable to the following survey objectives

- Establish/re-establish the species which are present in biotopes at a site including their abundance/biomass to within quantified limits of precision.
- Establish/re-establish the abundance/biomass of a particular species to within quantified limits of precision.

## Logistics

### Equipment

#### *Site location*

Maps and charts to an appropriate scale (1:10,000 or better) and a Geographical Positioning System/differential Geographical Positioning System (dGPS). On a large site it may be advisable to use rapid transport such as an All Terrain Vehicle (ATV) or hovercraft.

1 Scottish Natural Heritage, 2 Anderson Place, Edinburgh EH6 5NP, UK.
2 Environment Agency, Waterside House, Waterside North, Lincoln LN2 5AH, UK.

### *Sampling*

0.01m$^2$ cylindrical corer, 0.1m$^2$ box corer, 5cm diameter corer, plungers, spade/trowel/fork, 0.5mm mesh sieve, 1mm mesh sieve, buckets/strong plastic bags, specimen jars, wash bottles, weatherproof camera (with flash), waterproof notepad and pencils, waterproof marker, plastic/waterproof labels, folding quadrat 1m x 1m. Also appropriate protective clothing and health and safety equipment.

### *Storage and preservation*

10% buffered saline formalin solution (4% formaldehyde), 70% IMS, suitable buckets/containers. Also appropriate health and safety equipment for handling chemicals.

## Personnel

Minimum two field workers with knowledge of marine invertebrate taxonomy. Three field workers are optimum; two for wet work and one for dry (recording and photography).

## Time of year

There is no clearly identifiable time of year to survey littoral sediment communities. Summer months, which provide long periods of daylight and amenable weather conditions, involve the inclusion of large ephemeral populations of invertebrates and the recruitment of juveniles into adult populations. These factors must be accounted for in any data interpretation. More established winter populations are still prone to large fluctuations in structure through events such as heavy rainfall and freezing conditions. During winter, there are the logistical disadvantages of short daylight hours and potentially disruptive weather conditions.

Of primary importance is that any survey, if the results are to be compared over time, must take place at the same time of year to previous studies. Even then, major weather events between survey dates should be taken note of and included in any interpretation.

# Method

Locate site and collect specified number of core samples and supporting information.

## Survey objectives

To collect data on the abundance of a named species to a specified level of precision requires prior information on the density and aggregation of the species at the site. In general, the more abundant and less aggregated the species the less replicates will be needed. The procedure for establishing these criteria is described in Holme and McIntyre (1984). When the number of replicates required has been established the sampling procedure can be followed.

To collect standard information which will be applicable across the nature conservation agencies and the Environment Agency and Scottish Environment Protection Agency, the following CORE (Common Operation Required Element) and SSR (Supplementary Sampling Requirement) methods have been adapted from Barnett (1993).

## Field

### *Common Operation Required Element (CORE) methods*

The CORE methods are the minimum to be applied at each site.

(1) Five replicate samples should be taken to a depth of 15cm using a 0.01m$^2$ cylindrical corer. The samples may be collected from up to a maximum of 5m either side of the site centre but not up or down the shore.

(2) Each replicate sample (1 core) should be placed in a suitable container (resealable plastic bucket or strong plastic bag) and returned to the laboratory for processing. The outer surface of the container (not the lid) should be labelled with a waterproof marker and a waterproof label should be added to the sample to stay with it through processing. The label will show survey name, site number, survey station and date (for instance: 'Taw 15.2 on 12.9.98').

(3) The replicate samples are to be washed over a 0.5mm mesh sieve not more than 24 hours after collection (up to 2 days if refrigerated) and then fixed in 10% buffered saline formalin solution. (The reliability of field sieving is regarded as unproven and, therefore, only laboratory sieving can be confidently recommended.) Samples must not be fixed (or frozen) prior to sieving.

The samples will then be ready for processing in the laboratory.

### *Additional sampling*

In addition to the Environment Agency CORE methods the following is taken from the MNCR Rationale and Methods (Hiscock 1996) and deemed to be a minimum which must be applied at each site.

(1) A 1m  area is marked out using a quadrat within an undisturbed section of the site and a record taken of the abundance of obvious mounds and casts and any algal cover. The area is then excavated to a depth of approximately 20–30cm and examined in the field for larger macrofaunal species which may not be recorded in the core samples. Sample inspection can be aided by the use of a riddle (c. 5mm mesh) if practical.

(2) A sample for particle size analysis should be taken to a depth of 15cm using the 5cm diameter corer, with the sample frozen (within 24 hours) prior to analysis if information is required on organic components.

(3) Photographs should be taken of the site to show main features and also, where necessary, specific details.

(4) For the site as a whole the following site features must be recorded:

*Score 1–5:*

- surface relief (even–uneven)
- firmness (firm–soft)
- stability (stable–mobile)
- sorting (well–poor)
- black layer (1 = not visib., 2 = >20cm, 3 = 5–20cm, 4 = 1–5cm, 5 = <1cm)

*Note if present:*

- mounds/casts
- burrows/holes
- tubes
- algal mat
- waves/dunes (>10cm high)
- ripples (<10cm high)
- drainage channels/creeks
- standing water
- subsurface coarse layer
- subsurface clay/mud
- surface silt/flocculent

### *Supplementary Sampling Requirement (SSR) methods*

The SSR methods are to be applied at sites (in addition to CORE methods) where coarser sediments prevail. Coarser sediments are defined as <50% material passing through 0.5mm mesh sieve. Wherever possible it should be determined before the survey if SSR methods will be required, to economise on time and effort. SSR methods comprise two additional protocols dependent upon sediment type:

(1) Coarse sediment with silt/clay (substantial amount of <63μm diameter material). An additional 5 x $0.01m^2$ cores, supplementary to the CORE method, are taken and processed through a 0.5mm mesh sieve.

(2) Coarse sediment and others (sands and gravels, etc.). An additional 3 x $0.1m^2$ box cores, supplementary to the CORE method, are taken and processed through a 1.0mm mesh sieve.

*Subsequent fixing and laboratory processing is then standard as for the CORE methods.*

## Data analysis

Information collected on identification and enumeration of species present within samples (in addition to biomass/age where appropriate) plus ancillary information will require a computer with suitable database or spreadsheet software.

## Accuracy testing

The technique will produce quantitative results with precision and accuracy dependent upon the heterogeneity of the environment and the number of samples taken. Multiple sampling by different field workers can be used to test the accuracy of the field procedures. The guidelines of the NMBAQC[3] should be followed for all laboratory work.

## QA/QC

- Samples must not be taken any appreciable vertical distance up or down the shore from the site.
- Samples should not be taken from previously disturbed sediment (footprints, etc.).
- Care should be taken that the corers are inserted to the correct depth of 15cm and removed intact from the sediment, with excess material removed from the outside of the corer before placement into its container.
- Samples should be labelled correctly, on the outside of the container and with a waterproof label inserted into the sample to track it through processing.
- Any deviation to the CORE or SSR sampling methods should be clearly reported.
- Samples should be washed over a 0.5mm sieve not more than 24 hours after collection (up to 2 days if refrigerated) and then fixed in formalin solution. (The reliability of field sieving is regarded as unproven, and therefore only laboratory sieving can be confidently recommended.)
- Samples should not be fixed or frozen prior to sieving.
- Samples should be fixed in 10% buffered saline formalin solution (4% formaldehyde). The volume of residual sediment in a container should not exceed one-third to one-half the volume of formalin solution. For samples containing a high volume of clay/water a higher concentration of formalin may be required.
- The guidelines of the NMBAQC should be followed.

## Data products

Data products from core sampling traditionally take the form of species abundance per sample matrices or spreadsheets. Care must be taken when storing or exchanging information that all ancillary data is kept with the species records. Information on the physical habitat, juvenile counts, etc. will prove invaluable during analysis.

## Cost and time

### Costs

Costs involved with core sampling are as for other intertidal-based field work in terms of day rates for contractors, travel and subsistence. Day rates for contractors at the time of writing are in the order of £200–300 per person per day plus expenses. The added cost associated with core sampling is the laboratory analysis of the samples obtained. Contractors can charge either by volume or by sample basis with

3 National Marine Biological Analytical Quality Control programme – see **http://www.sepa.org.uk/research/NMBAQC/aq_main.html**

charges varying from £50–150 per $0.01m^2$ core depending upon sediment characteristics and species richness – species-rich samples or those with a large proportion of clay and organic detritus can be very time-consuming to process. Particle size analysis is in the order of £40–80 per sample.

### Time

#### *Field*

Two to three people will be capable of recording and taking five core samples and one quadrat dig within 30-40 minutes, longer if box cores are to be taken. Overall time will largely be dependent upon the spacing of sites and the number of replicates required. With large areas to be covered the possibility of using rapid transport such as quadbikes, other ATVs and hovercraft should be considered. Working two low tides a day will cut down on the time and hence the cost of field work.

#### *Laboratory*

A long time is usually required to process samples, though this depends upon a number of variables. It can vary between <1 hour to >1 working day for each core depending upon sediment type and richness of the sample.

## Health and safety

Particular care is to be taken to avoid being cut off by the incoming tide. Very soft shores should not be accessed on foot. Lone working should not be undertaken. Risk assessments must be addressed for specific locations where field work is being undertaken. Laboratory safety codes of practice (COSHH approved methods) must be followed.

## References

Baker, J M and Wolff, W J (eds) (1987) *Biological surveys of estuaries and coasts*. Estuarine and Brackish-Water Sciences Association Handbook, No.3. Cambridge, Cambridge University Press.

Barnett, B (1993) *National standard methodology for marine macrofaunal benthic sampling. 1: Intertidal soft sediments.* Peterborough, National Rivers Authority, Anglian Region.

Hiscock, K (ed.) (1996) *Marine Nature Conservation Review: rationale and methods*. Coasts and seas of the United Kingdom. MNCR series. Peterborough, Joint Nature Conservation Committee.

Holme, N A and McIntyre, A D (eds) (1984) *Methods for the study of marine benthos*, 2nd ed. IBP Handbook, No.16. Oxford, Blackwell Scientific Publications for International Biological Programme.

# Procedural Guideline No. 3-7 in situ quantitative survey of subtidal epibiota using quadrat sampling techniques

Eleanor Murray, English Nature[1]

## Background

Quadrats provide a quantifiable technique for measuring changes in diversity and abundance of conspicuous species. They provide quantitative data that can be analysed statistically, which helps us understand changes in communities in a monitoring context.

Quadrats facilitate accurate abundance measurements of numbers of species, thus reducing the errors incurred by inter-worker variability and achieving more consistent results, in both a spatial and temporal context.

Quadrats are traditionally used for monitoring the distribution of plant species. They are generally large in area, made of string, and laid out using pegs. Such a quadrat is impractical to use for subtidal quantitative sampling, where frame quadrats of $1m^2$ or smaller are used.

## Purpose

Quadrats are generally used for the quantitative assessment of biodiversity for a particular feature occurring within a site. The objective generally relates to the quality of a particular feature or biotope, where species richness may be an important or valued attribute of that feature.

Quantitative counts using quadrats provide a structured way to estimate abundance of species to estimate their population size, and/or to assess species richness and diversity of a biotope. The quadrat provides a simple, repeatable method, which is also suitable for a whole series of statistical tests; this makes it ideal for use in a long-term monitoring strategy. Quadrats are very versatile in terms of shape and size, and can be easily tailored to provide the best application for a whole range of different community types.

Quantitative counts in quadrats can also be used to determine biotopes, but it is generally easier and less labour intensive to use semi-quantitative methods to assign biotopes to particular areas.

It is important to recognise when communities and habitats are not appropriate for monitoring using quantitative quadrat methods. Ephemeral communities may change annually and could not be reliably monitored at the species level on a long-term basis. Similarly, mobile substrata are subject to considerable seasonal disturbance and would be inappropriate to monitor using quantitative methods.

### Advantages

Quantitative sampling by quadrat is advantageous as it:

- is generally non destructive;
- can be applied to a wide range of habitats, is easily repeated, and thus provides consistency to sampling;
- can provide very accurate and precise estimates of abundance;
- does not require any specialist equipment;
- provides a robust dataset for statistical analysis.

1 Northminster House, Peterborough, PE1 1UA, UK.

### Disadvantages

The disadvantages include:

- one quadrat size will generally not encompass all of the species being monitored;
- it is time-consuming compared to semi-quantitative or qualitative methods;
- it only samples very discrete areas within a larger feature.

## Logistics

A pilot survey of the area should be undertaken to identify representative examples of species or biotope, depending on the monitoring objective. For the assessment of species richness within a biotope, areas representative of a biotope encompassing most of the characterising species should be chosen. Where key species are being recorded, a transect or individual quadrat locations encompassing the majority of those species in reasonable numbers should be established.

It is essential that the following steps be undertaken:

(1) Define the area in which the quantitative sampling will take place. Moore (2000) recommended an area of uniform habitat, e.g. with consistent characteristics of substratum, inclination, water movement and depth.

(2) Determine community composition of the chosen area by undertaking a broad-scale baseline survey, using MNCR methods[2] or 'by eye' percentage cover estimates.

(3) Decide which species will be monitored within the quadrat and create a 'pro-forma' to aid quadrat counting.

(4) Determine what is the most appropriate quadrat size to use, depending on the size of species and community you wish to monitor.

### Equipment

The appropriate transport, navigation and safety equipment is required for undertaking all types of subtidal survey work. The appropriate diving equipment and underwater recording equipment, such as writing boards, underwater communication equipment and cameras (if required) are also necessary to undertake subtidal surveys.

The following additional equipment would also be necessary for quantitative recording work.

#### *Species 'pro-forma'*

A list of species should be compiled from the pilot study, including the commonly occurring and characterising species of the community. Moore (2000) recommended that unreliably recorded species not be included, such as cryptic species, very small species, very infrequently encountered species, or ephemeral species that are not characteristic of the chosen community. Mobile species such as crustacea and fish should not be recorded due to their transient nature. There are dangers in adopting this approach, as you are already limiting the assessment of species richness and community information (de Kluijver 1993), and particularly sensitive species groups may be missed: e.g. amphipod species are known to be sensitive to dispersed oil (SEEEC 1998).

Pro-formas should also have space for adding species that perhaps were not recorded during the pilot exercise. They should also provide identification notes for the species which are more difficult to identify in order to aid consistency of recording.

#### *Transects*

A transect can be used to help place the quadrats. The transect can be located either randomly or fixed in space; the quadrats can be located randomly the length of the transect, or at fixed positions along its length. Belt transects can be used for the quantitative counts of larger, more widely dispersed species (see Munro 1998; Howson *et al.*). 2000. A transect should be constructed with reasonably thick rope to avoid excessive tangling or knotting and should be weighted or negatively buoyant to prevent it moving in any water current.

2 See Procedural Guideline No. 3-3.

### *Fixing materials*

If fixed stations are to be used, suitable fixing materials such as ring bolts are needed. The method of fixing to the rock depends on the geology and accessibility of the site.[3]

### *Quadrats*

The design of quadrat will vary depending on the species or biotope to be surveyed. Quadrats are of a known area and may be round or rectangular, but are generally square, as these are easiest to construct, easily subdivided into grid-squares and are most amenable to percentage cover estimates (Kingsford and Battershill 1998). Quadrats can be made of any corrosion-resistant material, but should be neutrally or slightly negatively buoyant. When working in areas of kelp where it is difficult to place a full quadrat on seabed, a quadrat with an 'open' end may be used, where the open end can be 'closed' by a line to make a full quadrat; alternatively a two-sided quadrat may be used, with the position of the other two sides judged by eye.

The size of quadrat will vary depending on the survey objective, and the following conditions:

(1) The size range and distribution of organisms to be surveyed. This must take into account the fact that the larger, widely spaced organisms may need to be sampled by a different sized quadrat/transect approach. If there is a high species richness, then smaller quadrats should be considered in order to cut down the time of recording within a single quadrat.

(2) The heterogeneity of the community in terms of species patchiness or variability of substrata. The quadrat should aim to cover a representative range of species/substrata in order to obtain a representative sample of the community.

(3) The diving conditions: e.g. currents and limited visibility make recording by quadrat difficult, so it may be easier to take smaller quadrats to ease the diver's movement through the water. Depth is also a limiting factor in terms if survey time, and the appropriate size quadrat and counting method should be used in order to enable sufficient replicate samples to be taken in a single dive.

The table below provides guidance on the appropriate size of quadrat for the particular community sampled.

| *Quadrat size* | *Community to sample* |
|---|---|
| $1m^2$ | Areas with widely spaced, larger species and colonies, e.g. seafans |
| $0.25m^2$ | Areas with cover of foliose and filamentous algae, e.g. kelp forests |
| $0.1m^2$ | Areas of densely packed small, e.g. circalittoral faunal turfs |

### Personnel

Divers should posses the required diving qualifications to undertake underwater survey work (for the specified requirements, see Holt 1998).

Experienced marine surveyors, who possess the appropriate identification skills, should undertake this work. The workers should be familiar with the community and the species present: it is recommended that they are shown the checklist in advance of the survey so they can familiarise themselves with the species to be recorded. Pre-survey training in estimating percentage cover in quadrats would also be advantageous to ensure consistent records.

## Method

Divers should be fully briefed on how to deploy the quadrat before commencing the survey work. Instructions include the positioning of the quadrat to the relevant marker or transect line, and the rules of what species to count must be established.

In areas where the topography does not vary too greatly, belt transects may be used instead of placing quadrats along a single transect line. These are generally a fixed width and marked into intervals; counts/cover estimates are made in the marked area within the transect.

3 See Procedural Guideline No. 6-2 for site fixing methods.

## Sampling strategy: how many samples to take?

To achieve an efficient and cost-effective monitoring programme, a minimal sampling strategy must be designed in order to gain the correct amount of information with the least effort. This will vary depending on the biotope/species being surveyed.

To determine the number of samples to be taken, a baseline survey has to be undertaken to preferably over-sample the area to gain enough records to undertake analysis. The number of quadrats to reliably monitor change can be assessed using power analysis. Power analysis is a statistical technique which enables estimates to be made of the number of samples required to detect a given level of change (Snedecker and Cochran 1980).[4]

Cumulative species curves can also be used to assess when a population has been sufficiently sampled by a number of quadrats. The cumulative number of species is recorded with each increase in quadrat number until a point is reached when all of the common species have been identified and a further increase in quadrat number will not lead to any further significant increase in species number. Gamble (1984) gave a rough guide to the minimum number of samples as 'that which, if doubled, would yield only a 10% increase in information'.

Kingsford and Battershill (1998) and Moore (2000) recommended that 10 quadrats sampled within a discrete area would give adequate precision to detect notable changes in the whole community. Howson et al. (2000) concluded that between 8 and 12 quadrats would be adequate to detect a change in community of between 15 and 20%.

## Sampling strategy: fixed or random quadrats?

In areas where it is difficult to establish fixed locations, random sampling by quadrat may be the most appropriate technique to assess species richness/presence in a monitoring context. Random quadrats have also been used where destructive sampling techniques have been undertaken, e.g. population and condition of seagrass beds (Fowler and Pilley 1992).

The distribution of random quadrats is subject to bias by the worker. It is essential that the placing of a quadrat is not influenced by a diver trying to include a particular species, and it is important to stipulate this prior to sampling. In order to achieve even coverage of an area it may be appropriate to divide the area into compartments, and take random samples within each compartment, or use a randomly placed transect and take random samples along its length. Howson *et al.* (2000) used a 'ladder' transect to aid with randomising quadrats on sublittoral reef communities (see Figure 1). For a full explanation of different methods of randomisation, see Kingsford and Battershill (1998).

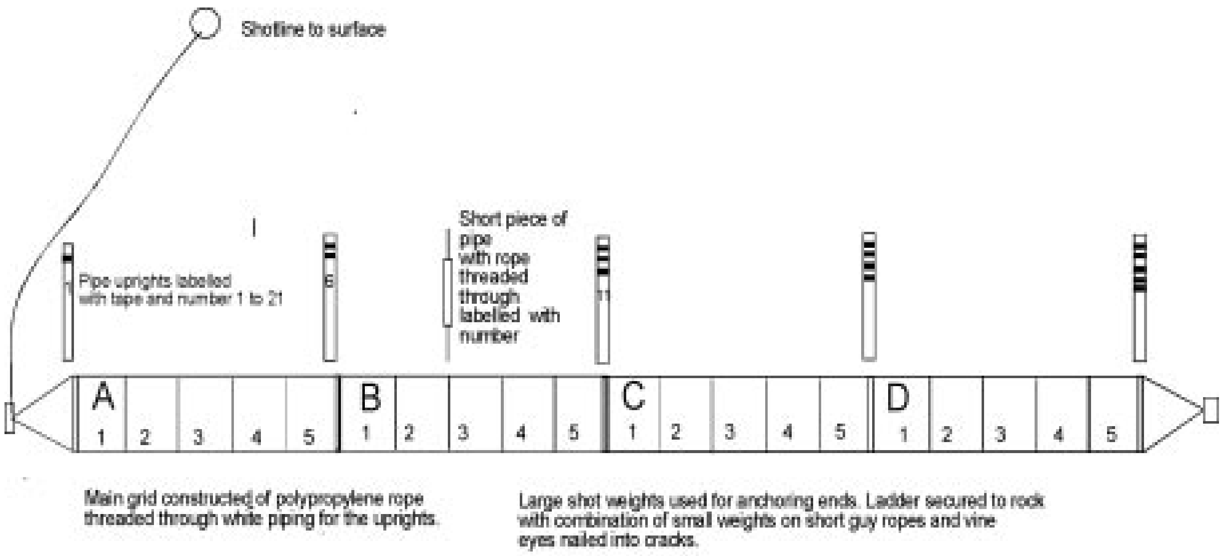


**Figure 1** Construction of ladder transect. Each square on ladder measures 1m x 1m (drawing not to scale).
To aid orientation by both the divers, the ladder was divided into four blocks, A–D, of five squares, 1–5. Each quarter of a square was a potential position for a quadrat. This enabled random positions to be selected for the quadrat sampling.

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4 A comprehensive review of software for power analysis is available at:
**http://sustain.forestry.ubc.ca/cacb/power/review/review.html**

Sites for single quadrats may be established and marked for relocation. A permanent marker for the site should be established (possibly a ring bolt in the rock face) and instructions or photographs for relocation constructed. Relocation time will vary with the quality of this information, and the familiarity of workers with the site. One or a number of the corners of the quadrat should be marked for exact repositioning. Moore (2000) used a permanently fixed transect to locate a number of permanent quadrats.

## Counting in quadrats

The quantity of a species within a quadrat can be assessed either by numbers of individuals, percentage cover or frequency of occurrence. Usually, for most recording schemes, there will be either a mixture of counts or % cover, depending on the species being assessed. The rules for deciding which is the most appropriate technique are given below:

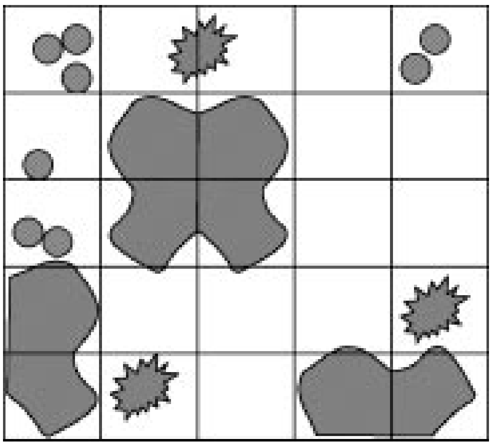
| *Counts* | *% Cover* |
|---|---|
| Mobile fauna | Flora and fauna forming crusts, mats or turfs |
| Sessile animals in low abundance, e.g. cup corals | Other ground-covering sessile fauna in high abundance, e.g. barnacles |
| Sessile erect animals, e.g. hydroids | Canopy cover of foliose algae |
| Tall algae, e.g. kelp | |

There are exceptions to these rules, which will have to be judged on a species-by-species basis, e.g. small patches of hydroids may be easier to assess using % cover, and uniformly sized sponge colonies may be easier to count.

For smaller quadrats (≤ 50cm x 50cm), it is easy to assess percentage cover by eye (de Kluijver 1993), although the accuracy of visual assessment is increased if the quadrat is subdivided into smaller grid-squares (Dethier *et al.* 1993). These smaller squares represent a percentage of the whole quadrat, and the number of squares filled by a single species can be easily counted which will give a percentage for the whole quadrat, with part records from the smaller squares also contributing to percentage cover. This method increases accuracy and may be appropriate where there is a complicated mosaic of species, such as algal turfs, but is much more time-consuming than unaided visual assessment.

Using the gridded quadrat also allows species to be recorded using frequency of occurrence scores. This is where the occurrence of a species within each of the grid squares is counted, giving a 'score' for each species between zero and the maximum number of grid squares. There are advantages in this approach in that it gives a single, simple measure for all species, and is potentially quicker to assess, although Moore (2000) found that the latter was not the case for small 0.25m$^2$ quadrats. Frequencies are used as an indicator of abundance, and should not be directly related to actual counts or abundance of a particular species.

A diagram representing species counted in a gridded quadrat is given in Figure 2 below.



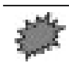
| *Species* | *Count* | *%* | *Freq.* |
|---|---|---|---|
|  | 8 | - | 4 |
|  | 3 | - | 4 |
|  | - | *25* | 8 |

**Figure 2** Representation of a quadrat with corresponding abundance estimates

# Data analysis

It is essential that prior to data analysis, the species records are closely scrutinised to eliminate any 'noise' which may affect the analyses. This may involve removing species that are unreliably recorded, e.g. those which are inconspicuous or difficult to identify. Species may be 'grouped' to genus level or higher where there is doubt or some discrepancy between workers as to the identification.

Multivariate and univariate statistics can be used for data analyses. Clustering and ordination methods can look at the variation of replicate samples within a single sampling area, to assess whether sampling had been restricted to a single biotope, and also to assess the variability of the biotope. Packages such as DECORANA and MVSP are very effective at undertaking these analyses. Ordination and clustering methods for community assessment are adequately described in Mills (1994) and Clarke and Warwick (1994).

Multivariate methods can be used to calculate the statistical significance to changes in the whole community (ANOSIM[5]) and highlight the species or suite of species responsible for the changes in community composition (SIMPER[5]). Multivariate techniques are relatively straightforward to interpret as they can present the extent of community change in a single visual graph.

Univariate analyses should be used to assess the significance of any change in the abundance of an individual species, or any changes in the diversity of a biotope. A student's t-test can be used to assess the change in abundance of individual species over time. There are numerous diversity indices that can be used to assess changes in species diversity over time, e.g. the Shannon–Weaver diversity index.

For fully worked through examples of all the statistics mentioned above, refer to Moore (2000) or Howson *et al.* (2000).

# Accuracy testing

The assessment of abundance within a quadrat may vary between workers; hence recorders must concentrate on giving an accurate assessment of abundance for each organism. Recording protocols must be prescriptive and carefully adhered to by the survey team. It should be written on the survey pro-formas whether an assessment by actual counts, % cover or frequencies should be undertaken for each species. Pre-survey training out of the water may be useful to familiarise the divers with the recording protocols.

For species counts, knowledge of all species to be counted is essential, especially with the more difficult taxonomic groups where there may be similar species within one quadrat. This should be achieved by using experienced surveyors who have been shown the species checklist in advance so that they can familiarise themselves with the species concerned.

An example of a survey protocol for Plymouth Sound is given in Box 1 (from Moore *et al.* 1999).

5 Both SIMPER and ANOSIM are available as part of the 'Primer' software (see: **http://www1.npm.ac.uk/primer/**).

**Box 1** Recording rules established for Plymouth sound monitoring study (from *Moore et al.* 1999)

The primary rule is to ensure that all records are obtained from the same precisely defined habitat. The habitat should be as uniform as possible, i.e. should not include any significant proportion of sub-habitats. This may require the surveyor to exclude or ignore certain sub-habitats (e.g. epiphytes on kelp stipes or the undersides of boulders). The communities present in these sub-habitats may need to be monitored separately; possibly with a different methodology from that used on the main habitat.

A survey duration should be defined. The length of the survey time will depend on the size of the quadrat/transect and on the biotope type. The time spent should be within 10% of the defined time, but the application of this rule will need to take account of the diving conditions. [Note: it should be possible for the diver to set a watch to beep at the end of the defined time.]

Although not proven by the available data, it is considered likely that the quality of the diving conditions will affect the quality of the recorded data. While some environmental factors cannot be controlled, operating rules should specify the threshold conditions for conducting the survey. These should include: available light and clarity of water, water currents, sea state. At the least, a record of the conditions should be maintained. It may also be appropriate to define the required torch beam characteristics (e.g. bright, medium or broad beam torch with fully charged batteries).

A series of rules should also be developed to define the types and forms of animals and plants that need to be surveyed. The abundance of some taxa is very difficult to record with any reliability because of their growth form, mobility or other characteristic. The presence of these taxa in data that are to be analysed quantitatively could reduce the power of the analysis, by introducing a much greater level of recording variability. It should be possible to reduce this variability by eliminating these species from the analysis. It may also speed up the survey if they are not even recorded. Thus, recording checklists should exclude such species and only include species which can be recorded most reliably.

The following species selection guidelines are considered to be appropriate for most situations where the conservation objectives are based on the composition and species richness of seabed communities of conspicuous species.

*Quantitative* monitoring should focus on species/taxa that are:

- sessile; i.e. not mobile like fish, crabs and gastropods. This is mainly because the presence of mobile species in full view (i.e. not hidden in crevices) can depend on factors such as time of day and other very short-term environmental fluctuations.
- attached to or living on the hard substratum surface (i.e. not epiphytic, except on encrusting coralline algae). This is partly to do with defining the sub-habitat, but also because it is often very difficult to estimate abundance of epiphytes.
- adult or near adult (i.e. not juveniles, spat, sporelings or eggs). This is because the presence of large numbers of juveniles etc. are usually temporary and can bias multivariate analyses. Furthermore, the juveniles of some species (e.g. *Metridium senile*) are produced in large numbers and often settle in habitats for which they are not suited; thus they may not survive there and cannot be considered true members of the community.
- easily recorded with the chosen units (i.e. either percentage cover or counts). Thus, if the chosen units are percentage cover (which will normally be the most appropriate) this rule will probably exclude many solitary erect species (in particular, many hydroids). This rule would need to be defined in greater detail for the specific biotope.

Note: it is emphasised that the application of these guidelines should not prevent the surveyor recording other species or taxa, either qualitatively or quantitatively. On the contrary, additional information will often be useful for more subjective and qualitative assessment of the data. However, objective analysis of the quantitative data should be restricted to those taxa that can be recorded most reliably and which are true members of the community.

# QA/QC

For monitoring purposes, it is essential that sites are relocated accurately to give a continuous accurate dataset. A good map of the site is required, and each quadrat should be given a unique reference, so that time series data for a single station can be easily accessed. In terms of sampling the following rules must be applied:

(1) Re-survey of a site should take place at the same time of year (if appropriate).

(2) The same size and shape of quadrat must be used each time.

(3) The same method of counting species (counts or % cover) should be used each time.

(4) For random samples, the same number of quadrats across a broadly similar area are to be counted each time.

Survey personnel must familiarise themselves with the fauna and flora or the area, and should undertake an inter-worker calibration exercise before starting the monitoring.

# Cost and time

A full review of the costs and times involved in subtidal quantitative sampling is given in Moore (2000).

The preparation of a checklist of species and the establishment of recording rules may result in reduced survey time or allow more quadrats to be surveyed in the same number of dives. These benefits must be offset against any additional time for undertaking a pilot study to define appropriate recording rules.

If fixed quadrat locations are used, they reduce the spatial variability element in the data and therefore reduce the number of quadrat records needed to detect any temporal changes. However, this saving must be set against the extra time, and therefore cost, required to establish and maintain the fixed locations. In many locations these costs may be very limited, particularly if it is necessary to mark the site for relocation purposes anyway. However, if there are potential problems with marking the site – e.g. on very mobile mixed substrata or at very popular diving sites – these costs may become excessive.

# Health and safety

All field staff must follow approved safety procedures published by their host institution, or that of the contracting agency, whichever are the more stringent.

All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[6] and must follow the Scientific and Archaeological Approved Code of Practice.[7]

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# Procedural Guideline No. 3-8 Quantitative sampling of subtidal sediment biotopes and species using driver-operated cores

Paul Brazier, Countryside Council for Wales[1]

## Background

This protocol has been adapted from the Marine Nature Conservation Review Rationale and Methods (Connor and Hiscock 1996).

## Purpose

### Applicable to the following attributes

Core sampling in the sublittoral is appropriate for attributes concerning identification of biotopes and their quality in terms of species richness and the abundance of species. Generic attributes are:

- Measure the species richness in the biotope and/or abundance of target species (rare, fragile, declining, representative) in biotopes.
- Measure the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is 'special').

It is also applicable to the following general survey objectives

- Establish/re-establish the species which are present in biotopes at a site including their abundance and/or biomass within statistical limits.
- Establish/re-establish the species which are present along a gradient of change away from a point source of disturbance including their abundance and biomass within statistical limits.

### Advantages

This method provides quantitative results which may be appropriate for statistical analysis and interpretation and provide a common standard between a potentially large number of datasets. Additional information is provided by diver observations of sediment type, sediment features and epifauna.

### Disadvantages

The collection and subsequent analysis of sediment samples can be very time-consuming and therefore costly. The use of a single pooled sample of cores may not provide an adequate sample for rigorous statistical analyses.

## Logistics

*Equipment required*

1 Plas Penrhos, Ffordd Penrhos, Bangor LL57 2LQ, UK.

- Appropriate vessel from which to operate SCUBA divers, navigation and safety equipment including Differential Global Positioning System (dGPS).
- Complete SCUBA equipment as required under the JNCC diver guidelines (Holt 1998).
- Eight 11cm diameter (approx. $0.01m^2$) cylindrical corers and a 5cm diameter corer, with means to seal the corers whilst underwater (caps or bungs); all items to be secured in a carrying basket which is secured to a lifting rope and buoy.
- Preferably a washing system including a puddling hopper, running water hose and sieve stand to ensure effective, gentle sieving of the samples.
- Specimen buckets and pots, notepad, reliable labels for placing into the sample containers (Dymo™ tape proves very effective) and also indelible pen for marking the outside (not the lid) of the sample container; strong plastic bags and labels for particle size samples.
- 10% buffered formal saline (4% formaldehyde) either on the vessel or immediately available after a day's sampling; 70% IMS (industrial methylated spirits) for subsequent storage of samples after initial fixing with formalin.

### Staff required

Minimum HSE diving team (four divers with appropriate qualifications, see Holt 1998) plus possible additional boat handling staff with appropriate skills to match the environmental conditions expected.

### Best time of year

There is no clearly identifiable time of year to survey sublittoral sediment communities. Summer months, which provide long periods of daylight and favourable weather conditions, are subject to the inclusion of large ephemeral populations of invertebrates and the recruitment of juveniles into adult populations. These factors must be accounted for in any data interpretation. Longer established winter populations are less prone to these seasonal influences. During winter, there are the logistical disadvantages of short daylight hours, potentially disruptive weather conditions and impracticable working conditions.

Of primary importance is that any survey, if the results are to be compared over time, must take place at the same time of year to previous studies. Even then, major weather events between survey dates should be taken note of and included in any interpretation (e.g. dramatic changes in freshwater input in estuaries, storms).

### Survey brief

Locate sites and collect the specified number of core samples along with supporting information.

## Methods

### Field

*Site location.* Latitude and longitude for sample sites should be determined prior to beginning field work (or should be the same as for sites surveyed in the first monitoring survey). In using the Geographical Positioning System make sure that the correct datum is employed, e.g. WGS84 or OSGB, etc. Positioning should be by dGPS with better than 5m accuracy (offset on the vessel should always be noted) with quality control checks taken from known positions and records of signal quality during the survey.

*Sample collection.* The corers and corer caps must be clean and secured in their container and a rope attached before the SCUBA divers leave the surface and take the complete assembly to the seabed. Depending upon the sediment type, completion of the coring may take from 5 to 30 minutes. Once a core has been forced into the sediment by a rotating and pushing action, a cap is placed on the top of the corer, the sediment around the corer is manually wafted away and a cap placed on the lower end. This ensures that no material is lost from the corer when it is pulled from the sediment. The whole process should be completed as quickly as possible to avoid loss of animals that would otherwise burrow down and out of the core. A larger scale search of the surrounding seabed is done to look for more widely dispersed, typically larger fauna such as large bivalves, urchins and fish which would not otherwise be recorded using the corers. Notes are made by the divers of sediment features and epifauna. An additional, smaller sample of sediment is also collected for particle size analysis. Additional notes are made by the divers of epifaunal species, sediment features, trace evidence of epifauna (tracks, burrows, etc.) water depth and time (GMT 24 hr clock). The surface cover lifts the complete assembly with full corers to the surface to begin sieving.

A single sample consists of 8 cores which are pooled and sieved over a 0.5mm mesh and preserved as a single entity.

For the site as a whole the following site features must be recorded:

| | |
|---|---|
| *Score 1–5* | Surface relief (even–uneven)<br>Firmness (firm–soft)<br>Stability (stable–mobile)<br>Sorting (well–poor) |
| Note if present: | Mounds/casts<br>Burrows/holes<br>Tubes<br>Algal mat<br>Waves/dunes (>10cm high)<br>Ripples (<10cm high)<br>Subsurface black layer<br>Subsurface coarse layer<br>Subsurface clay/mud<br>Surface silt/flocculent |

*On-board processing.* The sample should be checked for adequacy. In general a depth of greater than 15cm of sediment in the corer is ideal, although in coarse sediments this may be difficult to achieve on occasions. Samples that are less than 15cm deep are noted.

Additional notes are made on the surface colour, surface texture, change with depth, smell and presence of $H_2S$-blackened sediments, dominant fauna, presence of dead shells or single large stones, etc. These additional notes can often prove invaluable in the interpretation of data.

The sediment samples should be handled as gently as possible to avoid damage to the infauna. This requires placing the core contents into a receiving hopper. Water is added gently to the receiving hopper to produce a water sediment suspension. The sample is transferred in small quantities to a sieve in a separate water-filled hopper. Sieving should be by puddling (no direct jetting of water on the sieve). The residue on the sieve should be back washed into a pre-labelled specimen container. Back washing should be undertaken over a tray or fish box to avoid accidental loss of the sample. With coarser material (gravel and pebbles) it is advisable to remove material as it builds up in the sieve and place it into the sample pot at regular intervals to avoid damaging the biota in the sieve. The sieve should be checked and cleared of trapped fauna or any sediment impeding its efficiency. A waterproof label with site details should be added to the sample container (adhere to NMBAQC requirements). Fix the sample in 10% formal saline: this may be undertaken on return to the shore, but in all cases it must be done within 24 hours of collection.

*Additional sampling.* To collect data on the abundance of a named species to a specified level of precision requires prior information on the density and aggregation of the species at the site. In general, the more abundant and less aggregated the species the less replicates will be needed. The procedure for establishing these criteria is described in Holme and McIntyre (1984). When the number of replicates required has been established the sampling procedure can be followed as above. This may require the use of different size corers, number of pooled cores and different sieve mesh sizes depending upon the objectives of the monitoring survey. Clearly, if a targeted species is greater than 5cm diameter but lives further than 15cm down in the sediment, a deeper core will be required, but a mesh size of 2cm would be adequate to collect the specimens.

## Laboratory

Adequate wet facilities including a fume cupboard for processing samples are required. Bench space for binocular and compound microscopes and all appropriate taxonomic keys and guides. The requirements are:

- Identify the infauna to the highest taxonomic level practicable (usually to species level).
- Supply a list of taxa, with numbers of individuals for each sample on a standard sediment sample or in a spreadsheet format supplied on computer disc/tape. Taxa should be listed according to Howson and Picton (1997). Species not listed in Howson and Picton should be named according to a recognised authority, which should be cited together with the taxonomic publication used to identify the specimen.

- Provide a voucher collection of specimens. Examples (preferably several) of each taxon identified from the series of samples (each taxon stored separately in IMS in suitable vials or jars, if possible glass) or examples of predetermined target species. These should be properly labelled using specimen labels.

Particle size analysis should be undertaken according to the methods described in Holme and McIntyre (1984) or by more recently developed techniques using laser technology that are supported by research papers as valid and reliable.

## Data analysis

A range of data analysis procedures are available and those used will wholly depend on the objectives of the survey work. Data analytical techniques are described in Clarke and Warwick (1994). The techniques most widely accepted in the UK for the definition of faunal assemblages, although by no means the only ones (see Clarke and Warwick 1994), are Bray and Curtis similarity analysis in combination with a hierarchical clustering procedure and ordination by Multidimensional Scaling (MDS). These techniques are available in the Primer package (see Clarke and Warwick 1994). The multivariate analyses TWINSPAN and DECORANA are also useful programs to aid in the identification of biotopes (Hill 1979a, b).

In terms of monitoring it may be necessary to provide a quantitative comparison based on only part of the faunal assemblage (e.g. infauna only). The principal reason for this constraint is finding compatibility between counts of individuals of each species for the infauna and percentage cover or abundance scale data for colonial epifauna. The degree to which manipulation will be necessary is clearly related to the substratum type. Most fine particulate sediments will be comprised almost exclusively of infauna, whereas sediments with a significant gravel content and in relatively sheltered conditions have a diverse and abundant epifauna.

Having defined the faunal assemblage to be examined, the minimum data analysis should comprise a consideration of number of species, total abundance and biomass. These three ‘primary variables’ may be used to test year-to-year variation (in terms of percentage difference) and can in turn be used to undertake compliance monitoring according to the methods described in the GCSDM (1993). These methods were originally devised for compliance testing at sea disposal sites and have been expanded to include wastewater discharges. They can, therefore, be employed to provide a coarse measure of deviation from the *status quo* with limits applied on a site-by-site basis and may be considered as ‘Action Points’.

Where possible the analysis of primary variables should be supported by other univariate (diversity indices and graphical methods) and multivariate analysis techniques (MDS and supporting analyses such as ANOSIM), particularly where any identification from normality is noted. In all cases a broad approach to data analysis should be adopted, without losing site of the species that contribute to the data sets.

## Accuracy

The data produced will be quantitative although the heterogeneity of the environment and the number of replicates collected will affect the variability within the data. Inaccuracies can arise due to a range of factors, including the possible lack of experience and conscientiousness of workers and their sample identification skills. The amount of error or variability likely has been established by tests undertaken under the auspices of the NMBAQC and advice has been given on minimising such variability[2].

Information collected on identification and enumeration of species present within samples (in addition to biomass where appropriate) plus ancillary information will require suitable computing software.

### Time required

#### *Field*

The time constraints for using diver-operated corers are the practical limitations placed on the diver for repeat dives. Under the JNCC diving regulations (Holt 1998), divers are required to remain within no-stop times and to have a surface interval of at least 2 hours for repeat dives. Therefore, realistically, a

2 See National Marine Monitoring Programme Green Book: **http://www.marlab.ac.uk/greenbook/GREEN.htm**

team of 4 divers can complete 4 to 6 sites in a day provided that travel time between sites is not great. In addition to this is the time taken to launch and recover (or moor) the cover boat.

### Laboratory

Time required to process samples is usually high depending upon a number of variables and can vary between <1 hour to >1 working day for each sample depending upon sediment type and species richness of the sample.

### Data analysis

The input of data into a suitable format should be approximately standard for species, abundance and replicates. The following is copied from the procedural guidelines for sublittoral grab sampling (Thomas 1998): Time taken for data analysis will depend on the extent of the analyses employed. Simple compilation of a spreadsheet including classification using the MCS/Ulster Museum Species Directory codes and full QC checks may take up to two days for a 50-sample/400-species data set. Employing a multi-statistical package is very rapid (<1 day) once the data has been adequately formatted, but a time scale for the interpretation of the outputs is dependent on the complexity of the results and may involve several reruns of the data.

## QA/QC

- Samples should not be taken from sediment that has been disturbed by the divers' presence.
- Cores must be taken randomly within a defined area (e.g. 25$m^2$).
- Care should be taken that the corers are inserted to the correct depth (up to 20cm) and removed intact from the sediment, with excess material removed from the outside of the corer before being tipped into the receiving hopper.
- The content of the corer must be checked prior to being tipped into the receiving hopper to ensure that there has been no wash-out of sample through poorly fitted caps to the corers.
- Samples should be washed over a 0.5mm mesh sieve not more than 24 hours after collection and then fixed in formalin solution.
- Samples should be fixed in 10% buffered saline formalin solution (4% formaldehyde). The volume of residual sediment in a container should not exceed one-third to one-half the volume of formalin solution. For samples containing a high volume of clay/water a higher concentration of formalin may be required.
- The guidelines of the NMBAQC should be followed where available.

## Health and safety

Qualifications in boat handling must conform to the requirements of contractors for the purposes of safety and insurance. All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[3] and must follow the Scientific and Archaeological Approved Code of Practice.[4] The JNCC guidance notes must be met by all divers (Holt 1998). Risk assessments must be made to provide an analysis of the likely environmental conditions. Poor weather conditions in the shape of high winds or low visibility are particular risks during boating activities. High tidal streams and low underwater visibility have particular health and safety implications to divers. Laboratory safety codes of practice (COSHH approved methods) must be followed.

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3 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7
See: **http://www.hse.gov.uk/spd/spddivex.htm**

4 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997.Approved Code of Practice and Guidance - L107. HSE Books 1998. ISBN 0 7176 1498 0.
See: **http://www.hse.gov.uk/spd/spdacop.htm - a**

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# Procedural Guideline No. 3-9 Quantitative sampling of sublittortal sediment biotopes and species using remote-operated grabs

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## Background

Systematic benthic sampling and analysis originated from investigations of fisheries resources (for example Peterson 1911). Benthic grab sampling techniques have remained essentially the same since that time, although significant developments with respect to positioning equipment and data analysis techniques have occurred. Survey techniques have been developed and adapted to suit a variety of needs, particularly in the oil and gas industry (e.g. rig de-commissioning, pipeline routes), the water industry (outfall discharges), capital and maintenance dredging (spoil disposal), the aggregate industry (licence application) as well as pure research studies and most recently studies designed for the assessment of conservation status within SACs.

This guideline has been adapted from established benthic grab sampling methods described in Holme and McIntyre (1984), Baker and Wolff (1987) and Rees *et al.* (1990). Further consideration has been given to sampling strategies and data analyses from other texts including MAFF (1993), Clarke and Warwick (1994), Ferraro *et al.* (1994), GCSDM (1997), Rumohr (1999), Nikitik (2000) and workshops (Elliott 1997, Worsfold and Dyer 1997).

## Purpose

The present guideline has been designed to provide information sufficient to fulfil marine SAC conservation objectives taking into consideration the possible pressures that may exist within or in the vicinity of the SAC. Specific conservation objectives for marine SACs are in preparation and have therefore not been precisely defined. However, the following generic attributes may be met by using benthic grab sampling:

- Determine the distribution of the different biotopes or biotope complexes within a SAC.
- Identify rare, fragile, representative or rich biotopes at the site.
- Measure the species richness in the biotope and/or abundance of key species (rare, fragile, declining, representative) in biotopes.
- Identify and enumerate the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is 'special').

### Specific survey objectives

- Establishing the benthic community composition within and between biotopes.
- Ground-truth mapped areas (established by video or acoustic ground discrimination techniques, e.g. sidescan sonar) occupied by biotopes and biotope complexes).
- Establishing the species which are present in biotopes at a site, including their abundance and biomass within statistical limits.

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- Establishing the species which are present along a gradient of change away from a source of disturbance including their abundance and biomass within statistical limits.

### Advantages

The methods:

- are easily employed from a range of boat sizes;
- provide quantitative data on sedentary infaunal and slow moving or sedentary epifaunal species from particulate habitats, which accurately reflect environmental changes;
- provide quantifiable results which are open to statistical analysis and interpretation;
- produce replicable data to a common standard (if using the same sampling gear);
- provide data to which statistical limits may be applied, thus allowing determination of measurable change;
- provide data for certain habitats for which considerable comparative information is available;
- provide data from which biotopes may be quantitatively determined using multivariate analysis outputs.

### Disadvantages

- Large variations in community and biotope may occur over a small spatial scale due to natural patchiness, which consequently require intense sampling to account for the variation, due to the 'blind' nature of sample collection.
- Different seabed types require different grab or dredge sampling gear with consequential variation in efficiency.
- The choice of which gear to use relies on preliminary information either in terms of historic data about sediment type, seabed video or remote ground discrimination surveys (e.g. Roxann or sidescan sonar).
- Analysis of sediment samples for fauna can be costly and time consuming.
- Larger and more mobile epifauna tends to be undersampled.
- Data produced for epifauna and infauna may be in different formats.
- Biotope classifications are at present limited for many sediment environments.

## Logistics

### Equipment

#### *Site location*

Maps and charts to the appropriate scale should be obtained, along with as much information, in the form of historic data, as possible (particularly important is sediment characteristics, from which the correct sampling equipment can be determined). Ideally site-specific video should be obtained.[2]

#### *Sampling equipment*

Numerous types of sampling grab are available (see Holme and McIntyre 1984). For the requirements of the present guideline the following are recommended:

- van Veen (lightweight version), appropriate to soft sediments and shallow waters
- Day Grab, appropriate to a range of sediments, from muds through sands to mixed sandy gravel
- Hamon Grab, appropriate to mixtures of sediment, particularly consolidated coarse gravels and cobbles

Consideration may be given to alternative sampling gear, particularly spring-loaded grabs including the Smith-McIntyre or Shipek, which are able to sample coarse substrata and may be deployed from a small vessel. In general these samplers tend to be less easy to handle and take a smaller volume sample. As

2 See Procedural Guidelines 3-5 and 3-14.

an alternative to the grab samplers, a dredge (e.g. box dredge) may be employed, particularly if ground truth data only is required. Dredges produce, at best, semi-quantitative data and are not suitable for determining changes in community structure. However, dredges generally sample lower density epifauna more successfully than grab samplers.

Sampling gear and sample storage equipment should be recorded on a checklist. An example checklist is provided in Appendix 1, which contains all equipment likely to be required. Routine cleaning of equipment, using fresh water, will be required after each survey. Maintenance of shackles and any load-bearing cables should be regularly checked.

### *Vessel and positioning equipment*

The size of vessel required should be chosen as appropriate to the conditions in the sampling area and the type of sampling gear to be employed. For example a lightweight, hand-hauled van Veen Grab can be operated from a small open survey vessel (<6m) in sheltered estuarine waters, while the more robust Hamon Grab appropriate to exposed open coastal waters will need to be operated from a substantial vessel (>15m). In all cases where heavy sampling gear is deployed the vessel must be fitted with a suitable power winch and an 'A' frame or gantry (see also Appendix 2).

A differential Geographical Positioning System is essential, with better than 5m accuracy.[3]

### Personnel

Both the Day Grab and van Veen Grab can be operated by two survey staff in addition to a winch operator and skipper. In certain circumstances the van Veen Grab does not need to be winched. The optimum number of survey staff is three to include two for grab deployment and recovery with third for recording and sample processing. The third person may also operate the winch if sufficiently experienced. The Hamon Grab is less easy to handle and requires a third person to assist with deployment and recovery in addition to the skipper and winch operator. At least two of the survey team should be experienced with handling grabs and have experience of sampling and sieving marine invertebrates.

### Time of year

The optimum time for field work in inshore waters is May to September. In terms of avoiding recruitment periods the best sampling time is February to May. May is, therefore, the optimum sampling period. Practical constraints may preclude this period so the most important consideration is that repeat surveys should be completed at the same time of year, taking into account predictability of weather conditions.

## Method

### Field methods

### *Sampling arrays*

A variety of sampling arrays may be employed depending on the objective of the study. An important consideration is the applicability of certain of the statistical procedures that may be required subsequently. The following are examples that are relevant to monitoring SACs, but they do not include all types available:

*Random*. A random array is plotted using a grid over a map of the survey area, with numbered *x* and *y* axes. The location of each of the sites should be determined using pairs of numbers from random number tables. The first number corresponds to the x axis and the second to the y axis. Random surveys are frequently employed if no other data is available at the pilot survey stage. The problem with random arrays is that some areas may be undersampled. To avoid this possibility stratified random selection may be used, which requires some knowledge of the proposed survey area.

*Stratified random*. This method involves dividing the survey area into discrete sections which are allocated a proportional or weighted number of randomly selected sites. The stratification may be selected on the basis of environmental conditions, such as known biotope or other variables, including water depth, distance from shore, etc. Site selection with stratification is the same as for the random array. The number of sites per stratification should be proportionally related to the total number, generally in terms of area. Weightings may be applied which allow greater numbers of sites to be

3 See Procedural Guideline 6-1.

allocated to more important areas as required.

*Systematic grid.* A grid may be plotted over a chart or digital copy of the area to be surveyed. This array is generally employed to consider impacts due to known but diffuse pollution sources. The array should cover the full area within which an expected change may occur, with similar but remote areas included as control sites. Sites should be located at the intersection of lines on the grid. The grid need not be square.

### Site location

Latitude and longitude (or grid) for sample sites should be determined prior to beginning field work (or should be the same as for sites surveyed in the pilot or previous monitoring survey). When using the GPS make sure that the correct datum is employed, e.g. WGS84 or OSGB, etc. Positioning should be by dGPS with better than 5m accuracy (offset on the vessel should always be noted), with quality control checks taken from known positions and records of signal quality during the survey. See note [3] above

### Sample numbers

The number of samples and replicates required is subject to the necessity for achieving an accurate description of the fauna, while taking into account natural variation, which is dependent on the sediment type and environmental conditions. Ideally for pilot surveys a large number of replicates should be collected (6–10), with the optimum number required for repeat surveys calculated after analysis has been completed. In all cases it is better to collect more samples than required, if time allows. However, where costs are an important consideration it is recommended that, at each site, a minimum of 5 replicate samples should be collected in the case of the Day Grab or van Veen. A minimum of four replicates only may be used for the larger Hamon Grab samples (each of which may be up to 20l in volume).

### Grab deployment

Full deployment procedures are listed in Appendix 3. The following briefly describes field procedures. At each site the grab should be set down gently, with the winch wire remaining vertical. In the case of deep or fast-moving water this may require additional weights on the grab and maintaining position by motoring into the current or, in exceptional circumstances, anchoring. Site position should be noted at the time the grab sample is taken. Additional notes should be made of the water depth, time (24 hr clock), weather and sea state (see Appendix 4). On retrieval the grab should be placed on the landing table.

### On-board processing

The sample should be checked for adequacy. In the case of the Day Grab and van Veen the depth of the sediment at the centre of the grab should be measured. In general a depth of greater than 7cm is required in muds and 5cm in hard sands. Anything less may be retained, but should not be used unless no other sample is available. The Hamon Grab sample should be emptied directly into a box marked with volume gradations. Anything less than 7.0l should be discarded, unless no other sample is available. Records of sample size must be noted.

Where practicable, photographic records should be made of whole samples (only possible when decanted into hoppers in many cases), along with information on surface colour, surface texture (e.g. concretions, presence of mudstone), colour change with depth, smell and presence of $H_2S$ blackened sediments. Consideration should be given to measuring Redox potential, Eh (mV) with a platinum pin electrode, bearing in mind that in coarse sediments it is not possible to achieve stable values. Additional notes covering any aspect of the sample should be made, including dominant fauna, presence of dead shell or single large stones, etc. These additional notes can often prove invaluable in the interpretation of data. Ideally a pro-forma should be prepared to record these details (see Appendix 4 for an example); alternatively information should be noted in a log book.

If sub-sampling is required for metals, organic matter/CHN or other chemicals, these should be collected directly from the undisturbed grab bucket before the sample is decanted into the receiving hopper. Sediment particle size samples may be collected from well-mixed sediments once decanted. Appropriate scoops should be employed depending on the analysis required (metals need plastic scoops, others need stainless steel). In general once samples have been subsampled for granulometric and other analyses, they should not be used for faunal analyses.

The faunal samples should be gently decanted into a receiving hopper (large buckets in the case of Day and van Veen, a fish box for the Hamon). The grab is to be rinsed thoroughly before redeployment. Water should be added gently to the receiving hopper to produce a water sediment suspension. The sample is transferred in small quantities to a sieve in a separate water-filled hopper.

Sieving should be by puddling, with no direct jetting of water on the sieve and ensuring no water overtops the sieve. Consideration should be given to two-stage sieving for coarse sediments, to avoid specimen damage, i.e. 5mm initial sieve over a 1mm sieve.

The residue on the sieve should be back washed into pre-labelled specimen containers (mark on main body of pot and indicate job name/number, date and location). Once samples are collected containers should be marked three or four times with site and replicate number. Back washing should be undertaken over a tray or fish box to avoid accidental loss of the sample. The sieve should be checked and cleared of trapped fauna and any sediment impeding the efficiency of the sieve. A waterproof label with site details should also be added to the sample container.

Fix samples in 10% formal saline: this may be undertaken on return to the shore, but in all cases it must be done within 24 hours of collection. The sample containers must be filled with sufficient fixative to completely cover the sediment retained.

## Laboratory methods

### *Preservation and storage of faunal samples*

Formalin is added to the faunal samples obtained as soon as possible. Formalin at 40% w/v is added to the seawater already covering the samples until an approximate dilution to 4% w/v is obtained. If unbuffered formalin is used, di-sodium tetraborate (Borax) should be added to the sample at a ratio of 1.5g/l to prevent the leaching of calcium from shell material within the sample.

The above should be taken into account particularly if samples are to be transferred once treated with formalin. Only vehicles with separate driving compartments, or preferably open-backed trucks, are acceptable.

The samples collected should be registered on return to the laboratory in a central record book. Each site is allocated a unique registration number (which should be written on the bucket) and notes on the number of replicates, survey and job number together with date taken, sampler, and who registered the samples, analyses required and other notes are recorded in the book. Grab samples (and dredge samples containing fine material) can be stained with Rose Bengal, which turns animal protein red and aids the sorting process. Very little stain is required for most samples (<0.2g), and over-staining will hinder identification of the samples. Once stain and formalin have been added, samples should be stored in a cool, well-ventilated and secure area. Finally, a check on the labelling of all pots should be made to avoid later confusion.

### *Sorting, identification and biomass analysis*

A national standard method, such as that prepared by the EA (White 1993), with respect to laboratory treatment of biological samples, should be adhered to, although consideration should be given to ongoing developments as part of the best practice review (IECS 1998). In most cases a procedure should be adopted and modified in-house by the organisation undertaking the analysis and should include a clear QA element.

### *Special note*

An important consideration with respect to the objectives of the SAC monitoring requirements is the analysis of epifauna. Many of the existing biotopes identified by the JNCC are based on visually observed epifaunal components. Historically the analysis of particulate environments has been based on infauna, with limited regard for the assessment of the epifauna. Where epifauna has been assessed it tends to be given a presence/absence attribute. Clearly where the data acquired from benthic grabbing surveys are to be used in the context of existing and future biotopes, a numerically accurate assessment of epifauna must be adopted. To overcome this it is possible to employ a numerical abundance estimation based on the SACFOR scale (Jarvis, S in prep.). To allow inclusion of data in further analysis, a numerical equivalence, based on an inverse $Log^e$ transformation, may be applied.

### *Physico-chemical analysis*

Chemical methods are not defined in this series of guidelines but references to numerous techniques can be found in CEFAS (1997). Particle size analysis should be undertaken according to the methods described by Buchanan (1984) for sediments with a substantial proportion greater than 63mm in diameter. Sediments with substantial proportions less than 63mm in diameter may be more effectively analysed by laser diffraction methods. Data should be presented according to JNCC standard format.

# Data analysis

## Objectives

Reference back to the conservation objectives must be made at this time. The extent to which data analysis is pursued, or even the level of invertebrate identification, is related to the objective. For verification of many of the existing JNCC biotopes (surveyed by video and AGD ground truthing) it is not necessary to undertake in-depth identification and enumeration, as most of the existing biotopes are based on a relatively limited number of dominant species, frequently including evident epifauna. Further particulate-based biotopes, which will be defined in the future, will be based on a wider range of infaunal species and will probably rely on the use of the multivariate analysis described below.

Other objectives require that a measure of evident change in biotopes is made. To achieve this, analytical methods are required, to which statistical limits may be applied to determine acceptable variation.

## Procedures

A range of data analyses procedures is available. They are extensively described in Clarke and Warwick (1994), and GCSDM (1993).

An initial consideration will be to verify the biotopes present in the survey area. As indicated above this may be achieved relatively easily by identification of the most characteristic species only. These may then be fitted to known biotopes using Conner (1997). However, greater definition of existing biotopes, development of new biotopes and refinement of existing biotopes will be possible by utilising more advanced analytical procedures. The initial stage to achieve this will be an initial grouping of sites sampled according to faunal similarity. Once site groups have been defined the physical conditions present at the sites may be summarised to provide a habitat description. If sufficient faunal definition is possible a full associated species list may be determined. The techniques most widely accepted in the UK for the definition of faunal assemblages are Bray and Curtis similarity analysis in combination with a hierarchical clustering procedure and ordination by non-parametric Multidimensional Scaling (MDS). These are by no means the only methods; other frequently employed alternatives include TWINSPAN and CANOCO (see Clarke and Warwick 1994). Various software packages are available for these analyses including Primer and MVSP.

In terms of monitoring it may be necessary to provide a quantitative comparison based on the faunal assemblage. Having defined the faunal assemblage to be examined, the minimum data analysis should comprise a consideration of number of species, total abundance and biomass. These three 'primary variables' may be used to test year-to-year variation, in terms of percentage difference between years for each variable. In turn these differences can be used to undertake compliance testing against acceptable levels of change. A full explanation and description of these methods is given in MAFF (1993). These methods were originally devised for compliance testing at sea disposal sites, and have been expanded to include wastewater discharges. They can, therefore, be employed to provide a coarse measure of deviation from the *status quo* with limits applied on a site-by-site basis, which may be considered as 'Action Points'.

Where possible the analysis of primary variables should be supported by other univariate (diversity indices and graphical methods) and multivariate analysis techniques (MDS supporting analyses such as ANOSIM and BIOENV), particularly where any deviation from normality is noted (see MAFF 1993). In all cases a broad approach to data analysis should be adopted, without losing site of the species that contribute to the data sets.

# Accuracy testing

The data produced will accurately represent the true communities and biotopes, depending on the heterogeneity of the environment and the number of replicates collected. Inaccuracies can arise due to a range of factors including the possible lack of experience and conscientiousness of workers, both field and laboratory, and their species identification skills. The amount of error or variability likely has been established by tests undertaken under the auspices of the NMBAQC. Participation in the NMBAQC or a similar QC programme will assist in measuring and removing sources of error.

## QA/QC

Quality assurance measures should focus on the following areas:

- repeatability of site positioning
- quality and quantity of the sample
- accuracy and traceability of the sample numbering
- accuracy and traceability of sample registration
- accuracy of sample sorting and species identification (participation in NMBAQC)
- repeatability of physical and chemical analyses (UKAS preferably)
- accuracy of data compilation

To assure quality it is recommended that organisations should prepare their own in-house procedures and training records, including, but not limited to, the following aspects of the work:

- records of training and experience of survey personnel
- procedures for handling and use of chemicals
- procedures for handling survey equipment
- procedures for collection of biological material
- records of training and experience of laboratory staff
- procedures for sorting of biological material
- procedures for identifying biological material
- procedures for recording biological and environmental data
- procedures for analysis of biological and environmental data
- records and training (CVs) of data analysts

## Data products

Outputs may consist of the following:

- Ground-truth confirmation of biotope in tabulated format. Different levels of definition are possible related to the requirements of the survey for which the ground-truthing has been provided. For example, detailed biotope level outputs in support of video studies, or biotope complex level outputs for sidescan surveys.
- MNCR standard faunal spreadsheet of species at all sites sampled (Excel).
- Summarised environmental conditions.
- Summarised univariate statistics.
- Multivariate outputs including dendrograms of sites and MDS (or similar) ordinations.
- Biotopes derived from groupings of sites based on the multivariate outputs with inclusion of physical data.
- Results of hypothesis testing, using univariate statistics, particularly the primary variables species, abundance and biomass.
- Mapped outputs (in GIS compatible format) of sites, species and biotopes, as required.

## Cost and time

*Field.* Mobilisation and demobilisation will be site-dependent but will be at least one day each. On site it is possible to sample up to 40 times per day using the Day Grab or van Veen. The Hamon Grab is less easy to handle and a maximum of 30 per day is possible. In all cases sampling speed is subject to variation due to water depth, current speed, size of survey area, weather conditions, daylight, etc.

*Laboratory.* The laboratory time is usually very high, except where simple biotope confirmation is required, which may even be undertaken in the field. Sorting of samples is dependent on the nature of the sediment. Generally sands are very rapidly sorted (15 minutes); muds often take longer due to the large numbers of small specimens (several hours), whereas large consolidated gravel samples, with con siderable amounts of retained material, may take more than a day. Use of elutriation methods should be considered to speed up the sorting stage. Similarly, the identification stage will vary. Low diversity samples dominated by infauna can be identified in less than one hour, with high diversity muddy gravels, containing many epifauna, taking several days. Consideration should always be given to the additional time taken to complete QC checks and reference collections.

*Data analysis.* Time taken for data analysis will depend on the extent of the analyses employed. Simple compilation of an Excel spreadsheet including classification using the MCS/Ulster Museum Species Directory codes and full QC checks may take up to two days for a 50-sample/400-species data set. Employing an MDS package is very rapid (<1 day) once the data has been adequately formatted, but a time scale for the interpretation of the outputs is dependent on the complexity of the results and may involve several reruns of the data. Analysis of biomass data is dependant on the information required, which may range from simple year-to-year community biomass change (<1 day) to relatively complex and time-consuming calculation of the productivity of individual populations.

# Health and safety

A comprehensive code of safe operating procedures for field work should be drawn up, with particular reference to protective clothing to be worn during sampling and containing operating procedures for potentially dangerous equipment. Risk assessments must be prepared for specific locations where field work is being undertaken. Laboratory safety codes of practice (including COSHH approved methods) must be followed and would be expected to form an integral part of the procedures indicated in the QA/QC section above.

**FORMALIN IS EXTREMELY DANGEROUS. IT IS HIGHLY TOXIC AND A CARCINOGEN. IT WILL BURN SKIN ON CONTACT. EXTREME CARE IS NEEDED IN ITS USE ALWAYS.**

- Wear protective clothing (such as a fastened lab coat or boiler suit)
- Wear safety spectacles or a full face mask
- Wear protective gloves
- Take great care to avoid inhalation of fumes
- If contact with skin occurs wash thoroughly with water. If spills occur, dilute with plenty of water
- Always wash hands thoroughly after use

**Always use formalin in a well-ventilated area, preferably a fume cupboard or outside away from buildings and people.**

Examples of safe vessel operating procedures have been included in Appendix 2, along with vessel choice considerations.

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# Appendix 1

## Example equipment list
## Infaunal and epifaunal sampling methods and procedures
## Equipment checklist

| *Activity* | *Equipment required* |
|---|---|
| Navigation | dGPS (Sercel NR103; NR51; Leica MX412 Professional Differential GPS ) |
| Infaunal sampling | Hamon Grab (either $0.19m^2$ or $0.1m^2$ sampling area) |
| | Hamon Grab Table |
| | Optional extra Hamon grab bucket – 1 of stainless steel, 1 of galvanised steel |
| | vanVeen (light weight version $0.1m^2$) |
| | Day Grab with stainless steel buckets ($0.1m^2$) |
| | Day Grab weights and bolts |
| | Day Grab safety pin |
| | Day Grab landing table and bolts |
| | Shipek Grab and stainless steel buckets ($0.04m^2$) |
| | Shipek Grab landing tables |
| | Shipek Grab loading arms and safety handle |
| | 2 Shipek Grab weights |
| Epifaunal sampling | Armoured 1 metre naturalists dredge |
| | 2 metre Lowestoft beam trawl |
| | Scallop dredge |
| | Box Anchor Dredge |
| Additional equipment | Toolbox containing adjustable wrench and spanners to fit grab bolts and landing table bolts |
| | 2 x 200mm diameter brass sieves of 1mm or 0.5mm sieve aperture with raised plastic surrounds. An optional 5mm sieve may be used in coarse sediments to remove larger material |
| | Sample hoppers for catching sample from grabs – may be boxes or waste bins of suitable waterproof construction and adequate volume. Purpose-built hoppers with spouts to decant samples through the sieves may also be employed |
| | Deck wash, preferably with a ‘shower head’ |
| | Wash bottles |
| | Forceps |
| | Scoops (plastic for metals samples, stainless for pesticides and hydrocarbons) |
| | Empty plastic boxes for sample storage |

| *Activity* | *Equipment required* |
|---|---|
| Safety equipment | Life jackets |
| | Hard hats |
| | Safety footwear (preferably waterproof) |
| | Waterproof clothing |
| | Thermal clothing |
| | First aid kits |
| | Antiseptic wipes |
| | Thick, protective gloves |
| | Sun tan lotion (where applicable) |
| Consumables | Paper towelling |
| | 30cm x 45cm plastic bags with white panel for labelling for PSA samples and organic content samples |
| | Plastic cable ties for securing bags |
| | Faunal containers: a range of plastic containers (buckets or pots of volume suitable for the size of sample to be taken). Normally an assortment of sizes between 1l and 10l are suitable |
| | Other jars as appropriate for chemical analysis, e.g. pentane washed glass jars with foil lids for pesticides |
| Chemicals | Buffered (Borax) 40% w/v Formalin for preservation of faunal samples |
| | Rose bengal for staining (as appropriate) |
| Other | Non-water-based permanent marker pens (black ink) |
| | Admiralty chart of the area |
| | List of sampling station positions in OSGB Grid or OSGB lat/long |
| | Bound survey log book |
| | Sample and record sheets |
| | Weather sheets |
| | Anemometer |
| | Mobile phone |
| | Camera |
| | Log book |
| | Food and drink |

# Appendix 2

## Safe working practices on boats
## General rules to be observed when working on boats

A weather forecast should be obtained by the person in charge of the work before embarking. This should be obtained from a reputable source (e.g. Meteorological Office or Metfax) with as much detail about wind and sea conditions as possible.

- Access to the vessel must be limited to the crew, survey and anyone sub-contracted to them.
- If the vessel is hired with crew, the responsibility for safety ultimately rests with the operators. However, the team leader should satisfy him/herself that the safety standards are adequate. A risk assessment should be conducted.
- Life jackets must be taken on to the vessel and worn at all times when working.
- Safety footwear must be worn when operating grabs or heavy equipment.
- Safety headgear must be worn when operating grabs or working on a deck with overhead equipment pulleys/blocks, etc.
- Protective gloves (thick rubber) must be worn when handling grabs or cables.
- Footwear must have appropriate soles with good grip.
- Care must be taken when boarding the vessel. If there is a risk of falling into the water (e.g. climbing down a ladder) put life jacket on first. Move around vessel with caution.
- Before handling and operating equipment make sure you are familiar with the appropriate safety guidelines.
- Familiarise yourself with the location of the safety equipment on the vessel, e.g. VHF radio, lifeboat/raft and fire extinguishers.
- Any accidents or incidents must be reported to the person in charge and recorded in the appropriate accident book.
- When sampling, any cuts or grazes on exposed parts of the body should be covered with waterproof plasters/dressings.
- Long hair must be tied back when operating equipment.
- Smoking is forbidden when collecting samples (can also cause contamination).
- Antiseptic wipes will be available and should be used for cleaning hands before eating and drinking.
- The working deck area should be kept as clear as possible, especially areas where equipment is being deployed or retrieved.
- A portable first-aid kit (complete with basic first-aid equipment including emergency eye-wash) must be taken on each survey.

All vessels must be certificated by the MCA to brown code standard. Where such a vessel is not available a suitable vessel may be used in agreement with the client and the MCA. The vessel must be checked **before the survey** to ensure it has the following:

- echo-sounder, radar
- hydraulic winch with adequate length of cable in good condition
- sufficient clearance for the grab at back/side of the boat
- adequate deck space to work on
- skipper with VHF licence and *valid* relevant qualifications
- deck wash
- water (drinking) supply
- power supply – 12v
- position fixing equipment
- adequate space for the number of people working

- safety equipment – life raft, VHF radio, flares, $CO^2$ extinguishers, etc.
- toilet (HSE requirement)
- cabin space

To reduce the time taken to carry out the survey, the available times of access to a harbour need to be checked before the survey. The harbourmaster or local fishermen will know at what tidal states a harbour is accessible. Also ensure that there is a suitable place for the loading and unloading of heavy equipment on and off the vessel. Contact the harbourmaster in advance for availability of berths.

# Appendix 3

## Deployment procedures for grabs

### Day Grab operation

#### *General handling*

Beware when moving the grab that the firing plates may be pushed up, trapping fingers. Always wear safety footwear for even the smallest move. Only hold in safe areas. No fewer than two people to lift the grab, no fewer than two to handle it when being winched. Ensure safety pin is inserted to hold jaws in position. Always wear thick gloves, safety footwear, life jackets and hard hat when operating grab on boat.

Do not attempt to use grab if weather means it will swing.

#### *Loading*

- Tie table to boat for stability.
- Place grab on table and ensure it is secure.
- Slacken cable to close jaws.
- Draw jaws together, raise the bar to enable them to meet and lower bar between the catches. 'Rattle' the bar to ensure a good fit.
- Insert safety pin.
- Ensure safety pin and weights will not interfere with grab operations on the seabed.
- **It is now ready to fire.**

#### *Deploying*

- Ensure cables are around pulleys.
- Hold grab by frame only.
- Winch the grab off the table and guide by use of the frame off the side of the boat, ensuring it does not fire prematurely.
- Remove the pin.
- Lower the grab slowly until clear of the boat.

#### *Retrieval*

- If the grab is swinging wildly on retrieval, drop it back in to the water until the boat is stable. Do not attempt to land it.
- Hold grab by frame only, keeping fingers clear of the danger area where firing mechanism will rise.
- Lower onto the table.
- Once on the table, ensure it is stable before lifting buckets to release the contents into a hopper. It is possible to knock the buckets against the trigger bar to reduce wash water requirements.
- Sample taken should be discarded if (a) sediment has been obviously disturbed due to wash out on winching up from the seabed; or (b) the grab bucket is less than half full. If the jaws of the bucket are held open because of stones etc., the sample should only be discarded if points (a) and/or (b) apply. Notes on sample volumes should be made on the log sheet/book.
- Sub-sampling should be undertaken before the sample is decanted into the hopper.

### Hamon Grab operation

#### *General handling*

- The grab must be lifted with a winch, crane or fork-lift vehicle (approx. wt. 350kg although reduced scale versions are also available)

- Landing table is designed to be welded to the deck of the survey vessel. Grab must not be used unless this is so, or the table is secured by some other means (bolting, etc.).

### *Loading*

- Ensure that there are three people available to carry out the operation in addition to a winch operator.
- Ensure safety catch is engaged as tension on the cable for winching off boat is applied.

### *Deploying*

Winch off the boat with two people ensuring the grab is guided over the stern by the frame.

### *Retrieval*

If the grab is swinging wildly on retrieval, drop it back into the water until the boat is stable. **DO NOT ATTEMPT TO LAND IT.**

When boat is stable, grab is winched up the stern until the chain loops on the frame are accessible. If the orientation of the grab frame is incorrect, one person should hold the frame and turn the grab until the chain loops are accessible. The other two staff can then attach the hauling lines to the chain loops on the frame. The hauling lines are then manually pulled taut and the winching on to the boat resumed, maintaining the tension on the hauling lines until the grab is safely lowered on to the table. The hauling lines can then be safely removed. Place hopper underneath before opening grab.

Sample taken should be discarded if; (a) sediment has been obviously disturbed due to wash out on winching up from the seabed; or (b) the grab bucket is less than half full. If the jaws of the bucket are held open because of stones etc., the sample should only be discarded if points (a) and/or (b) apply. Notes on sample volumes should be made in the log book. A pre-marked hopper is used to estimate the volume of sediment collected within the grab bucket. Sub-samples from homogenised sediment are taken if required.

# Appendix 4

## Example pro-forma for on-site records

Sample recording sheets are being developed for the National Marine Monitoring Programme and will be issued with the next revision of the *Green Book* in March 2001. They can be downloaded from the *Green Book* internet site.[4]

4 **http://www.marlab.ac.uk/greenbook/GREEN.htm**

# Procedural Guideline No. 3-10 Sampling marine benthos using suction samplers

Dale M. Rostron, Subsea Survey[1]

## Background

Airlift suction pipes have often been used by archaeologists to excavate sand and silt from ancient wrecks (Cousteau and Roghi, quoted by Flemming, 1962) and by civil engineers. However, suction samplers have a history of spasmodic usage in marine biology. Examples include:

- baseline information from SAC sub-features, e.g. seagrass beds, maerl beds (Falmouth, Rostron 1985); shallow areas in the Harbours Rias and Estuaries surveys (Rostron 1987, Hiscock 1986); Isles of Scilly (Rostron 1983); Scottish Sea Loch Surveys (e.g. Howson 1991, Davies and Connor 1993)
- local pollution studies (Whiteness Voe, Rostron 1989)
- zonation studies of sublittoral cryptofauna on rock (Lundy), and population/quantitative sampling studies (Hiscock and Rostron, unpublished; Rostron 1983).
- complement to visual or photographic studies (Gulliksen 1980; Rostron 1996)

### History of Use

Brett (1964) described a portable diver-operated hydraulic sampler which produced suction by the aspirator principle using a jet of water from a portable pump. The dredge was used to suck animals and plants from within a steel frame of known area, 15cm deep and driven into the sediment by hand. But this device did not work satisfactorily on some hard-packed sands.

A solution to these difficulties was the use of an airlift pump. Water and sample material are pulled through the sampler by the force of the rising low density air/water mixture in a vertical pipe. Barnett and Hardy (1967) designed an airlift sampler in two parts (Figure 1). The first part was a cylinder which was pushed into the sand to enclose a known surface area to a known depth. The second part was a suction pump used to excavate and sieve the sand and animals from within the cylinder.

Hiscock and Hoare (1973) modified the Barnett and Hardy sampler for use on hard bottoms (Figure 2). They required a portable system, with sufficient suction to prevent detached species from falling or being swept away, and the possibility of taking several samples which could be easily removed from the apparatus. Lead weights were fixed to the suction chamber end of the unit to prevent buoyancy during operation, and 3m of wire-wound flexible tube was used for suction as this was found to be easier to transport than rigid tubing. This sampler is not generally suitable for sediments because of the limited capacity of the sample chamber.

Gulliksen and Deras (1975) constructed a diver-operated suction sampler for fauna on rocky bottoms (Figure 3). It consisted of a sampling bottle with a 0.5mm sieve connected to a manual suction pump. This sampler was suitable for sampling sediment and smaller sessile fauna, and several samples could be obtained in storable plastic bottles during one dive. Gulliksen (1980) used this sampler during investigations of the macrobenthos in Borgenfjord, Norway.

A more recent design (bucket sampler) based on the Hiscock and Hoare machine (Figure 4) incorporates a larger sample chamber and can be used on sediment. However, periodic emptying of the sample chamber is necessary if several samples are collected.

The most recent design (by J. Woolford) is a miniaturised airlift sampler (Figure 5) known as the JW Miniature. This uses a pony cylinder which can be attached to the diver's main cylinder, and an on/off

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switch more normally associated with diver direct feed systems. Copper tubing is used to provide the air supply to the inside of the 5.5cm diameter plastic pipe. The sampler is 52.5cm long overall, with a small lead weight attached 12cm from the bottom for stability. There is no collection chamber and material is deposited into a detachable bag. The system is very light, enabling the diver to swim to the required station before sampling.

### Summary matrix

| *Substratum* | Steep gradiant | Rock | Mixed substrata with stones | Coarse gravel | Maerl | Medium fine sand | Muddy Gravel | Mud |
|---|---|---|---|---|---|---|---|---|
| Barnett and Hardy | ✘ | ✘ | ✘ | ✓ | ✓ | ✓ | ✓ | ✘ |
| Hiscock and Hoare | ✓ | ✓ | ✘ | ✘ | ✓* | ✓ | ✓ | ✘ |
| Bucket type | ✓ | ✓ | ✓* | ✓* | ✓* | ✓ | ✓ | ✓ |
| JW miniature | ✓ | ✓ | ✘ | ✘ | ✘ | ✓ | ✓ | ✓ |

* Care must be taken not to exceed the capacity of the sample container.

## Purpose

It is clear that non-destructive *in situ* techniques observe only those species which are large and/or prominent on the substratum, and that the true range of species present within a biotope cannot be investigated by these methods. Many of these larger species are fairly ubiquitous, and may not be sensitive to environmental changes. Pollution studies have often shown the sensitivity of smaller animals, such as amphipods, to adverse environmental change and suction sampling will capture these.

For sediment biotopes, the principle of grab sampling, a destructive technique, is well established. On sediment, suction sampling offers a smaller scale, possibly more objective way of achieving the same results. It is also useful for collecting baseline information from small areas.

In the rocky sublittoral, the principle of destructive sampling is not encouraged and much emphasis has been placed on non-destructive methods. However, previous comparative studies (Gulliksen 1980, Hiscock and Rostron, unpublished) have shown that the majority of the biota is not recorded by such methods. Suction sampling, on a very small scale, would therefore provide good baseline information and a fuller appreciation of the communities monitored.

Suction sampling can be used as a monitoring technique in cases where other methods are not appropriate; for example on coarse or mixed substrata. It is also a thorough technique for delineated biotopes such as maerl beds. It is most economically used for 'whole community' information, but at the same time could provide important population statistics for 'potential key species'. However, in view of the large volume of sample material and the time needed for sorting this, it is not a suitable method in cases where, for example, only a few key species are monitored.

In summary, suction sampling can:

- be a good technique to use prior to deciding on a final monitoring programme or key species to be monitored. It provides baseline information, particularly about biodiversity, interesting biotopes or sub features.
- be useful to check the overall health of specific communities/biotopes, e.g. maerl beds, muddy gravel.
- be used to establish/re-establish the species which are present in a biotope.
- provide comparative numerical data for regular or relatively large scale studies.

### Advantages

- Fully portable apparatus. Ease of deployment depends on the model used.
- Personnel need only brief instructions to use the sampler, which is not technically difficult.
- The exact habitat conditions at the site can be recorded, e.g. phase 2 recording for rocky substrata. Sediment data can be collected from exactly the same location as the biota, often a hit and miss affair with grabs, which must be deployed more than once.
- Samplers can be deployed from a small boat. Thus divers can sample in areas which may be inaccessible for larger vessels deploying grabs, e.g. Whiteness Voe, Scilly (Rostron, 1989). Small-scale surveys can be undertaken

- Sampling efficiency is high. Christie (1976) found that on fine sand 40% of the species present to 60cm depth occurred deeper than 10cm. Keegan and Konnecker (1973) found that on maerl substratum as much as 98% of the standing crop may be found 20–40cm below the surface of the substrate. Suction samplers can reach these depths if required.
- Suction sampling methodologies are complementary to other non-destructive techniques such as photography or quadrat studies.
- Samples which are difficult to collect by other means can be obtained. Coarse substrata such as gravel and stones can be collected. Algae and sessile organisms on rock can be collected quantitatively.
- Samplers can be used for varied types of seabed, and different mesh sizes can be easily inserted if needed. Different surface area samples can be taken.
- None of the material removed from the rock is lost and almost all of the biomass is collected.
- Counting and abundance assessments are possible. Rrobust statistical methodologies can be used, such as parametrics or multivariate classification techniques, etc.
- Samplers can be constructed from cheap and readily available material with minimal machining.

### Disadvantages

- It can be expensive using divers to sample relatively small areas.
- Depth and number of samples are limited by the diver's capabilities. In addition, samplers will not work at depths less than the length of the suction tubes.
- Samplers are efficient at deeper levels, but require a greater supply of air to maintain the same suction pressure.
- It is sometimes difficult to fill machines with water for descent and to carry them down, especially in rough surface conditions. Deployment requires considerable skill. Too much buoyancy in the chamber when air is introduced for sampling can cause some samplers to rise.
- Large specimens on rock may need to be removed before using the sampler.
- Strong suction and scraping can damage fragile biological specimens. Sessile tube-dwelling species and barnacles can be difficult to collect.
- It is not usually possible to see the accumulating sample material. Large samples may overfill the bags. The British Antarctic Survey designed a sampler similar to that of Hiscock and Hoare, but with a clear perspex tube which allowed one to see the quantity within the sample bag inside, and also other modifications to make the machine more suitable for very low temperatures.
- It can be difficult to extract samples from some sample bags.
- Laboratory time for sorting samples from sublittoral rocky bottoms is very high. Gulliksen (1980) intended to sort material alive, but found that some samples needed up to 10 days of concentrated sorting. Hiscock (1987) estimated that each 0.1m$^2$ sample took 5 days to sort and count, and this did not include the identification of all species.

## Logistics

### Equipment

Boat, plus diving, navigation and safety equipment, as required for normal diving operations under the HSE regulations. An echo-sounder is essential in cases where the seabed conditions are not known. Buoyancy aids and rope are also required: the latter may be needed to retrieve the sampler from the seabed by hauling it from a support vessel.

Sampling equipment, scraper, spare sampling bags and lids, quadrats, spare air cylinders. The area which can be sampled with one cylinder of air will depend on the amount and type of material being collected, the depth, and the suction applied. Hiscock and Hoare (1973) took three 0.25m$^2$ samples at 15m with a 1.6m$^3$ cylinder.

Quadrat shape may vary, with deep cylindrical shapes suitable for sediment and more usual square shallow designs for rock. Workers need writing boards and sample carrying equipment on the seabed. Numerous sample bags are heavy and unwieldy to transport, and could be fixed to a line buoyed at the surface (Figure 6).

Buckets for surface storage, one or two per sample. Sieves, reliable labels, such as Dymo™ and preserving fluids.

### Personnel/time

Minimum HSE diving team (4 divers) plus possible additional boat staff. The divers must have appropriate qualifications (Holt 1998).

## Methods

### Site location

Latitude and longitude for sample sites must be determined accurately, especially if repeated monitoring work is anticipated. When using the Geographical Positioning System, the correct datum should be employed (WGS84 or OSGB, etc.) with quality control checks taken from known positions. In nearshore areas, prominent coastal and seabed features may also be useful for accurate relocation of sample sites.

### Deployment

Once the correct position and depth have been located, those samplers with chambers need to be immersed until the air in the chamber is replaced by seawater, resulting in negative buoyancy. The equipment may be lowered by means of a buoyed rope, or alternatively transported to the seabed by divers. Additional equipment, such as spare bags and quadrats, may be easily lost if not assigned to a specific worker. It is therefore a good idea to discuss which diver will perform the various operations prior to their descent.

### Field sampling

#### *The Barnett and Hardy type of airlift design (Figure 1)*

This sampler has no chamber and is easy to submerge. The 0.1m$^2$ cylinder is placed on the seabed and pushed a few centimetres into the sediment by hand. For deep samples, the lid is secured by means of four clamps. The air supply to the airlift pump is then turned on slowly and water pumped out of the cylinder. The head of water above the lid forces the cylinder into the sand and penetration of the cylinder to a depth of 60cm usually takes about five minutes, after which the clamps are released, lid removed and sand inside removed by the second part of the sampler.

In practice, it is often possible to manually work a cylindrical quadrat into the sediment by holding the handles and rotating rapidly in clockwise and anticlockwise directions.

The sampler has a long rigid pipe with an internal diameter of 8cm, weighted at one end. It can be very difficult to manoeuvre and hold this sampler in a vertical position, which means that it cannot be utilised when tidal streams are present. The air supply is turned on slowly until there is a rapid flow of water up the suction pipe. The suction tube is then directed towards the substratum, within the quadrat. The sampled material is caught in a mesh bag, but the silt and sand may descend onto the divers, making sampling difficult.

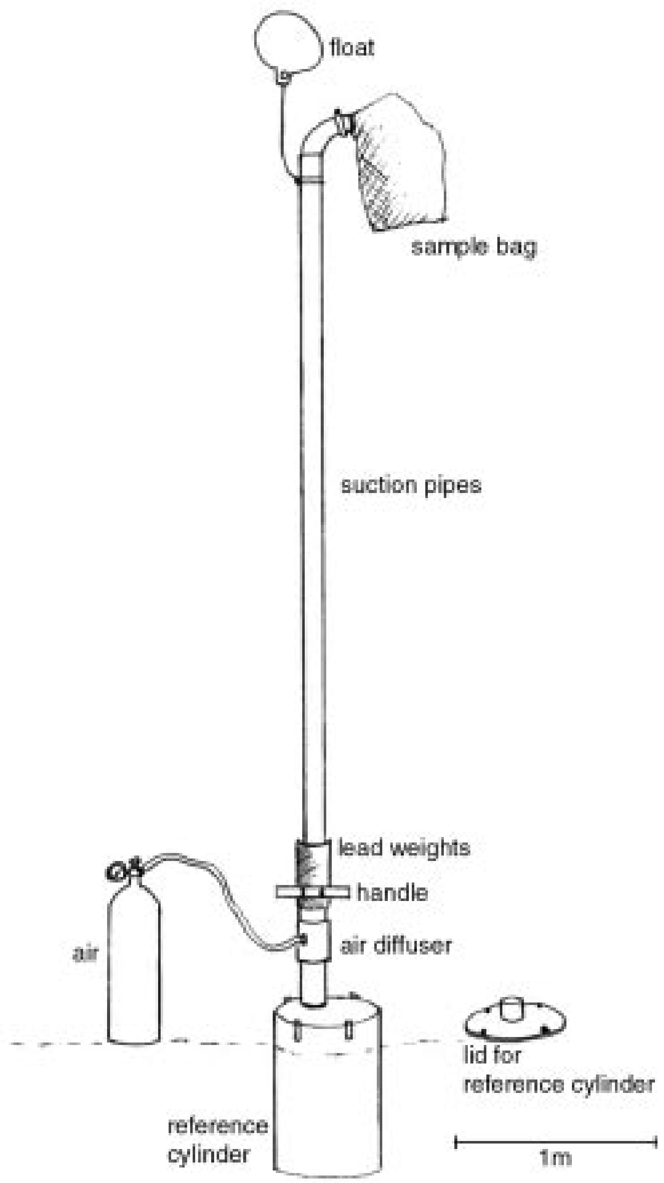


**Figure 1** The Barnett and Hardy (1967) type of sampler

### *The Hiscock and Hoare type of airlift design (Figure 2)*

The divers enter the water and inflate their buoyancy control devices. The sampler is handed to a diver, who allows it to fill with water before adjusting buoyancy to submerge. Supplementary equipment (quadrats, tubing, etc.) is taken to the seabed by the other diver.

The sampler is assembled on the seabed and placed appropriately on the bottom; the quadrat is then put in place. Large specimens liable to clog the tube are removed for later inclusion in the sample. This is done by means of a paint scraper used to detach the organism carefully from the rock. Tubing is unwrapped and the float carries the suction tube to a vertical position. The air supply is turned on at the pillar valve to create the necessary suction. The paint scraper is used in front of the collecting tube to dislodge organisms within the quadrat. When the quadrat is cleared, the air supply is increased for a few seconds to draw any material left in the collecting tube into the sample chamber. When the sample has been taken, the number of barnacle or tube worm scars can be counted or the site photographed for later counting or measurements of percentage cover. The sample bag is removed and capped and another bag is screwed in place ready for the next sample. If a buoyed line has been tied to the sampler, the apparatus can be pulled to the surface after removing all loose parts.

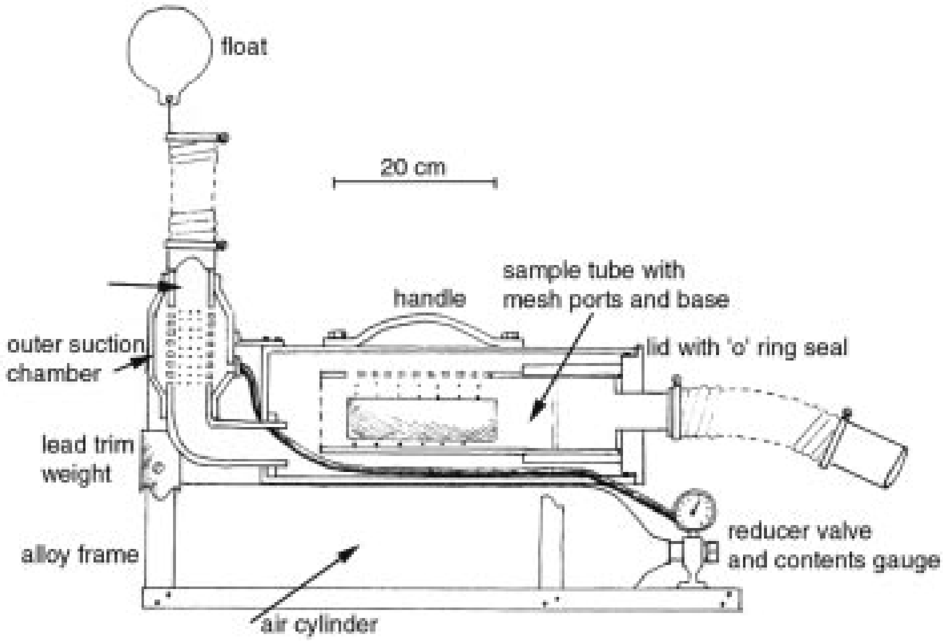


**Figure 2** The Hiscock and Hoare (1973) sampler

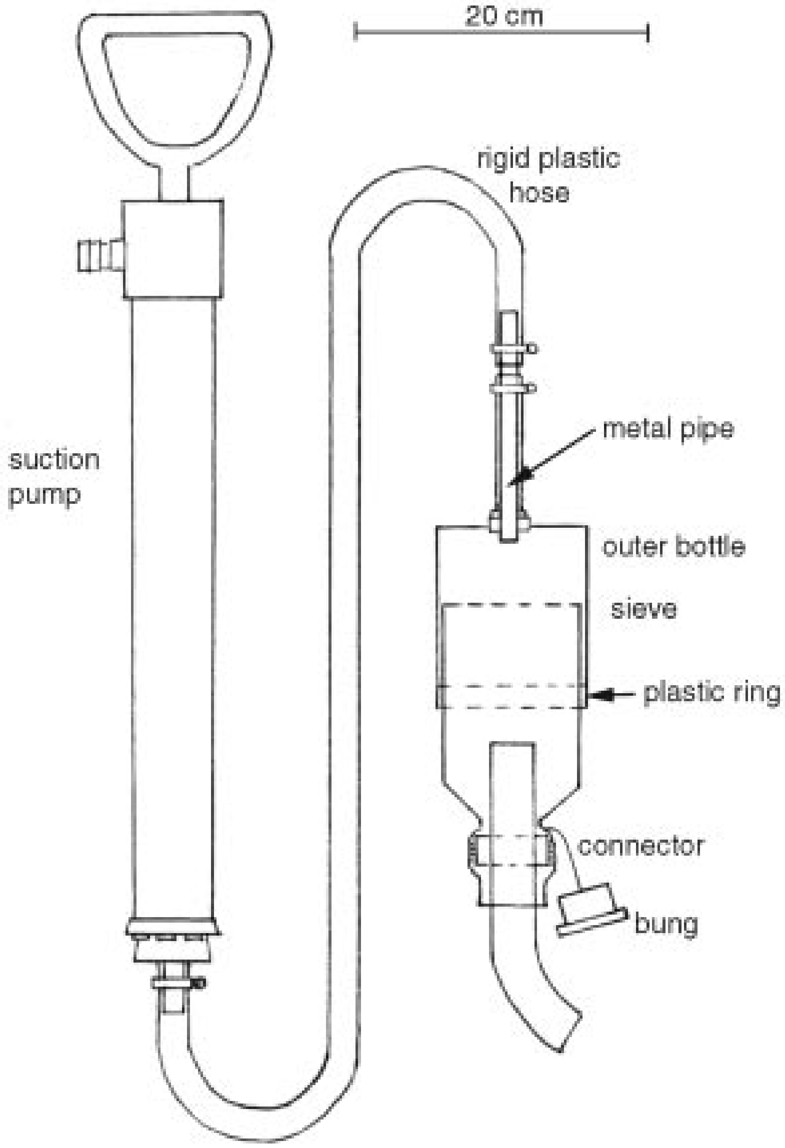


**Figure 3** The Gulliksen and Deras (1975) sampler

### *The bucket sampler (Figure 4)*

The tubing is attached before deployment. This sampler has a large chamber, and takes several minutes to fill with water. This is generally achieved by undoing two of the clips on the lid, holding beneath the surface, and then re-fastening the clips before descent. Lead weight can be placed into the chamber, but this makes the sampler heavier for retrieval. It is a good idea to save underwater time by fixing the first sample bag before descent. The air supply should be connected at the surface, although bottles can be exchanged underwater if necessary. The sampler is attached to a buoyed rope.

Once on the seabed, the quadrat is placed by whatever means are appropriate. Suction is quite powerful, and can result in positive buoyancy and shifting of the machine if the air is turned on too quickly. One diver concentrates on the air supply and sampler, whilst the other positions the suction tube inside the marked quadrat. Communication and co-ordination between the two are needed. At the end of the first sample, the suction tube should be held upwards to avoid loss, the air must be turned off, the lid opened and the bag replaced. Sediment accumulated in the bottom of the chamber should be emptied. The screw thread attaching the bags can take some time to deal with, but does ensure that the bags are firmly fixed and can hold large samples, including stones. Filled bags should have a screw cap.

This sampler, particularly if it contains sediment, is too heavy for easy transport to the surface and divers should ascend the line carrying the loose equipment. The sampler may be pulled to the surface later.

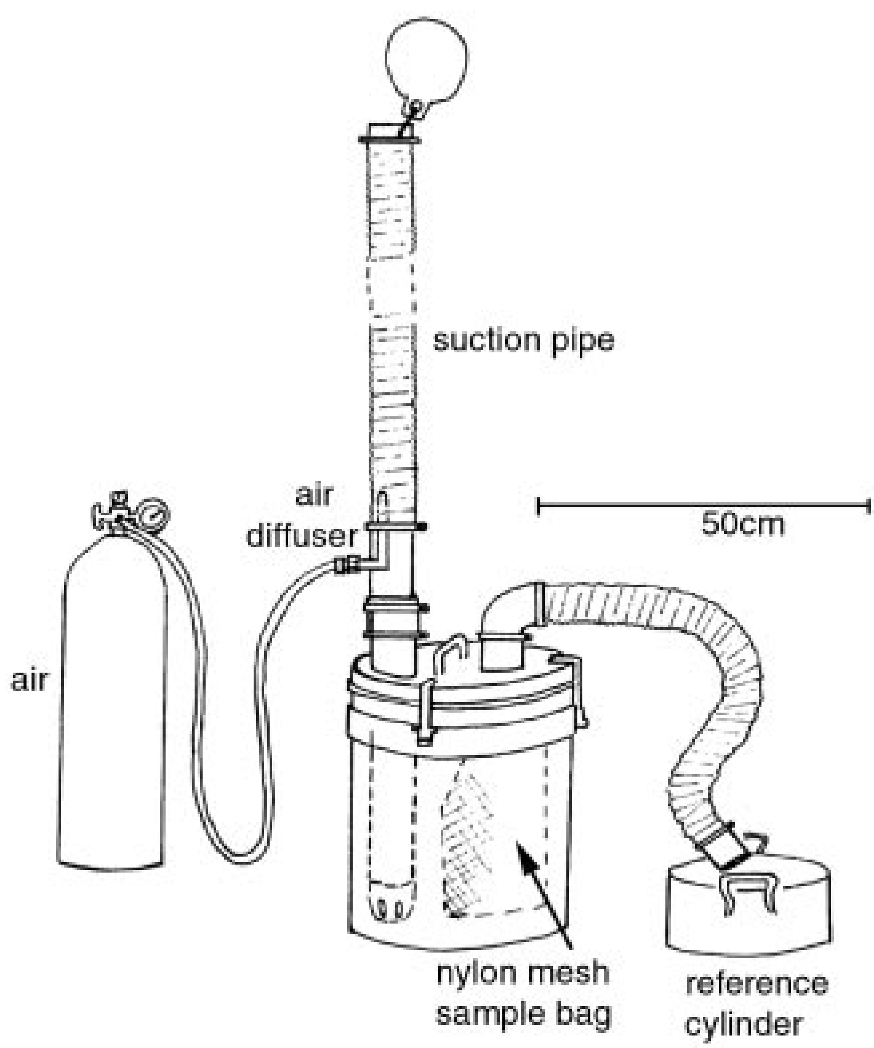


**Figure 4** The bucket airlift with a large sample chamber (Hiscock 1987)

### *J. Woolford rock epifauna sampler design (Figure 5)*

The air supply, a pony cylinder, is fixed upside down to the diver's main cylinder, in order to make the valve accessible. The air supply is attached to the direct feed on the sampler which in turn may be attached to the diver by means of a line and clip. The quadrat, scraper, nets and flexible tubing can be carried down separately and attached at the seabed. The tube is curved and fits over the diver's shoulder, so that any silt disturbed does not interfere with the sampling procedure. The quadrat is placed, and the diver is able to scrape with one hand and use the airlift with the other. Pushing the button on the direct feed regulates the air supply. Alternatively, a second diver may assist.

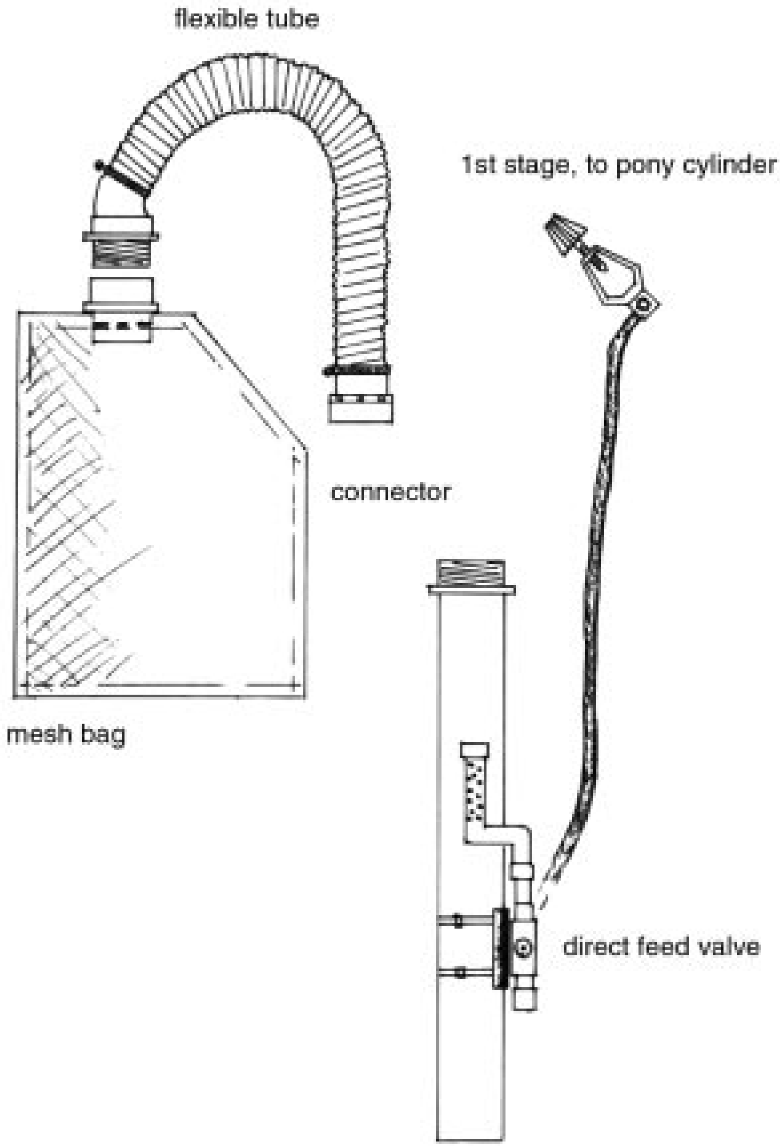


**Figure 5** The JW sampler (original drawing)

## Substratum and mesh size

Normal mesh sizes are 1mm and 0.5mm and the client should specify the size required. When sampling a benthos of gravel, stones or mixed substrata, most will be retained within either mesh and the limiting factor is the bag/chamber size. The grain size of coarse sand may be between 0.5mm and 1mm. In this case, for efficient sampling, it would be more practical to use the larger mesh size. Finer sands and muds should all pass through the 0.5mm mesh.

## In situ observations

If time allows, in situ observations detailing depth, habitat type, sediment structure, etc. should be recorded. It may be appropriate to record abundances of colonial species at sample sites using a SACFOR scale, particularly if sampling from rock.

## Retrieval of sample equipment

Divers may have difficulty in retrieving samplers from the seabed if:

- the sample site is >15m deep
- full sample bags, spare cylinders or other heavy items need to be attached
- a sample chamber (bucket sampler) is full of sediment
- tidal currents are present
- divers are carrying surface marker buoys
- visibility is bad or sea surface conditions are adverse

For these reasons it is safer to use an attached line for retrieval from the boat, once the divers are safely on board. All detachable parts should be securely fixed to avoid loss. However, these considerations do not apply to the JW miniaturised sampler, which is carried by the diver.

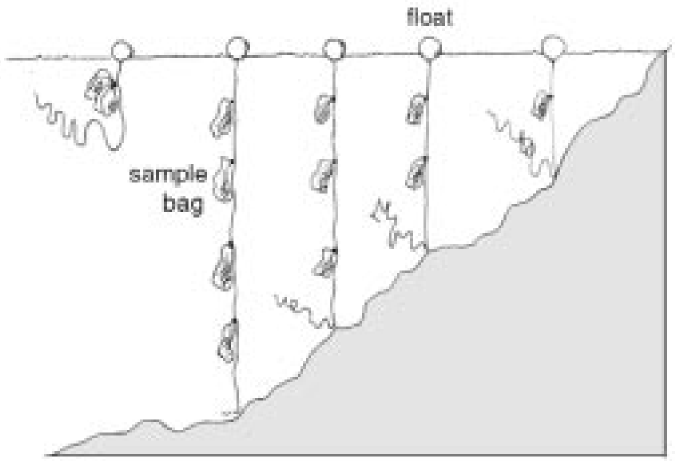


**Figure 6** A method for retrieving samples

## Sample storage and labelling

On the boat, sample bags should initially be placed in buckets containing seawater and labels. The latter should be made of plastic paper and cross-referenced to any numbering system or in situ notes recorded underwater by the divers. It should not be necessary to empty sample bags at this stage.

Once on shore, sample bags are emptied into individual containers containing seawater: they may need to be quite large. The bags are made of tough nylon mesh and access is provided through a Velcro™ fastening. Some material may be difficult to get out, but care should be taken not to damage organisms. One method is to use a large spoon to remove much of the material, before inverting the bag and rinsing material off the mesh by immersing in seawater. Each sample may then be sieved and placed in preserving fluid along with an appropriate label.

## Laboratory

Adequate wet facilities including a fume cupboard for processing samples are required, along with bench space for binocular and compound microscopes and all appropriate taxonomic keys and guides.

For rock samples, quantitative and qualitative material is separated before identification and counting, or abundance estimates. Because the volume of material can be large it is useful to initially sort into taxa, such as amphipods, algae, prosobranchs, polychaetes, bryozoa, etc. From here, the fauna and flora should be identified to species level whenever possible and a list of taxa compiled. Taxa should be listed according to a recognised authority (Howson and Picton 1997). Individual animals may be counted. Colonial animals and algae must be assessed by other means, e.g. by *in situ* diver observation at the sample sites. In the laboratory, a more subjective estimate of the probable surface area % of the species within the sample would provide a comparative measure.

Procedures for mixed samples such as pebbles/mud or maerl may be similar to the above.

For sediment samples, sorting, identification and enumeration procedures are well established. Voucher specimens should be kept separately and properly labelled.

## Data analysis

Data generated should be stored on a spreadsheet or database from where it is accessible for computer analyses. Data analysis depends on the initial objective of the suction sampling programme.

## Accuracy

Objectives should be clearly set out before suction samples are taken. For repeat surveys of sediment areas, it is essential to accurately relocate sample positions according to established protocols. The type of sampler should be appropriate for the work undertaken. In sediment or loose mixed substrata, there is always a temptation to take samples to a deeper level than necessary which should be avoided by using quadrats of the appropriate shape, depth and width.

Replication is not a desired option when using a suction sampler at deeper sites because of the time implications, the size of the samples and also the fact that working conditions (visibility) could be compromised by repeated sampling at one locality. Cost may limit the number of localities sampled.

In rocky sublittoral areas, the heterogeneity of the environment means that the provision of statistically useful data for repeat monitoring over a large area cannot be expected. Data should not be over-interpreted.

Unless there is a sufficiently large number of samples, great care should be taken when making sample comparisons between:

- one year and another (temporal)
- one depth/place and another for a particular biotope (spatial)
- widely spaced samples from the same area (spatial)

## QA/QC

- Well-defined objectives should be set before employing this methodology.
- An equipment inventory should be checked before leaving the shore.
- Boat personnel should be able to locate the survey station precisely from the position of the surface buoy and be able to retrieve the sampler and other items by hauling from the seabed.
- There should be standard, appropriate quadrat sizes and general agreement on depth to be sampled.
- Divers should be familiar with equipment to be used. Operators should be able to collect standard samples, adequately describe the site, habitat and larger biota, ensure that the sample chamber does not overfill, clear any tube blockages, and take care not to lose material during bag changing or by turning off the air too soon.
- Samples must not get confused either underwater or on the surface.
- Samples should be handled so that minimal damage is done to biota, e.g. do not swing bags around in air; always support in water.
- It is essential to be realistic about the laboratory time necessary for sample processing.

## Data products

- New information in many cases
- Detailed data matrix – stored as a spreadsheet
- Collection of specimens

# Cost and time

## Field

Using a team of 4 divers (2 pairs) on a schedule of two dives per day, it would be possible to obtain between 8 and 16 samples depending on the depth, underwater conditions and type of habitat to be sampled. (Sandy sediments are easier than rock epifauna.)

## Laboratory

The laboratory time may also vary significantly depending on the sample type collected. Sorting a large sample takes between 1 and 3 days, whilst accurate identification and enumeration takes 3 to 5 days. The times involved are long because suction samples from sediment are larger than grab samples of the same surface area, whilst samples of rock epifauna and associated cryptofauna are extremely diverse, with identification complicated by the fact that many organisms are epiphytic on others. Costs for a 15cm deep, $0.1m^2$ sample may vary from £800 for an interesting sediment sample with 30+ taxa to c. £1,500 for a detailed analysis of the same area rock epifaunal sample taken from a diverse circalittoral turf.

## Data analysis

Given an accurate spreadsheet from the laboratory work, computerised data analysis techniques take relatively little time, probably about 1 day.

# Health and safety

All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[2] and must follow the Scientific and Archaeological Approved Code of Practice.[3]

A minimum team size should be specified.

Buoyancy (both positive and negative) of the equipment and accumulated sample material is a problem and must be addressed in the risk assessment.

Additional risk assessments are needed for certain areas such as tideswept sites.

# References

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# Procedural Guideline No. 3-11 Littoral monitoring using fixed quadrat photography

Jenny Glanville, Devon Wildlife Trust[1]

## Background

### Fixed quadrat monitoring

Photographic monitoring using fixed quadrats has long been established as an efficient, repeatable method for long-term monitoring studies. This paper is based on experiences from Wembury Voluntary Marine Conservation Area (VMCA) in Devon, but this type of survey has also been used at the Skomer Marine Nature Reserve (MNR) and, sublittorally, at Lundy Island. It involves the photographing of permanently marked quadrats along broad belt transects. Supported by standard MNCR recording, it can provide a valuable record of the condition of an area of coastline.

The method is very simple and therefore ideal for use by volunteers or non-professional surveyors. Quadrat locations are decided according to the survey objectives, but will generally be representative of the entire area. The simplicity of the method lies in the fact that, after initial site selection, minimum expertise is required to carry out the survey. The design of the quadrat and camera support (see Figure 1) obviates even the need for highly skilled photographers.

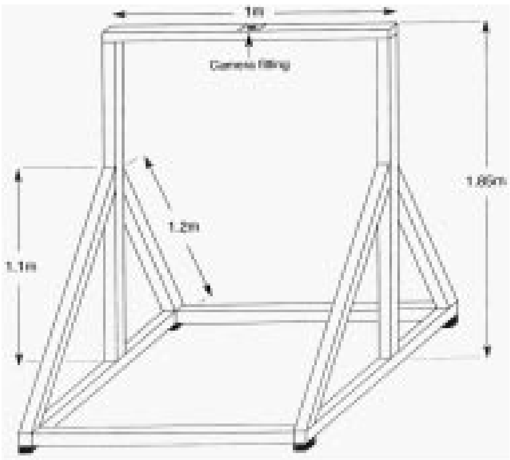


**Figure 1** Quadrat design for photographic biotope survey. The height of the camera above the quadrat depends on the lens length – 1700mm for a 35mm lens, 1400mm for a 28mm lens. For certain types of survey, for instance monitoring growth rates of covering species, it is useful to divide the quadrat into smaller units using cross-hairs.

Quadrats are photographed at regular intervals and the photographs scanned into a Geographical Information System (GIS) and digitised to show area cover of key species. Yearly data is then overlaid and area cover compared.

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# Purpose

Monitoring the population of characteristic, important or indicator species on:

- rocky shores/seabed
- *Zostera* beds
- saltmarsh

Monitoring growth/expansion rates of solitary and colonial species such as:

- *Eunicella verrucosa* (pink sea fan)
- *Sabellaria* spp.
- composition of characteristic biotopes

## Advantages

- Low maintenance
- Minimum equipment
- Minimum training needed
- Can be carried out by non-specialist staff after initial site selection
- Low cost (after initial outlay for equipment)
- Non-destructive sampling technique

The simplicity of data collection also reduces the likelihood of error in the analysis. As technology (e.g. digital cameras, image analysis software) improves, data processing will become easier and will have less margin for error.

## Disadvantages

- Restricted area covered
- May not reflect wider changes
- Restricted to predominantly bedrock/hard substrata biotopes (but can be used with care for sediment biotopes such as *Zostera* beds)
- Site selection/marking and data processing can be labour-intensive

# Logistics

## Equipment

There is a long list of equipment for the initial site location and marking, but once that has been completed, much less equipment is required.

### *Set-up phase*

- Map, sighting compass and GPS
- Tide tables
- Drill with fuel and spare drill bits
- Hartnoll and Hawkins (1980) suggest using an air-drill powered by a SCUBA tank to mark quadrats. However, there are several petrol-driven drills available that are powerful enough to drill rock and infinitely more portable. Note, even the most modern battery-driven drills are not powerful enough to drill hard rock

- Quadrat It is particularly important to try the quadrat in awkward-to-reach habitats, such as overhangs, to make sure the surroundings do not obstruct the camera's view of the quadrat. For smaller biotopes, such as overhang turfs, it is useful to have a 0.25m square quadrat specifically designed to get into small places
- Marker bolts and resin for setting them
- High visibility caps and/or paint for bolts
- Camera (SLR or digital) – a 35mm lens will work, but with a 28mm or 24mm the quadrat camera support can be lower, with negligible distortion (Figure 2)
- Chinagraph pencil and slate/weatherwriter
- Safety equipment, including:
  - protective eyewear
  - heavy duty gloves
  - non-slip boots
  - first aid kit
  - radio/mobile phone for remote sites
  - life jackets for exposed sites

### *Survey*

- Map, sighting compass and GPS
- Tide tables
- Directions/site guide to relocate stations
- Quadrat and associated equipment, such as spare nuts for camera supports (see Figure 1)
- Survey camera and spare films
- Snapshot camera and spare films
- Numbered identity cards/slates for each quadrat
- Chinagraph pencil and slate/weatherwriter
- Survey forms
- Paint to remark sites if necessary
- Safety equipment, including:
  - first aid kit
  - radio/mobile phone for remote sites
  - life jackets for exposed sites

### *Equipment for data processing*

- Personal computer
- Scanner
- Geographical information system/image analysis software

**Figure 2** Quadrat *in situ* at Wembury VMCA during a survey. The lens used here was a 35mm, hence the height of the cross-bar camera supports.

## Personnel

Set-up and data processing are the most time-consuming parts of this type of project. A considerable amount of time is needed to research the entire survey area so that transects and quadrats are located so as to best fulfil the survey objectives. Manual data entry and digitising is slow and labour-intensive.

### *Initial site selection and marking*

At least two experienced littoral surveyors are required to carry out biotope mapping. If the survey area is large, this will take several days and may have to be carried out over an extended period of time because of tidal restrictions.[2]

For quadrat marking, when power tools are being used, an absolute minimum team of three is recommended, ideally with a fourth person to help carry heavy equipment. At least one of the team should be an experienced littoral surveyor and, for continuity, preferably one who carried out the initial site selection. Duration of site marking will depend on several factors, in particular the accessibility of the survey site and the hardness of the rock. Allow about 20 minutes per quadrat.

### *Survey*

A team of three is recommended for the survey, mainly to help carry equipment. Specialist biologists are not necessary, but at least one of the team should be a competent photographer. Allow about 15 minutes per quadrat. Two transects close together can be surveyed on the same falling and rising tide.

### *Data processing*

This is more time-consuming without the use of a digital camera. Photographs are scanned into a standard GIS package and manually digitised. This involves digitising areas of main species cover and assigning scaled points to individual species such as limpets. Quadrats with algal canopies are digitised with and without the algae. Overlays for successive years can then be directly compared for area and individual species cover. Photographs of quadrats can be linked via the GIS to maps of the whole survey area.

At the time of writing (2000), digital cameras and image analysis software are becoming much more affordable and easy to use and it is anticipated that this technology will dramatically reduce the time required to process data from this type of survey.

2 See PG 1-1 for the guidance on biotope mapping.

# Method

## Site selection and marking

(1) Map whole survey area to biotope level (or obtain previously prepared maps).
(2) Select transect locations according to survey objectives.
If the survey is aimed at monitoring a large area, transects should be located to cover as many features of that area as possible. For instance, where the survey area is at the mouth of an estuary, transects should be located to survey all levels of salinity and physical exposure.
(3) Select quadrat locations to provide a representative sample of entire transect/survey area.
Quadrats should be located so as to provide a representative picture of the survey area. At Wembury, representativeness was decided by carrying out a biotope survey of each of the five transects. A matrix of all biotopes found was then drawn; if a biotope was found in three or more of the transects, it was deemed to be representative.
Where possible, care should be taken to locate quadrats away from the biotope margins.
(4) Mark quadrat locations with bolts – marking diagonal corners as in Figure 3. Occasionally, an additional bolt to mark the general location of a quadrat may be necessary, e.g. for overhang or boulder biotopes, where a bolt in a prominent place will help relocation.
Bolts should be set so that the legs of the quadrat sit directly on top of them, to ensure exact repositioning. It is good practice to mark the same corners on each quadrat, to ensure that the photographs are always orientated in the same way.
(5) Photograph quadrat *in situ*.
(6) Produce field locating guide using a combination of field notes, photographs and bearings/transits or differential GPS readings for each quadrat.

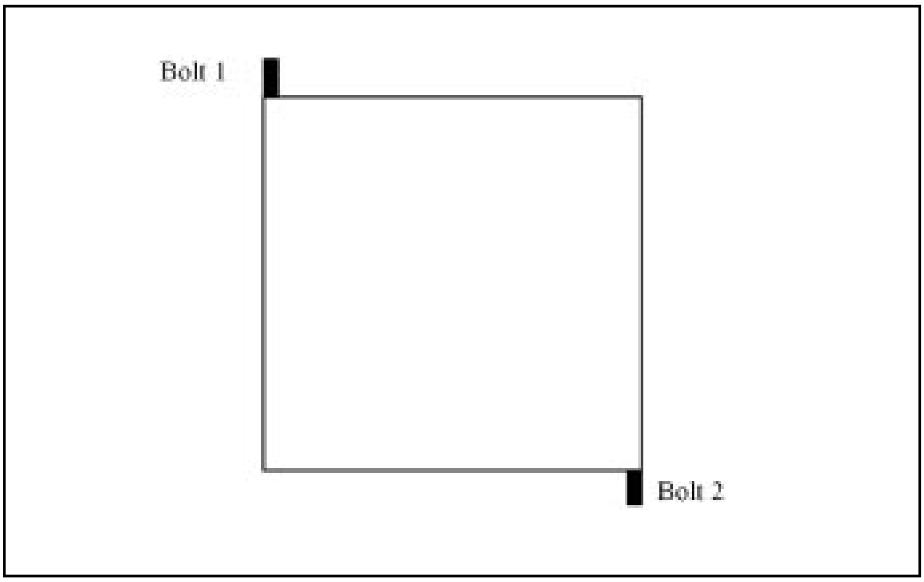


**Figure 3** Showing position of marker bolts relative to the quadrat. An additional position indicator bolt can also be set – for instance, if the quadrat is under an overhang, a locator bolt could be placed on top of the ledge.

## Survey

### *Fieldwork down the shore*

- Follow the falling tide.
- Ensure that the quadrat, and hence camera, is orientated in exactly the same way each time it is photographed.
- Ensure that the inside edges of the quadrat are within the photograph frame.
- Ensure that the quadrat identity slate is within the photograph frame but not obscuring important features.

- Photograph quadrat, recording the camera settings. Pictures should be bracketed.[3] If using a camera with automatic settings, it is possible to standardise light levels by using a diffused flash for all photographs.
- For biotopes with an algal canopy, photograph the quadrat with and without the algae in place.
- Support the photographic data with a detailed habitat survey every 3–5 years. The easiest way to do this is to complete a Marine Nature Conservation Review (MNCR) habitat survey form for each quadrat.
- Sample difficult to identify species with care, for subsequent identification preferably from adjacent areas.

### *Laboratory/field base*

- Ensure all films are correctly labelled and that numbers of photographs correspond to the field notes.
- Check photographs against notes once developed.
- Identify all samples and add data to survey forms.
- Scan photographs into GIS package and digitise areas of main cover. Manual scanning of photographs is very time-consuming and produces large files. A scanning resolution of 300dpi gives images of sufficient quality for digitising, as well as reasonably sized files for most PCs. Figure 4 shows an example of a quadrat picture and digitised overlay.
- Assign large individuals with points.
- Compare overlay with previous years' data.

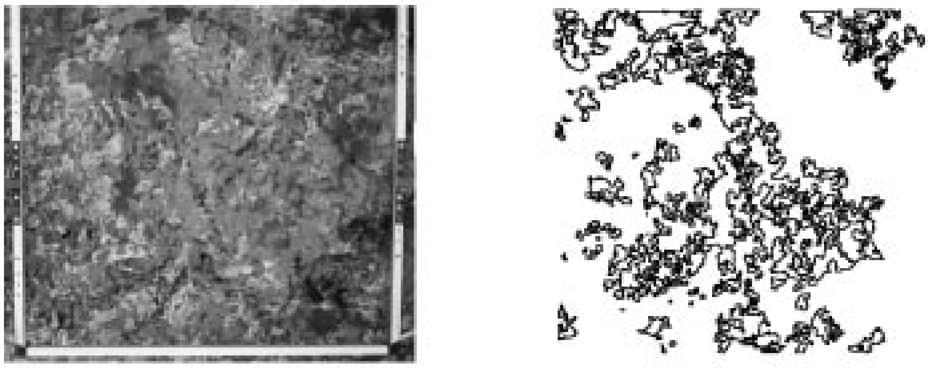

**Figure 4** Example of quadrat of a yellow and grey lichen biotope (left) and its associated digitised overlay of main species cover (right)

## Data analysis

The principal data analysis consists of direct comparison of area cover, abundance and/or size of individuals/colonies (e.g. *Eunicella verrucosa*). Where surveys are aimed at area cover, as opposed to growth of an individual species, statistical analysis of data can be done, but the method is designed to be as simple as possible and direct comparison is more relevant.

## QA/QC

- Relocation – at the beginning of a survey, the directions for quadrat location are tested by new surveyors.
- The surveys take place at the same time each year.
- To standardise the photography, camera settings are not adjusted during the survey.
- At the beginning of each data entry phase, comparative exercises in digitising are carried out to determine the variability of data processors.
- Surveys are backed up by detailed habitat surveys (MNCR survey forms) every 3 years (DWT).
- ID for 5–10% of records should be cross-checked by an independent individual.

3 Author's note – experience has shown us that lightly overcast days are better for surveying than sunny days, when any cloud dramatically affects the light levels.

# Data products

This type of survey will produce a detailed pictorial image of the study area over a set period of time. The images can be linked to base maps of the survey area where appropriate, or simply kept as a direct comparative record. Whilst the linked maps and photographs can be reproduced in report form, they are much better displayed using a computer. Habitat survey form data can also be linked electronically, either directly or via an external database, such as the MNCR Database or Recorder 2000.

Images and overlays can be stored on CD. Prints and slides should be carefully archived and stored in appropriate conditions according to manufacturers' instructions.

# Cost and time

**Table 1** Typical costs and timing of a survey of sixty quadrats in five transects (DWT 2000). The costs shown do not include basic survey equipment, such as slates, compass, writing materials, etc. Comparative figures for a digital camera survey are shown in brackets.

| *Resource* | *Cost* | *Time* |
|---|---|---|
| Quadrat construction | £25 for materials | 0.5 days |
| Biotope mapping | Personnel time | 5 days |
| Quadrat location and marking | Personnel time | 7 days |
| Bolts and fixative | £40 | |
| Drill hire/fuel | £15 per day | |
| Survey | Personnel time | 5 days |
| Good SLR camera | £300+ | (1 tide per transect) |
| Film | £25 | |
| [Digital camera] | [£500+] | |
| Data processing | | |
| Development of photographs | £35 | |
| [or CDs for digital image storage] | [£1 per CD] | |
| | Personnel time | 30 days |
| | Manual scanning/digitising | [8–10 days] |
| | [Digital photography and image analysis] | |
| Reporting | Personnel time | 4–5 days |

# Health and safety

## Survey team

The usual conditions for a shore survey apply:

- A team of at least two should carry out any shore survey.
- At least one member of the team should be qualified in first aid.
- A first aid kit must be carried and all members of the team must be made aware of its location.
- Always inform someone of the survey details – location and estimated time of return.
- Carry a mobile phone/VHF radio (though the remoteness or topography of many shore locations often renders one or both of these unusable).
- A good knowledge of the tides and the shoreline (i.e. the potential for being cut off) is essential.

In addition to the generic risk assessment for survey work, a site-specific risk assessment should be completed for each survey.

A separate risk assessment should be carried out when using power tools.

### Public risk

In addition to the risks to those carrying out the survey, there is the danger to the public that may be caused by leaving bolts sticking out of rocks on a busy seashore. Ensure that quadrat markers project as little as possible from the rock face and protect them with a high visibility cap.

The Health and Safety Executive produce various free guides to help people assess risks and prevent accidents. These can be obtained from HSE Books (telephone 01787 881165).

## References

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# Procedural Guideline No. 3-12 Quantitative surveillance of sublittoral rock biotopes and species using photographs

Blaise Bullimore, Countryside Council for Wales[1] and Keith Hiscock, MarLIN[2]

## Background

The use of photography for quantitative survey and for the study of seasonal and long-term fluctuations in rocky sublittoral communities has been developed particularly in Sweden and Norway. Lundälv (1985) describes the results of work which followed changes on sublittoral rocks on the Swedish west coast, including providing an assessment of sample area required to describe adequately the community present and to assess change. Whilst Lundälv employed a housed medium format Hasselblad camera, systems using paired Nikonos cameras with synchronised shutter release were subsequently developed offering a less expensive and less cumbersome option. Christie, Evans and Sandness (1985) describe the equipment and methodology together with an assessment of the time and costs involved. Both systems employed in the Scandinavian studies used picture areas of $0.25m^2$ (50cm x 50cm).

In the UK, the technique was adopted and developed at Skomer (Bullimore 1983, 1986), where a long-time series of photographs is now available, and sites for photographic surveillance have also been established at Lundy and the Isles of Scilly (Fowler and Pilley 1992). The technique is routinely used as a standard data gathering tool in the Skomer MNR, using both mono and stereophotography and picture areas up to $0.7m^2$ (70cm x 100cm), and was used in candidate SACs during the LIFE monitoring trials.

Several systems have been developed for specific applications. Stereophotography offers many advantages during analysis of photographs: species are easier to separate and identify, there is increased ability to view under canopy-forming species, and more accurate measurements can be made. A highly precise anchoring and reference system has been developed independently in Ireland to meet the specific requirements of measuring growth of sponges (Picton, pers. comm.).

## Purpose

Quantitative photographic sampling is suitable for measuring variables of attributes describing:

- community/biotope composition and species richness (species >2mm and not obscured by overgrowth or silt);
- numerical abundance or percentage cover of species in communities/biotopes within defined statistical limits;
- species density and distribution, size, growth rates and, for certain taxa, physical condition ('health'), presence of reproductive structures.

Data generated may also potentially contribute to increased understanding of species behaviour, recruitment and longevity and reveal subtle, unanticipated changes over time at fixed sites.

The technique is suitable for epibenthic species and communities on rock, including large boulder and stable cobble habitats. Although it is particularly suited to surveillance or monitoring of defined

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areas, there are no insurmountable reasons why it should not also be possible to collect randomised samples. However, no examples of the technique having been used for random sampling are known to the authors.

The specific purpose for which the technique is selected will determine the precise data requirements and thence the sampling locations, areas and frequency, the equipment configuration and image and data analysis requirements.

# Fitness of technique for purpose

Photographic techniques offer significant advantages over other techniques for collecting quantitative data describing sublittoral species and communities. Although the photographic technique described in the present guideline has a number of limitations, several of the same limitations are applicable to other data gathering techniques and therefore limitations are not necessarily synonymous with disadvantages.

## Advantages

- non destructive
- enables surveillance of marked individuals, colonies, communities etc over time
- enables collection of large volumes of data per unit time underwater
- provides a permanent record
- enables accurate quantification of organism abundance, cover, size, etc.
- facilitates inter-worker calibration
- time series enables retrospective analysis
- stereo images enable accurate identification
- relatively low cost
- divers may not need taxonomic expertise

## Limitations and disadvantages

- dependency on reasonable water clarity (Lundälv 1971 suggests 3m as the limiting visibility for the Hasselblad system; experience at the Skomer MNR suggests a minimum visibility of 4 times the camera-to-subject plane distance for usable images)
- significant time requirement for laboratory analysis of photographs
- potentially unsuitable for communities dominated by tall and overhanging organisms (e.g. kelp forest)
- taxonomic voucher specimens are not acquired
- cryptic fauna are not sampled
- equipment dependency
- equipment relatively cumbersome (not heavy, but reference frames may have high drag factor)
- initial capital equipment costs

## Other considerations

Taxonomic accuracy is dependent on the communities targeted and a range of other factors, and may be better or worse than *in situ* recording. Although certain taxa are difficult to identify in photographs, taxonomic accuracy may be enhanced by the use of stereo or close-up photographs.

Efficiency, cost-effectiveness and area covered will be dependent on the relationship between the specific data requirements and the prevailing physical conditions.

# Logistics

## Equipment

### *Site and station marking*[3]

See Procedural Guideline 6-2 for details.

### *Photography*

Photography to enable quantitative analysis necessitates acquisition of images of areas which are known or contain quantifiable reference points. The use of cameras mounted on reference frames enables photographs to be taken with fixed area of coverage at constant camera-to-subject plane distance. This provides the additional practical advantage of enabling the use of fixed focus, aperture and lighting, which frees the diver to concentrate on the photographic subject and accurate positioning rather than the actual photography. (*Note: the standard camera with wide-angle lens for 'viewpoint' photography is considered to be a non-quantitative indicative or illustrative technique and is not addressed in this Guideline.*[4])

### *Reference frames*

The size of reference frame or area will be in part determined by the subject size(s), area to be photographed and underwater visibility, which determines subject area indirectly as a consequence of camera-to-subject distance. Reference frames ranging in size from 40cm x 50cm to 70cm x 100cm have been used with success in British waters. Close-up lens framers provide an additional option for work in poor visibility and for small subjects.

Aluminium box section (25mm) and 'quick fit' preformed, rigid, plastic coated, corner sections (2, 3 and 4 way) are readily available[5]. Camera/strobe mounting bars have been constructed from 40 or 50 x 5mm aluminium angle. These materials enable sturdy, appropriately sized, purpose-built reference frame/support units to be readily, economically and rapidly constructed.

### *Cameras and lenses*

Nikonos cameras fitted with 15mm focal length lenses are ideal tools for reference frame photography. Fifteen millimetre lenses reduce camera-to-subject plane distance, minimising potential optical backscatter, with acceptably low optical distortion, and maximise potential depth of field in the photographic images. Dual cameras can be used to produce stereophotographic images.

Nikonos cameras with a 28mm or 35mm lens fitted with close-up lens and framer can be used for small areas.

Other camera systems have been and may be employed, for example the sort of housed Hasselblad system used by Lundälv (1985). Other than the larger film format of that system, there are no advantages in using a housed camera for this type of work. In the case of a medium format system the high equipment and consumables cost and the short film lengths are significant disadvantages.

### *Lighting*

High output, rapid recycling strobe units are required to enable small lens apertures to be used to maximise depth of field (especially important when working at close range and/or with tall target species). Units with modelling lights are useful to ensure correct lighting alignment and in low light conditions. Dual strobes are strongly recommended to minimise heavy shadows which may make analysis of images difficult. If dual strobes are to be used, note that slave strobes may be unreliable and that the range of units capable of accepting dual-sync leads is limited.

### *Digital photography*

The low cost of consumables and the ease of importing images to computers for analysis make the use of digital photographic techniques particularly attractive. Progress in the development of digital imaging has been rapid during the period of preparation of this Guideline. Housings for many digital cameras are now available. However, products designed for the general diving photographic market are not necessarily suitable for routine scientific application where simplicity and limited features, but also the highest image resolution and widest lens angles, are required. A limited number of digital cameras

3 In this guideline the term 'site' is used to denote a location at which photographic sampling events are undertaken; 'station' is used to denote a specific photographic sampling location within a site, e.g. a quadrat or cluster of quadrats.

4 See PG 1-2 for guidance on viewpoint photography.

5 For example from RS Components (indexed under 'Storage: racking' in their catalogue)

designed for specialist commercial underwater applications are beginning to become available.

At the time of writing, the lower resolution of digital systems compared to film and the relatively poor fields of view of digital cameras (compared with, for example, Nikonos 15mm) make digital still imaging not yet a viable option for this work. However, further advances in specification (e.g. high specification, but very expensive, cameras with interchangeable lenses are now available) and falling costs are likely to make digital still imaging attractive and of greater potential application in this field in the near future. However, the memory requirement for the highest resolution, true colour images and capital costs of highly specialised equipment are likely to remain high and housed cameras are less suitable for mounting on reference frames than compact cameras such as the Nikonos

### Personnel

Suitably experienced and qualified divers. Site familiarity is advantageous, although it should not be essential since the relocation of a site and the sampling stations should be facilitated by detailed instructions and marks.

## Meeting photographic sampling requirements

### *Initial planning*

It is not possible to provide project-specific advice in this Guideline since requirements will vary depending on the species or communities to be monitored, the measurements to be made and the particular environment in which the monitoring project will be undertaken. The data requirement (number of samples, replicates, sample area, etc.) need to be determined prior to consideration of whether or how quantitative photography could provide that data.

Where the objective is to determine community change, or whether a target condition is being met, either:

(a) the minimum number of individual samples that needs to be taken to provide the basis for determining statistical significance needs to be established (as guidance only, Tomas Lundälv (pers. comm.) has found that about twenty 50cm x 50cm random samples are required to obtain adequate data to identify mean densities or cover of the main organisms in Swedish fjords, and that data from random samples showed the same trends as on the fixed sites); or

(b) the minimum area which is representative of the target community needs to be established and defined: Lundälv (1985) found that four 50 x 50 quadrats were required to obtain mean density or % cover in what he called a 'dynamic minimum area'.

Other objectives may include the measurement of species size, determination of growth rates or quantification of numbers of target organisms per unit area. Sampling requirements will need to be determined for each, taking into account all the relevant variables.

Despite the availability of extreme wide-angle lenses, the necessary camera-to-subject distances may be too great for clear photography in many areas of the British Isles where water turbidity is high.

### *Sampling area*

The area of coverage required will vary, being dependent on (at least):

- the target environment and the dynamics of the target species/biotopes
- the size of the species within the target biotopes/communities
- the heterogeneity or homogeneity of the target species/biotopes and seabed topography

### *Timing of photographic sampling*

Timing will usually be related to ensuring the best likelihood of calm conditions and consistency in time of year to minimise seasonal effects. Summer is usually therefore best on the open coast. Consideration needs to be given to any seasonal differences in biota. Although this may lead to sampling always being undertaken at the same time of year, it might also, for example, necessitate sampling of encrusting or low-growing species when the growth of ephemeral algae is least.

### *Site selection*

Sites selected will be dependent on the particular subject features or characteristics to be recorded, as appropriate. In addition to considering biological criteria for selecting monitoring or surveillance sites, consideration should also be given to:

- the physical ease or difficulty of marking/relocating the sites/stations
- the local topography of the seabed surface (reasonably flat surfaces are more readily photographed)
- exposure to wave and current action (will it be possible to handle and accurately reposition photographic systems in water conditions typical of the site?)

### *Site and station marking*

The ease of location and sampling fixed sites will be dependent on the comprehensiveness with which the sites are marked. However, comprehensive clear permanent marking may not be desirable because it may attract attention or interfere with the community being monitored, or may not be feasible depending on rock type, slope, exposure and subject.

Ideally, site and sampling station location should be planned so as not to necessitate specific relocation dives and/or dives to temporarily remark sampling locations. In practice this is rarely likely to be achievable.

Sites are most reliably marked by permanent marker buoys, acoustic beacons or other fixed, robust, easily visible or relocatable features. Only where divers can reliably descend to the seabed without risk of horizontal displacement by water movement should surface site location not be supplemented by foolproof aids wherever possible. In these circumstances, precise surface positioning is vital, using dGPS, transits, bearing and distance (radar).

To enable rapid and efficient relocation, sites should be mapped, sketched or photographed as appropriate and clear, unambiguous, foolproof written instructions for locating stations should be prepared. Precise bearings and exact distances between reference points are particularly useful. This is particularly important when temporary surface markers cannot be left in place during sampling; for example, one monitoring station in Milford Haven lies immediately beneath the approach line to the Irish ferry berth.

Permanent fixed station reference attachment points to which camera frames can be rapidly and precisely attached are advantageous. Where permanent transects, lines or other station marking devices are inappropriate, long (e.g. 30m or 50m) tape measures provide robust, rapidly and easily deployed and retrieved transect lines. Deployed from diving surface marker buoy reels and fastened between permanent, regularly spaced, unobtrusive, robust markers (ring bolts, rock anchors, pitons, screw-eyes), they enable the clear and unambiguous relocation of sampling stations.

## Personnel

The minimum team size will be dependent on ease of site and station relocation, the amount of temporary station marking necessary, the number of sampling stations and the sampling time available.

The absolute minimum diving team size will be two (i.e. the minimum number required to dive to collect samples; rather than the minimum team size to meet HSE requirements). The camera operator must have sufficient biological familiarity to enable the sampling to be carried out effectively. The second diver will be required to give sampling position guidance, keep a sampling record, provide safety cover and possibly assist with supporting the reference frame. Site familiarity is clearly advantageous.

### *Photographic equipment configurations*

The photographic equipment selected will depend on several variables including:

- specific objectives
- subject size
- area of coverage required
- anticipated visibility
- predicted density of canopy forming species

Frame size and camera-to-subject distance will depend on the variables noted above. As a guide, using Nikonos cameras with 15mm lenses:

- a 400mm (vertical axis) x 500mm (horizontal axis) reference frame requires a camera (film plane) to subject plane distance of 510 mm;
- a 500mm x 700mm reference frame requires a camera (film plane) to subject plane distance of 590 mm;
- a 700mm x 1000mm reference frame requires a camera (film plane) to subject plane distance of 810 mm;

Using a Nikonos camera with (Nikonos) close-up lens:

- both 35 mm and 28 mm prime lenses require a camera (film plane) to subject plane of 325 mm, to provide useful picture areas of c. 150mm x 100mm and 225mm x 150mm respectively.

Three basic photographic configurations have been used in sublittoral monitoring in the UK:

- single (Nikonos) camera/wide-angle (15mm) lens mounted on reference frame (wide-angle monophotography): see Figure 1
- dual cameras/wide-angle (15mm) lenses mounted on reference frame (dual camera stereophotography): see Figure 2
- camera with close-up lens and reference framer (close-up photography)

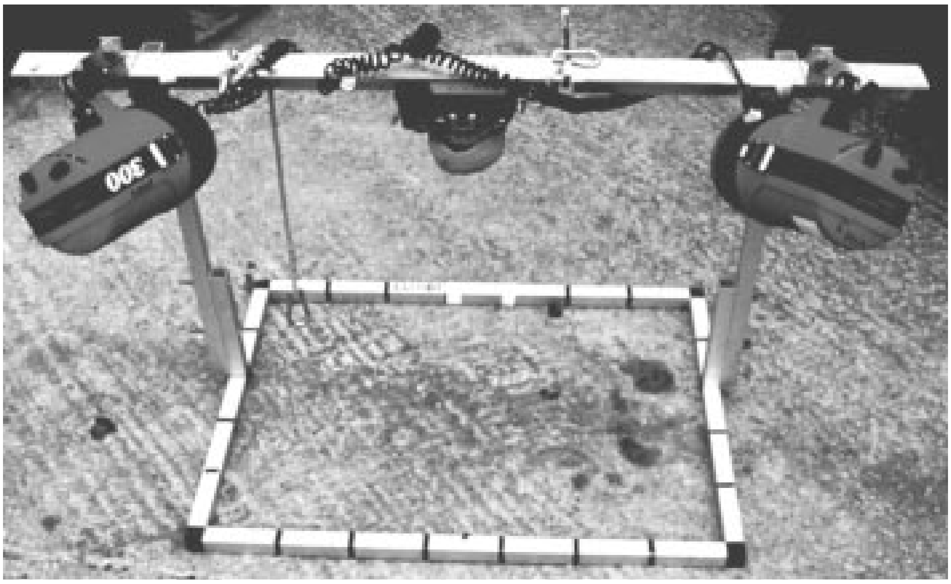


**Figure 1** Configuration of wide-angle monophotography rig

Twin strobe lighting units are almost essential for both the reference frame configurations to prevent images with heavy shadow areas.

The fields of view of Nikonos cameras mounted with lens axis separation of 160mm (i.e. 80mm either side of centre) are accommodated by the frame sizes described above. The cameras must be mounted so that the optical axes are exactly parallel.

All three systems require minimal photographic expertise. Each uses fixed camera-to-subject distances and once focus and exposure requirements have been determined for any particular combination of equipment, these too can be fixed to minimise a source of operator error, leaving the operator free to concentrate on accurate location and framing.

A further medium close-up system utilising a housed 35mm camera, 28mm lens and dome port has been developed to measure sponge growth (Picton, pers. comm.). The system was designed to enable sampling of an area of c. 1.8 x 1.2m as a mosaic of 30 (6 x 5) images and employs a frame with a travelling camera support bar which is temporarily fixed to permanent mounting bolts at each sampling event. Accuracy of camera positioning is reported to be excellent, within 1cm or better.

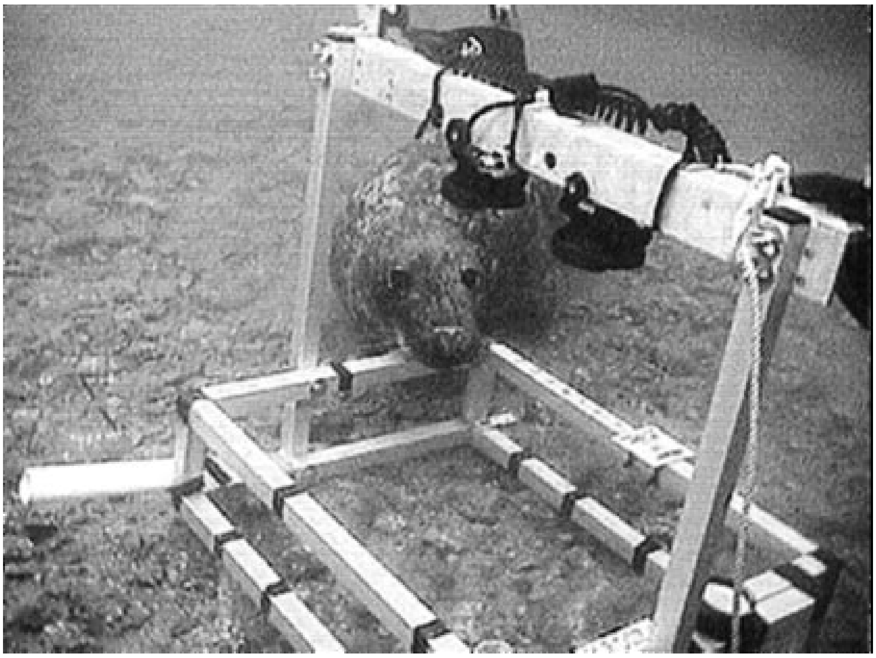

**Figure 2** Configuration of a dual camera stereophotography rig (with curious bystander)

### *Relative advantages of mono- and stereophotography*

The main justifications for using dual camera stereophotography are that:

- three-dimensional images are generated and significantly improve species identification, particularly of small and drably coloured organisms and in low-contrast images;
- the masking effect of smaller canopy-forming species is reduced (but not eliminated);
- photogrammetric measuring techniques are made possible.

The major drawback of dual camera stereophotography is that synchronisation of both cameras with the flash requires careful operation and a well practised operator;

Single camera stereophotography (i.e. moving the camera between exposures) is impractical unless the reference frame can be rigidly fixed to the seabed and the subject species will not move between exposures.

Specialised or bespoke viewing systems are necessary to see three-dimensional stereophotographic images.

Additional factors are shown in the following table.

| | *Single camera monophotography* | *Dual camera stereophotography* |
|---|---|---|
| Equipment set-up and operation | simpler | more complex |
| Risk of equipment failure | marginally less | marginally higher |
| Equipment capital cost | | approx. 40% higher |
| Consumables cost | marginally lower (negligible) | marginally higher (negligible) |
| Image quality | same | same |
| Image viewing requirements | simple – projection, printed, scanned and viewed on computer | requires specialised viewing system to view 3D images; potential to produce computer-generated 3D 'virtual' images; single images may be viewed as for monophotography |

### *Close-up photography*

The Nikonos camera system fitted with supplementary lens and frame-finder provides the simplest readily available method of photography, and is valuable for photographing small areas and species and for use in poor visibility. Advantages are ease of use and relatively low capital cost. Disadvantages are the small area included.

# Methods

## Station location

Following site relocation, and possible temporary marking if it is to be sampled over a period of time, station markers should be relocated using previously prepared maps or other instructions, their condition assessed and any temporary lines or other markers installed. The opportunity of maintaining the condition or visibility markers should be taken during the retrieval of lines or other temporary station markers.

## Photographic procedures

Except in the simplest sampling programme, photographs should be taken following a predefined plan. A written record may be valuable to ensure that the sampling programme is completed to plan and to record errors (failures, duplications, positioning errors, photographs out of sequence, etc.).

Extreme care should be taken to ensure that photographs are taken:

- with the greatest positional precision possible;
- with the camera axis as perpendicular as possible to the rock surface;
- without causing damage or disturbance to the communities being monitored;
- without mobilising silt deposits which would reduce water clarity and consequently image quality.

Depending on the location, current exposure, slope and equipment configuration, the camera operator may be capable of positioning and supporting the reference frame unaided, though assistance in maintaining position may be useful in certain circumstances. In most programmes the assistant will provide guidance for positioning and act as recording secretary.

### *Additional instructions for dual camera stereophotography*

The major practical difficulty of dual camera stereophotography is ensuring simultaneous exposures in both cameras. Nikonos cameras have a mechanical shutter release. Although simultaneous mechanical triggers have been used in Scandinavian systems, when they were investigated in Wales they were found to produce unreliable results because of the extremely fine tolerances required to release the shutter exactly synchronously.

The exposure technique in current use at the Skomer MNR is as follows:

(1) One camera (usually the left of the pair) is set at shutter speed 'bulb' (B).

(2) The other camera is set at either automatic or flash sync speed, and connected to both strobes via dual sync lead.

(3) Exposures are made in the sequence: left camera shutter released and manually held open; right shutter released; left shutter allowed to close.[6]

With practice, the actual exposure time of the left camera is estimated to be about 0.5 seconds. Whilst this is undoubtedly a long exposure time, in practice it is of minor consequence and does not result in loss of picture sharpness because, at a normal working lens aperture of f11 or f16, the only significant light that the film is exposed to (in normal conditions in UK waters below c. 5m depth) is from the strobe, which is of extremely short duration (<0.001 sec).

6 See Bullimore (1986) for further details.

# Analysis

## Photographic analysis

Analysis will depend on the purpose of the specific project.

### *Viewing images*

Images may be projected onto a screen, viewed directly under low power microscopes or other low power optics, scanned and viewed on a computer monitor, or converted to photographic prints.

Stereo pairs need to be viewed, using pairs of low power microscopes, a stereo comparator or other appropriate stereo-optical viewer.

Images must be viewed at an appropriate size to discriminate the smallest organisms resolved by the images.

### *Data gathering from images*

The best possible taxonomic accuracy is fundamental to the extraction of any data from images. Species that are most difficult to identify or discriminate from similar species may be excluded or aggregated. Keystone species or species which might act as surrogates for overall change must be recorded. Christie *et al.* (1985) suggest that organisms down to 2–3mm may be identified. It may be necessary only to record a proportion of the total number of species present.

Care is essential in counting numbers of individual organisms (per unit area) or in using point sampling to estimate cover. Measurement of absolute organism sizes or areas requires the position of the subject relative to the plane of the reference frame to be known or to be calculable (with stereopairs), or reference scales included in the images.

Computer-assisted measurements may enable more rapid measurement of certain species.

### *Point sampling*

Determination of percentage cover is best achieved by point sampling. Depending on the viewing method, a sampling grid is overlaid on the image (e.g. digital overlay on computer, acetate underlay beneath a transparency) and the individual organisms at each point recorded. Note that it is possible for two or more organisms to be recorded at a single point (caused by overgrowth or overhanging of one species over another) and total cover to exceed 100%.

Several workers have established that there is no advantage in using random as opposed to systematically placed points. Points that are systematic make analysis much easier than wholly random points, although some workers use randomly selected points from a grid of a large number of systematically arranged.

Workers in Scandinavia have found that 100 points are adequate to describe communities dominated by reasonably large organisms. However, Bullimore (1996) concluded that this was insufficient for communities in which a significant proportion of the rock surface was dominated by small organisms and used a 320-point (20 x 16) grid.

### *Area and organism measurements*

Stereo comparators are available which are operated with a graticule. Green (1980) suggests that size measurements of approximately 1.5mm can be made using the Nikonos system. Bullimore (1996) reports measurement from 35mm transparencies to an accuracy of ±0.05mm, equivalent to ±1.0mm in life at a camera-to-subject distance of 510mm. Gilbert (1998) made measurements from scanned digital images to a resolution of 1mm. However, it should be noted that the high measurement resolution possible with available viewing systems exceeds the positional accuracy possible during image capture and it is the latter which will usually be the limiting factor in absolute size determinations.

### *Analysis of digital images*

Many software applications are commercially available for analysis of digital images, whether captured from digital cameras or scanned from transparencies. Gilbert (1998) investigated the suitability of several image-analysis applications for use with Skomer MNR images. She concluded that few offered the functionality required, either being highly over- or under-specified. Several applications designed specifically for medical applications were investigated. Their functionality depended heavily on high-contrast images containing clearly identifiable target objects and were expensive.

Gilbert (1998) concluded that GIS software offered most of the functionality required. The desk-top GIS application MapInfo™ was selected for its ability to easily and accurately register images (using 'non-earth' registration), ease of data handling, flexibility of measurement options and the ability to layer information over images, enabling comparison of images in time series.

The generation of 'virtual reality' 3D images from stereo-pairs using VRML software on a desk-top environment appears feasible (Pan, Cardiff University, pers. comm.). Such virtual reality images have potential application for rapid and easy visualisation and quantification of attributes of sublittoral species and habitats.

### Data analysis

Analysis of numerical or other data derived from quantitative photographic sampling will be project-dependent and is not considered in this Guideline.

## QA/QC

### Sampling

- Precise re-location of quadrats is essential.
- Framer must be used to ensure a perpendicular angle of photography; underwater horizontal visibility must be better than minimum levels (>3m for taking 50 x 50cm quadrats using a Nikonos and 15mm lens, >1m for using the 28mm Nikonos lens and supplementary lens).
- No silt disturbed by the diver should be in the picture area.
- Film stock should be of high quality, fine grained (50–100 ASA) and in-date.
- Photographs must be accurately exposed.
- Water column discontinuities which may cause optical distortion, such as a halocline, must be avoided.
- Image capture requires careful recording, and individual images need to be precisely and promptly labelled with project, date and station to avoid misidentification of images.
- Where reference frames are employed, the date and station should be marked on frames where they will be clearly visible within captured images.

### Analysis

Taxonomic accuracy is dependent on image clarity and resolution and on taxonomic skill of the analyst. Accuracy of identification of many organisms from photographs may be as high or higher than field recording by competent diving biologists if the image area and target species sizes are appropriately matched. The photographic record makes it possible to check the accuracy of taxonomic identification. Accuracy is compromised if organisms being measured are obscured by overgrowth. In analysing photographs, different workers should be able to have an error of 3–4%, but no more than 10%, in % cover and density measures if well trained (Lundälv, pers. comm.).

Measurement accuracy is dependent on the position of the subject within and relative to the plane of the reference frame. Barrel distortion caused by wide-angle lenses is greatest closest to the image edge, though the measurement errors introduced are less than c. 1%. As noted above, positional accuracy during image capture will usually be the limiting factor for size determinations rather than measurement resolution from images.

### QA advantages of photographic techniques

- avoids variation due to patchiness (random sampling requires too many samples to overcome heterogeneity on broken rocky surfaces);
- detailed analysis is possible in the laboratory and the standard of accuracy is much higher than for *in situ* survey, arising in part from the pressures on available time inherent with *in situ* survey;
- stereo pairs can be used to accurately measure growth rates and calculate biomass (indirectly);
- photographs provide a permanent record so that possible errors can be checked and more detailed work can be carried out at a later date if required;
- photographs enable the distinction of smaller organisms than *in situ* survey;

- photographs can be used to demonstrate or illustrate feature change or stability;
- reasoned allowances can be made for variation in cover of tall and/or highly contractile organisms.

### QA restrictions on photographic techniques

Photographs may under-record species or individuals that are obscured by overgrowth (partly overcome by stereopairs) or silt. The consequent underestimate of abundance is particularly important if seasonal changes are being studied in the species that is occasionally obscured.

High turbidity tends to increase image contrast. Image analysis is constrained by low image contrast.

It may be difficult, particularly in British waters, to locate a sufficiently extensive area of unbroken rock with the same inclination to provide an optimum sampling area or a sufficient number of replicate photographs (though this restriction is not limited to photographic techniques).

## Data products

Permanent images: both original film-based material and electronic copies need to be stored in suitable, secure locations.

Numerical or other data: require storage in industry standard spreadsheets, databases, GIS data tables and map layers as appropriate.

## Costs and time

The main costs arise from personnel time and the capital costs of equipment.

### Site establishment

Site preparation for fixed station photographic sampling may be significant. Depending on the requirement of the project, distribution of target species, rock type, exposure and depth , the establishment of a site may take several days excluding the time required for selection of the location.

The time taken to drill holes in rock for plastic plugs or ring bolts, or to hammer pitons into suitable cracks, depends on rock type and station depth. The time required to mark hard rock sites may be considerable.

Equipment and consumable costs are not high in comparison with personnel costs.

### Site relocation

Relocation time will vary with quality of relocation information, and familiarity of workers with the site. Once the site is relocated, it will take one full or part dive to mark it for photography unless permanent seabed markers have been installed

### Sampling

The time required for photographic sampling is dependent on field conditions and the proximity of sample stations to each other. In optimal diving conditions completion of 36 adjacent sequential quadrats within 15 minutes is quite feasible. Consequently, depending on depth constraints and personnel availability it may be possible to complete several sample sets in a single tidal window.

Consumable costs are not high in comparison with personnel costs and capital equipment costs.

### Photographic analysis

Counting of individual organisms or measurement of percentage cover, organism size and comparison of photographs can be very time-consuming. For example, point sampling analysis can take in excess of an hour per photograph whilst counting of individual organisms depends on density (Lundälv, pers. comm.). Scanning, registration and measurements from digital image scans may take several hours per image depending on the numbers of measurements being made. The time necessary for analysis is essentially a reflection of the data required.

*Data analysis*

Analysis of numerical or other data derived from quantitative photographic sampling will be project-dependent and is not considered in this Guideline.

# Health and safety

Diving regulations must be followed. Risk assessments must be prepared for each project and location where sampling will be undertaken.

# References/further reading

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We are grateful to Thomas Lundälv for discussing this Guideline and providing text based on personal experience.

# Procedural Guideline No. 3-13 *In situ* surveys of sublittoral epibiota using hand-held video

Colin Munro, Marine Biological Surveys[1]

## Background

Video and computer technologies are continually advancing, and consequently it is inevitable that parts of these Guidelines will become out-of-date quite rapidly. Given this changing technology, details concerning specific camcorder and housing models have been kept to a minimum. It is suggested that anyone considering purchasing video equipment for biological monitoring should seek advice on current formats and equipment around the time of purchase.

Like all skilled tasks, producing consistently good video recordings, in terms of image quality and details of biota and habitat, is not achieved by reading a set of guidelines. There is no substitute for a thorough understanding of the strengths and weaknesses of the medium you are working with, and only experience will tell you how different environmental conditions will affect results. These are simply guidelines, and are not in any way intended to be used as a set of instructions on 'how to survey using video'.

In the past few years digital video formats have largely superseded analogue and give slightly better resolution than hi-band analogue formats such as SVHS or Hi8. This change has not significantly altered the methods for recording video footage underwater, and so the guidance below is equally applicable to digital and analogue formats.

Similar techniques to those described here have been developed for monitoring on the Great Barrier Reef. Christie *et al.* (1996) describe that work and the associated operating procedures with a much greater level of detail than in the present Guideline.[2]

## Purpose

Video survey using a hand-held camera will be appropriate for attributes relating to biotope presence and extent of biotopes, where these biotopes are defined by conspicuous species or life-form types. Generic attributes for which video may be useful include:

- Measuring the range and types of biotopes present in an area.
- Measuring the extent of the different biotopes, for classified groups of biotopes or biotope complexes at the site (without compromising other important features).
- Counting the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is 'special'). (Only conspicuous epibiota for video survey.)

### Advantages

- Video can provide very wide-angle images and resolves images well in poor light;
- It provides a moving image record across a site;
- It generally gives a better 'overall appearance' view of sites than wide-angle still photography;
- Archived video data, from the same site over a period of time, can be particularly useful for detecting subtle changes in a habitat, e.g. increases in sediment cover within areas of mixed substrate, decline in foliose algal cover, etc.;

1 Orchard Cottage, Coombe Barton, Shobrook, Crediton, Devon EX17 1BS.

2 See: **http://www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop2/sop2-00.html**

- Video allows rapid, visual comparison of extensive sites; it is non-destructive and non-invasive.

### Disadvantages

Image resolution is significantly poorer than that of film for two reasons. Firstly, film has significantly greater detail and tonal resolution than even broadcast quality digibeta videotape; and secondly, expensive (consumer) digital camcorders are supplied with cheap plastic lenses, whilst still cameras tend to have very high quality glass lenses fitted. Consequently video is less suitable for recording and counting small or cryptic organisms.

### Logistics

#### *Equipment*

Camcorder, underwater housing, underwater video lights (unless in shallow and clear water), videotapes, standard SCUBA equipment.

#### *Personnel/time*

A full HSE dive team is generally required. Time requirement will be very dependent on the precise objective of the study.

## Method

The method will vary depending on the specific objectives. However, general points are given below:

(1) Generally, the greatest focal depth will be required during video recording to ensure that erect biota and crustose species will be in focus. The following recommendations are given:

- Wider angle zoom settings give a greater depth of field (however, very wide angle shots will distort the image, if measurements are required).
- Auto-focus setting is not generally recommended. This can cause ‘hunting’ (the lens shuttling back and forth between objects), creates additional power drain on the battery and may result in the camcorder focusing on particles in water column. Wide-angle, fixed focus, with the focus pre-set to around 0.3m, appears to work well for habitat recording.
- Depth of field is a function of lens angle of acceptance, shutter speed and aperture size (the smaller the aperture, the greater the depth of field). Most underwater housings do not allow either shutter speed or aperture size to be controlled manually underwater, aperture size being adjusted automatically to control exposure. The shutter speed should therefore be pre-set to the slowest practical speed (normally around 1/50th) to ensure greatest depth of field.

(2) Many video cameras automatically adjust exposure based on the average brightness of the image. Videotape does not handle contrast as well as film. Consequently, a small dark ‘object of interest’ against a light background will appear very dark on the recorded image, similarly a light object against a dark background will ‘burn out’. To record detail in such objects, they must fill the majority of the frame.

(3) Avoid jerky movements when recording.

(4) Switch the video to record a few seconds before recording the objects/area of interest; this gives time for the mechanical delay (pre-roll) of the camcorder and provides additional frames if tape editing is required.

(5) Use lights to bring colour back to images from deeper water, and to sharpen up images (by increasing depth of field and reducing signal noise from excessive gain). However, if the aperture size is reduced, the area outside that illuminated by artificial light will become very dark on the recording, and thus the viewable area will be substantially reduced.

(6) ‘Burn’ the date and time onto the original tape at the time of recording (i.e. through camcorder settings). This will greatly aid subsequent sorting and object (on tape) identification, especially when many tapes are recorded.

# Data analysis

This is a developing area. The simplest method is direct observation of video image, recording notes as the video is viewed. Two monitors are recommended for comparative data analysis, which allows simultaneous viewing of monitoring tapes from successive monitoring periods. Image analysis software is available for video images, but its use for biological monitoring is currently very limited.

Accuracy testing

Independent review of samples of videotape, and re-checking of a sub-set of sites (to confirm positional accuracy, site marking and biotope data) are useful methods for testing accuracy.

# QA/QC

Much of the above applies to this section. On-site QA will very much depend on the study requirements and prevailing conditions at the study site. As a guide, it is suggested that it is used only in horizontal visibilities of greater than 3m. Swimming speeds should be kept low. Ensure that the date and site are logged and recorded on each videotape.

Differences in height above the seabed from which the video is shot, the angle at which it is shot and the direction (if along a fixed transect) can create dramatic differences in images between monitoring records. These should be noted during the baseline recording and prescribed for subsequent monitoring.

# Data products

The key product will be the recorded videotape. To minimise the risk of damage to or loss of original data, it is suggested that the recorded master tape is duplicated (either onto tape, or onto computer media such as hard disc drive, CD, DVD, Zip or Jazz drives). The master should be securely stored and analysis conducted using copies. Storage on disc can be advantageous in that 'clips' can be copied, retrieved and reviewed (on a computer) in a non-sequential fashion, and stills extracted easily. However, high-resolution video requires large amounts of disc storage space. At the time of writing, the largest PC hard drives available were around 75Gb; 1Gb will hold around 3.5 minutes of DV quality video footage. DVD will hold 5.2Gb of data and CD will hold 650 Mb.

# Cost and time

## Cost

Purchase of a video system, including camcorder, housing and lights, is currently around £5000.

## Time

Time in the field will depend on how extensive the site is. Essentially, all that is required is to relocate the site(s) and swim slowly across the defined route, recording as one swims. Data analysis will take considerably longer than recording. Four hours to review one 90-minute tape is a fair rule of thumb, but this will vary considerably depending on the complexity of the site and objectives.

# Health and safety

All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[3] and must follow the Scientific and Archaeological Approved Code of Practice.[4] There are no specific

3 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7
See: **http://www.hse.gov.uk/spd/spddivex.htm**

4 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997.Approved Code of Practice and Guidance – L107. HSE Books 1998. ISBN 0 7176 1498 0.
See: **http://www.hse.gov.uk/spd/spdacop.htm - a**

additional risks associated with hand-held video operation.

## References

Christie, C A, Bass, D K, Neale, S J, Osborne, K, and Oxley, W G (1996) *Surveys of sessile benthic communities using the video technique. Long-term monitoring of the Great Barrier Reef Standard Operational Procedure Number 2*. Australian Institute of Marine Science, Townsville.

## Websites

**http://www.aims.gov.au/pages/research/reef-monitoring/ltm/mon-sop2/sop2-00.html** – AIMS standard operational procedure for surveys of sessile benthic communities using the video technique.

**http://www.sli.unimelb.edu.au/research/mers/Irene_AMSA/index.htm** – Measurement of benthic species using drop-video platforms: comparative uses of stereo and single video systems.

# Procedural Guideline No. 3-14
# *In situ* survey of sublittoral epibiota using towed sledge video and still photography

Matthew Service, Agriculture and Food Science Centre, Department of Agriculture for Northern Ireland,[1] and Neil Golding, Agricultural and Environmental Science Division, Queen's University Belfast[2]

## Background

Towed video sledge and still photography techniques provide a means to visually survey large areas of seafloor without the depth or time constraints usually associated with other techniques such as scuba-diving. In the past, techniques such as this have been used to monitor the condition of features in candidate Special Areas of Conservation (SAC) (Sanderson *et al*. 1999; Magorrian 1996). Towed video sledge data can be used to estimate the relative abundance of epibenthic species using the Visual Fast Count (VFC) technique (Kimmel 1985).

## Purpose

Video and still camera surveys are appropriate for attributes concerning the presence and extent of biotopes, and their quality in terms of the richness and the abundance of associated species. These techniques can be used to:

- Evaluate the variety and number of the different biotopes or biotope complexes, without compromising other important features.
- Determine the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is 'special') – provided they can be identified.
- Estimate the extent of the area occupied by all or selected biotopes or biotope complexes in a defined area.
- Record/re-record the numbers or cover of named conspicuous species.

### Advantages

- Able to survey large areas of seafloor quickly
- Allows precise density measurements of features/species of interest
- No depth or time restraints (in coastal waters)
- Robust and generally reliable equipment
- Provides a permanent record (in the form of video/photograph)
- Equipment is readily available

1 Newforge Lane, Belfast BT9 5PX.
2 Newforge Lane, Belfast BT9 5PX.

### Disadvantages

- Equipment is cumbersome and requires a large launch/research vessel with dry space
- Equipment is in contact with and may damage fragile habitats and biota
- Sledge can only be used on relatively level seabed: unsuitable for use on excessively rocky reefs
- Equipment is expensive
- Unless an acoustic transducer is fitted to the sledge to give a position relative to the vessel, significant error may occur in calculating the position of the sledge

## Logistics

### Equipment

#### *Sledge*

The towed video and camera sledge described here and shown in Figure 1 is a modified version of the SOAEFD Marine Laboratory sledge (Shand and Priestly 1999). The use of other sledges is not precluded but the version illustrated has proved durable and robust.

The sledge is fitted with floats or buoyancy tank on top to help maintain an upright position during deployment. A buoy is attached to an appropriate length of rope (at least twice the operational water depth), which is attached at the rear of the sledge to aid retrieval in the event of entanglement, and to provide a drag force which reduces the yaw of the sledge.

#### *Video and camera equipment*

- Example equipment used by authors:
- Photosea (California) 1000A 35mm U/W camera
- Photosea (California) 1500S strobe
- Kongsberg Simrad (Aberdeen, UK) U/W colour video camera
- Sony Trinitron colour video monitor
- Panasonic SuperVHS video recorder

Still and video cameras can be mounted in a number of different configurations. In the configuration described here a colour video camera and a 35mm stills camera are mounted at 45°, with the stills camera pointing slightly behind the video (this allows the video to act as a remote viewfinder for the stills camera). Video lights and flash strobe point vertically downwards. While it may be argued that mounting the video and stills vertically may produce a more quantifiable image in terms of measurable area, experience suggests that taxonomic identification is easier from images produced in the former configuration.

The video and stills images should be time and date stamped. It is also possible to imprint GPS Navigation data on the video using a proprietary system such as Trakview®.

Camera and video equipment immersed in seawater should be washed and dried on return to base. Care should be taken when changing bulbs/film, etc. to ensure that o-rings are cleaned and lubricated sparingly with silicone grease on reassembly.

Video is recorded in the SuperVHS format using a Panasonic SVHS video recorder connected to the video camera control unit.

The vessel should be suitable for work in the locality with adequate (dry) cabin space for electronic equipment.

Suitable winch for towing camera sledge (normally 8mm wire is optimum). Pot haulers and rope may be used as an alternative. Vessels with extensive freeboard should be avoided.

When undertaking towed sledge studies it is important to use a vessel capable of maintaining steerage at low speeds. A master experienced in towing at low speeds is essential. Tow speeds of 0.75 knots or less at slack water are recommended for optimum video analysis.

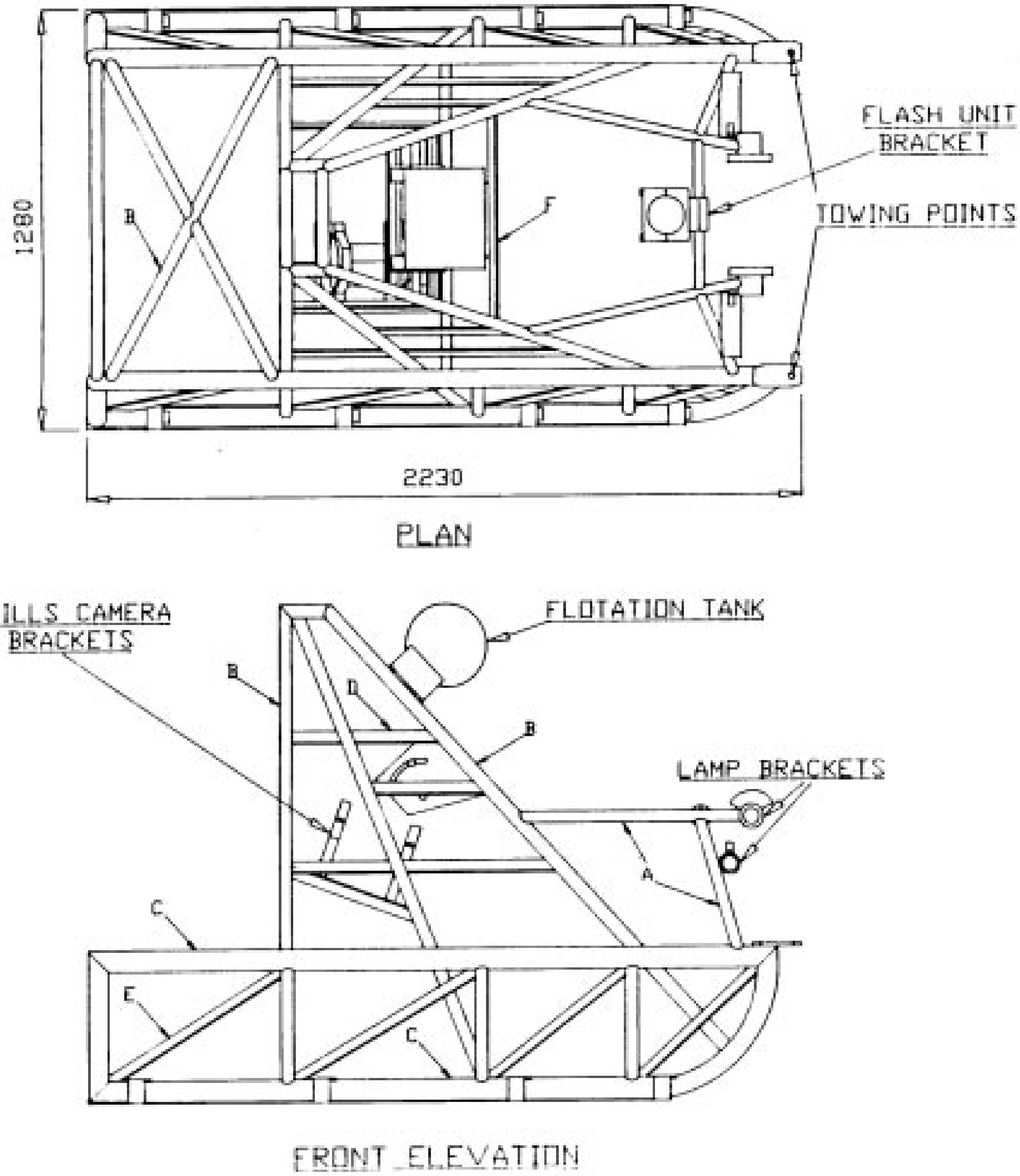


**Figure 1** Plan and front (side) elevation drawings of a sledge based on one developed by the Marine Laboratory in Aberdeen. Measurements are in millimetres. (A–F refer to materials not described here).

## Power supply

Power supply to power the video cameras, lights and recorders must be available.

Checks must be made that the power supply is adequate to power the systems under full load.

If a portable generator is used an emergency stop and thermal overload switch should be fitted and operators made aware of the health and safety implications of using such equipment in this environment. Ear protection is advised.

## Navigation system

A dGPS Navigation system should be used for recording the position of the tow track.

However, it should be noted that in most towed video surveys the position logged is that of the vessel itself, not the camera sledge. This layback of the sledge can be corrected by fitting acoustic transponders to the sledge (O.R.E Inc. LXT Tracking System). Alternatively, the layback can be calculated using ‘Pythagoras’, from the water depth, angle of towing wire and length of wire deployed.

### Personnel/time

Normally two skilled and experienced operators are required plus the assistance of one deckhand.

The video operator should be experienced in the taxonomic identification of marine species and biotopes.

The time to sample is usually related to ensuring best likelihood of calm conditions and the same time of year as for previous surveys. Therefore, summer is usually best on the open coast

## Method

### Field

If the control umbilical of the camera is not load bearing, the sledge should be deployed over the side or rear of the survey vessel and attached to the wire warp by cable ties. Weak links may be used between the sledge and the umbilical. An emergency recovery buoy should be attached to the rear of the sledge as described in Shand and Priestly (1999).

The vessel should maintain slight forward way to allow the camera sledge to stream out behind. Once in the water the video camera and lights can be switched on and the video operator can monitor the descent. Once the sledge is on the bottom the winch operator and master should be advised.

It is normally necessary to pay out further cable (2–3 times depth) until the progress of the sledge is stabilised. Vessel speed at this point should be about 1 knot or less.

Once a good quality image is being produced the vessel's position should be noted and the VCR set to record. Following this, the vessel position should be logged every minute (either manually or electronically) and an experienced biologist should make appropriately referenced field notes.

If a still camera is fitted, stills can be taken at set time intervals or when an event of interest is viewed on the video monitor. The position of each still should be noted along with a description of the image.

The duration of the tow will depend on the extent of the area of interest and objective. Tows are normally 1 to 1.5 hours' duration, although certain operational conditions may allow longer tows. The length of cable deployed may be shortened or lengthened during the tow if the water depth changes appreciably.

Once the survey is completed the video and lights should be switched off and the cables winched in. Side-cutters will normally be required to cut the cable ties and care must be taken to recover spent ties. Film should be recovered from the still camera and labelled. Completed videos should be labelled and the security tabs removed.

Videos should be copied to protect the original during analysis. A good quality SVHS camera, recorder and tape should be used. If possible, the use of digital camera technology, as used by Sanderson *et al.* (1999), could be explored, although these are relatively expensive.

A running commentary should be maintained, recording changes in seabed type and biotopes, which is synchronised with the video

### Mapping studies

Run parallel transects at intervals of between 100 and 250 metres (depending on detail required) across the area to be surveyed. Ensure that the position of the boat (or the sledge if differential can be calculated automatically) is recorded, preferably on the video image. If the position of the sledge has to be calculated after the run, ensure that records of depth of the sledge and length of towing line are kept.

Note the bottom type and/or biotopes along the transect and where boundaries or transitions occur. Re-survey boundaries if there is any possibility of error.

### Recording change in species abundance or biotope composition

Run transects along lines which can be relocated in future years or which were run in previous years. Record the abundance of species as described below.

# Data analysis

## Video analysis for quantitative counts of species abundance.

The reader may find it helpful to refer to Magorrian and Service (1998) for detailed methodology of the VFC technique (Kimmel, 1985).

Underwater visual data provide immediate qualitative descriptions of epibenthic communities. However, management and monitoring requires quantitative visual data. Video tends to be recorded in the form of long continuous strips which need to be broken down into segments to extract more detailed information. Changes in altitude, pitch and roll result in variable or unknown fields of view of the images produced. Michalopoulos, Auster and Malatesta (1992) demonstrate that videotapes with such problems, that are not useful for density estimates, can be enumerated using species-time techniques. These techniques substitute time for area and produce estimates of relative abundance of species based on time. One such technique is the Rapid Visual Count (RVC) method. Here time is broken down into five regular time intervals and a species is recorded as present in the interval where it is first seen. RVC species scores are based on a weighted order of encounter that does not take abundance into account. If a species was seen during the first segment, it received a score of 5, in the second segment a score of 4, third segment 3 and so on. Relative abundance was calculated by dividing the score of the species by the sum of scores of all species (Kimmel 1985; Michalopoulos *et al.* 1992). However, DeMartini and Roberts (1982) suggest that the RVC technique is inaccurate because the species are scored solely on the basis of encounter and it makes no provision for varying spatial distribution of different species. Another technique, the Visual Fast Count (VFC), involves counting the actual number of individuals during each time interval. Each time interval is given a score which represents expected frequency of occurrence instead of arbitrary interval scores, and abundance estimates are based on the product of individual species counts and the time interval score (Kimmel 1985). Kimmel compared three visual techniques and found that RVC relative abundancies were significantly different from those of the VFC and transect methods. He suggests that if transect methods (performed by divers) are assumed to be the most accurate, then VFC yields more accurate relative abundancies. Michalopoulos, Auster and Malatesta (1992) also found VFC to be more closely correlated with the transect method than the RVC method. Visual analysis may underestimate abundancies of small and cryptic species.

While the method described here will allow analysis using video data only, considerable extra information may be gained from the use of still photography (see below). The increasing developments in digital imaging processing should also be noted.

Each video is replayed and field notes are expanded to include more detailed descriptions of the bottom type, benthic communities, and dominant epifauna.

Short time sections of video with limited water turbidity, a slow tow speed, constant bottom contact and no weed obscuring the view, should then be selected for further analysis using the VFC technique.

Each section of videotape analysed can be treated as a separate sample, which may be used for statistical procedures. If the Bray–Curtis similarity coefficient is used its sensitivity to skewed species distribution and domination by species with higher abundances should be noted. In order to reduce this effect the data should be transformed using a double square root transformation.

Random samples may be selected using random number generators.

## Quantitative analysis of still (35mm colour transparency) photographs

Each still photograph (mounted) is projected in turn onto the screen of a portable slide projector. An acetate grid of 1cm squares, the same size as the image, is overlaid on the screen. The percentage cover of each species is estimated by counting the number of squares in which each species occurred and then dividing this by the total number of squares.

If sediment, weed or poor resolution rendered a square unreadable then that square should discarded and the percentage cover based on the remaining number of squares.

If individuals of certain species were clearly distinguishable then they can be counted and the number included alongside their percentage cover estimate.

# Accuracy testing

A weak link in the analysis of video data is the identification of biotopes. Where possible, external validation of the video data should be pursued, ideally by someone who has knowledge of the survey site.

# QA/QC

- Videotapes and films should be clearly labelled with date, site and associated field notes.
- Tows should only go ahead when horizontal visibility is >3m.
- Tow speeds should be <1 knot.
- Analysis – see 'Accuracy testing'.

# Data products

## Video data

Following the VFC technique, each section of tape analysed is assigned a habitat category score, derived from the qualitative video descriptions.

## Stills data

The percentage cover of each species in a particular still frame should be obtained.
Stills should be archived, recording survey date, time and equipment.

| *Details* | *Cost per day (unless specified)* |
|---|---|
| Sledge and camera equipment | £250 |
| Boat hire | from £300 |
| Scientific officer | from £143 |
| Boat crew | from £85 |

# Cost and time

Approximate time to complete a 1 kilometre sledge tow is 2 hours, depending on sea conditions. This does not include time taken to deploy and retrieve the sledge.

Allow half a day for video analysis of a 1-kilometre tow (also dependent on habitat type).

Allow half a day for stills analysis of a 1-kilometre tow (also dependent on habitat type).

# Health and safety

- Standard shipboard safety including wearing of hard hats, life jackets and steel capped boots by deck operatives. Preferably, field staff should have attended an appropriate sea survival course such as provided by the SeaFish Industry Training Board.
- Take particular care when launching and recovering the sledge not to be pulled or fall overboard: use boat hooks and steadying ropes.
- Normal precautions should be taken when using electrical equipment including generators on a boat.
- Ear defenders should be worn when using a generator.
- Staff should be made aware of manual handling precautions, especially when loading and unloading the vessel.

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# Procedural Guideline No. 4-1 Sampling benthic and demersal fish populations in subtidal rock habitats

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## Background

There have been few detailed and systematic quantitative investigations of mobile macrofauna carried out in the UK rocky sublittoral zone. Rocky habitats make up approximately 35% of the UK coastline (Anon. 1993), yet rocky sublittoral habitats are difficult areas in which to observe and quantify animal abundance. Benthic species present, particularly fish, are often small and cryptic, whilst hyperbenthic species may only be transient occupants. Quantifying abundance in such an environment is often a compromise between being invasive enough to obtain reliable quantitative information and taking care not to disturb or alter abundance patterns.

There are three techniques detailed in these guidelines for sampling benthic and demersal fishes in the rocky sublittoral zone. A fourth method using underwater television (UWTV) is also included, but costs of equipment and associated analysis make it an unlikely choice for routine survey work. The method selected will depend on the objectives of the survey and the species of interest. Interspecific differences in sampling efficiency make comparisons among species difficult. For example, the absence of a fish species in a trap does not necessarily indicate that it is absent at that site, simply that it did not enter the trap at the time of trapping. Despite these restrictions, the three methods detailed in these guidelines are suitable for monitoring temporal changes in fish populations as long as the quality assurance procedures outlined below are followed.

Rocky sublittoral species commonly seen by SCUBA divers include cod (*Gadus morhua* (L.)) first year juveniles, two-spot goby (*Gobiusculus flavescens* (Fabricus)) and leopard-spotted goby (*Thorogobius ephippiatus* (Lowe)). Goldsinny wrasse (*Ctenolabrus rupestris* (L.)) adults are territorial and relatively easily seen by divers, as is the rock cook (*Ctenolabrus exoletus* (L.)), although during summer months the latter species tends to shoal over weedy subtidal areas making quantification difficult.

## Purpose

To provide as accurate an estimate as possible of the abundance, species richness and age structure of fishes in subtidal rocky habitats.

### Applicable to the following attributes

Sampling fish populations will be appropriate for attributes concerning biotope quality in terms of species richness and the abundance of species and for detecting whether areas of impact away from point sources are expanding or contracting. Generic attributes are:

- Maintain or increase the species richness in the biotope and/or abundance of key species (rare, fragile, declining, representative) in biotopes.
- Maintain or increase the quantity of particular species of conservation importance (rare, fragile,

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declining species – those for which the site is ‘special’).
- Reduce the extent of impact of point source disturbance.

## Applicable to the following survey objectives

- Establish/re-establish the species which are present in biotopes at a site including their abundance and biomass within statistical limits.
- Establish the species present in biotopes and their density within defined statistical limits.
- Establish/re-establish the species which are present along a gradient of change away from a point source of disturbance including their abundance and biomass within statistical limits.

# Methods

## Fyke netting

Fyke nets consist of a one or more leader nets which direct fish into a conical-shaped net held open by metal rings. The conical net comprises a series of interconnecting nets with one-way entry doors which trap the fish (Van der Veer *et al.* 1992). Although they can be used singly, fyke nets are usually sold in pairs. Fleets of fyke nets can be joined together into a line to sample a much larger area. In some circumstances it may be desirable to distinguish fish that have encountered the leader net from different directions; the net described by Baelde (1990) could easily be modified to produce directional information. To prevent otters entering the net and drowning, otter boards should be attached. Fyke nets are not suitable for use in areas of strong currents. Where the net is likely to be exposed to moderate currents it should be very firmly attached to metal stakes hammered into the substratum by diver (where possible) or heavily weighted. Currents are likely to interfere with the performance of the leader net (by pushing it over) and may cause the net funnel to roll over the substratum. Fyke nets can be used for short periods, and where strong tidal currents are likely to be encountered, they should be used during slack water.

### *Equipment*

- Fyke net (Collins Nets, Bridport, Dorset) and otter boards
- Boat
- Shot weight (at least 10kg per pair of fyke nets)
- Protective and safety clothing (gloves, oilskins, buoyancy suits, lifejackets, etc.)

### *Personnel*

At least two staff (plus a boat skipper).

### *Technique*

Sew the otter boards into the mouth of the net funnel as directed by the manufacturer. Attach the shot weight to the closed end of one of the nets and then lower it to the bottom using the net (there is no need to attach an additional length of rope). When the weight reaches the bottom the rest of the fleet can be paid out as the boat slowly reverses. Most fish in the rocky subtidal move parallel to the shore, and therefore the net should be orientated perpendicular to the shore. It is useful to survey the site visually, prior to deploying the fleet, to check for obstacles. Areas with large boulders, very steep slopes/cliffs and detritus which could become entangled in the net should be avoided. If deploying the net on a steeply sloping substratum attach an extra long shot line and use a larger buoy. This layout reduces the chances of losing the net if it is deployed slightly off site and where the weight of the fleet pulls the marker buoy under the water. Recovery is achieved by lifting the buoyed rope and fish can be removed from the end compartment by untying the ends of the net (see Figure 1).

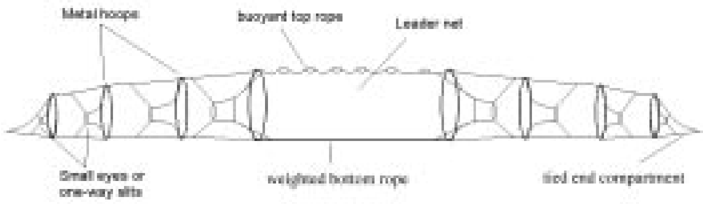


**Figure 1** Fyke net

### *Cost and time*

Boat deployment and recovery takes around 5 minutes per net pair (Sayer *et al.* 1996). Removing the fish takes c. 10 minutes. Fishing time depends on the survey objectives but fyke nets are commonly left in position for one day or one tidal cycle (Treasurer 1996). Fyke nets cost £50–£300 depending on size (pers.comm. Collins Nets, telephone 013808 427352).

### *Advantages*

- more objective than visual census
- cost effective
- easy to use
- non destructive (fish are maintained alive)

### *Disadvantages*

- restricted depth range (c. 15m maximum)
- there are problems relating catch with the actual population; the catching power is unknown for most species and may vary according to season and other factors (Darwall *et al.* 1992)
- cannot be successfully used in areas subject to even moderate currents

## Trapping

The target species and objectives of the survey will dictate the optimum trap type to use. Traps are very species-selective and without a thorough understanding of relative catch efficiency the data generated should not be used to predict relative abundances of different fish species. Traps for use in fish surveys are often modified commercial traps and can be deployed either from a boat or from the shore. For species such as wrasse modified Nephrops creels can be used. Although smaller traps are manufactured (e.g. for crayfish) they do not seem to be effective for small fish such as gobies. Cheap, effective traps can be made from plastic mesh (Kruuk *et al.* 1988). Bait can be used to encourage certain fish species to enter the trap. Baits commonly used include crushed mussels, crab, salted fish and broken sea urchin. The use of baits can, however, result in biased results because one bait may attract a particular species to the exclusion of others. In addition, it is not known if territorial fish, such as goldsinny, will move across adjacent territories to enter a trap. Trapping efficiency is governed by a number of factors, including bait type, fish activity and behaviour (which depends *inter alia* on season), and where, in relation to fish territory, the trap is deployed. Consequently, accurate abundance estimates using trap data are difficult to make. However, for a given species, date, time of day, location and tide, the catch efficiency should be similar. Data thus generated indicate relative numbers and can be used to monitor yearly changes in population. Traps are quite robust and can be deployed in areas of moderate current and over rough ground. However, they can foul on detritus and it is advisable to have some indication of the substratum type and the presence of detritus at the proposed site. Traps can be moved by other users in the area, so avoid placement close to anchorages or areas subject to fishing activity.

### *Equipment*

- traps (Gael Force Marine Equipment, Stornoway; or Caithness Creels Ltd, Wick), rope and buoys
- boat
- buckets
- scales/measuring board if required
- bait (if required)
- protective clothing (gloves, boots, survival suits, oilskins, life jackets, survival suits, etc.)

### *Personnel*

Two staff.

### *Technique*

To avoid entanglement the fleet should be rigged as shown in Figure 2. Throw the first trap of the fleet into the water, over the chosen site, and lower by the rope attached to the other traps, deploying these as necessary. Attach a rope and buoy to the ground rope and lower this to the bottom. Reverse the boat away after throwing in the first trap whilst deploying the others. Where access permits, traps can be deployed from the shore or pier. In water deeper than 10m, retrieval should be relatively slow to reduce the risk of fish damage through pressure changes. For a fleet of five traps the ground rope should be c. 30m with a 3–5m trap rope separating each trap from the ground rope (Figure 2).

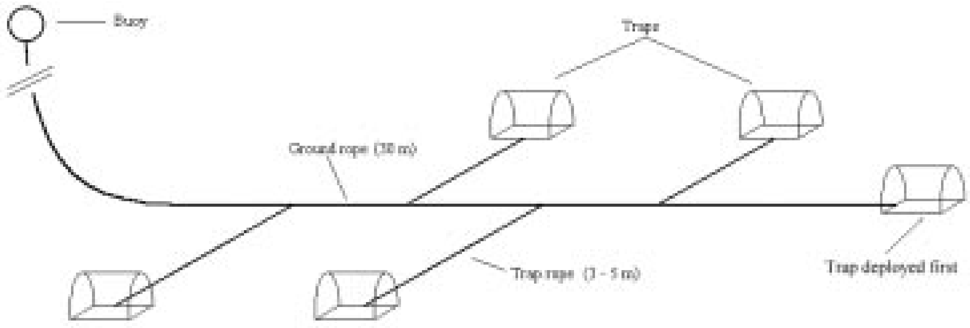


**Figure 2** Suggested layout of a fleet of five traps

### *Cost and time*

A fleet of five traps can be deployed in 10 minutes. Recovery time is similar. Fish are easily removed by opening the trap. Any measurements, as dictated by the sampling protocol, can then be made. Prices for traps can be obtained from Collins Nets, 01308 427352.

### *Advantages*

- more objective than visual census
- cost-effective
- easy and quick to deploy
- can be deployed for short periods (c. 1hr)

### *Disadvantages*

- very species- and size-selective (some common species cannot be sampled using traps)
- perceived as competition by local fishermen
- there are problems relating catch with the actual population; the catching power is unknown for most species and may vary according to season and other factors (Darwall *et al.* 1992)

## SCUBA diver observation

SCUBA technology allows direct observation, identification and counting of fish. However, the close presence of SCUBA divers can affect fish behaviour and this must be considered when using such techniques (Chapman and Atkinson 1986; Costello 1992). Censuses by SCUBA diver using transects or point counts can be a useful way to monitor long-term fish population changes. However, the efficiency of this technique is dependent *inter alia* on species, diver, season, underwater visibility and weather. This technique is, therefore, subject to considerable experimental error and cannot accurately be used, for example, to compare relative abundance of different species. Transects used in fish survey research are usually permanently fixed belt-transects and accurately delineate a finite area. Where the establishment of rope transects is impractical (e.g. because of the presence of very large boulders or if the site is used for other purposes) point counts can be undertaken. These can be in the form of fixed, marked stations where a diver stops and counts the fish, or a series of short (1–5m) fixed transects. In certain circumstances individual fish refuges can be marked and monitored. This technique applies particularly to territorial fish where individuals can be identified and recorded over extended periods. Fixed belt-transects should be used in preference to simple line transects or point counts whenever practical and are described in these guidelines.

The following general questions should be considered when initiating a visual census:

- Depth: can the work be adequately carried out within depth-imposed restrictions on diving time? Ideally, transects should be less than 20m deep.
- Exposure: are windy/rough conditions likely to restrict access?
- Tide: is enough slack water time available even during spring tides?

- Ease of access: is a boat required, and if so where will it be launched?
- Is the site representative of the area of interest?
- Is the area subject to heavy traffic, fishing or to boats anchoring?
- Is the site convenient for the deployment of transect lines ? (Boulders over 1m diameter should be avoided.)
- Species: less abundant species will require a longer search.
- Deployment method: is a boat available?

## Equipment

- weighted rope
- shot weights (redundant chain is ideal)
- tape measures, marker buoys
- 30–45mm diameter rigid plumbing pipe

## Staff required

Suitably qualified, experienced and equipped diving team (Dean *et al.* 1997). At least one diver must be experienced in identifying the fish species found in the rocky sublittoral zone.

## Technique

*Transect manufacture* 10–15mm diameter negatively buoyant, brightly coloured, polypropylene rope should be used for the transect. Form the transect width by attaching 30–45mm diameter plastic pipe cut to the desired width of the transect to both pieces of the transect rope (Figure 3). This will act to help maintain the desired transect width during and after deployment. Dividing the transect length into sections can yield additional variability data within the transect.

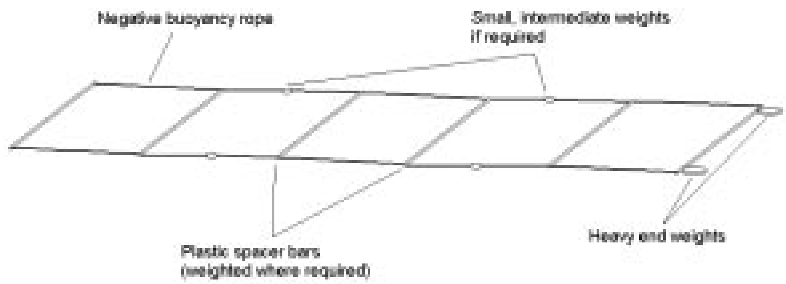


**Figure 3** Suggested design for a belt-transect

*Deployment* The preferable method of deployment requires a boat. Attach steel or concrete weights (c. 50kg) to one end of the transect and lower it to the bottom over the bow of the boat. By pulling against the weight the transect can be deployed taut: the weights can be recovered after deployment if necessary. Keep the rope from twisting and with the boat in slow reverse pay out the transect. At regular intervals – the best way is to use points marked by the pipe –attach weights (5–10kg) to the rope. When the whole length is deployed attach a buoy, if desired, and lower the end of the transect to the bottom. After deployment, divers should remove twists and ensure that the transect width is correct. Where appropriate, and especially in areas of strong current, divers can deploy further ballast or, where practical, stake the rope to the substratum using stout posts.

Shore deployments can be made, where pipe spacers and weights are not used, but they are difficult and time-consuming.

*Surveying* The amount of time spent surveying each transect should be standardised and is species-dependent; surveying small benthic fish will require a certain degree of searching. More active, visible species can be counted whilst swimming a standard speed (commonly c. 4m/min$^{-1}$). As each fish is seen it should be recorded on a pre-prepared species list written on a white plastic board with a soft lead pencil (underwater tape recorders or surface communications have also been used). The use of underwater torches is recommended when surveying species inhabiting crevices. To assist in quantifying fish in complex areas the anaesthetic quinaldine can be used. However, this is a complex underwater task which should only be undertaken by experienced divers (Sayer *et al.* 1994).

#### *Cost and time*

Commonly transects are 30–100m long and 2–3m wide and can take up to 1 hour to survey (although a dive time of 30–40 minutes is more practical). Access time to the diving site will depend on location. Costs associated with diving surveys can be quite high (up to £500 per day).

#### *Advantages*

- Good method of showing annual change in abundance at the same site
- Divers gain a feel for changes and observe potential causes

#### *Disadvantages*

- Lacks objectivity (different divers see differently)
- Relatively expensive (requires a full, trained dive team)
- Requires a boat

### Underwater television

This technique is non-intrusive and gives a good indication of the behaviour of fish over extended periods (a camera can operate for >24 hours). It is possible to observe fish which are either disturbed by diver presence or not captured remotely. However, the camera system is expensive (£15,000–20,000) and analysis of the video tapes is very time-consuming and requires professional analytical video recorders. Underwater television gives a good indication of the presence of fish within the viewable area of c. 2–4m$^2$ but is of limited use for assessment over larger scales. This technique is therefore unlikely to be suitable for routine fish population quantification over large spatial scales.

## Accuracy testing

Where appropriate, methods of assessing sampling accuracy are either outlined or referenced in the description of methods given above or in quality assurance measures (see below).

## QA/QC

High natural variability within fish populations and the problems of observation and capture efficiency mean that standardisation of techniques used to assess a fish population is essential if other sources of variation are to be minimised. Quality assurance depends on the technique chosen (see advantages and disadvantages). However, in general terms apparent changes in abundance may simply be caused by a change in catchability (Beja 1995; Costello *et al.* 1995; Sayer *et al.* 1994; Sayer *et al.* 1996) or by movements into or out of the sampling area (Allen *et al.* 1992; Claridge *et al.* 1986; Gibson *et al.* 1993; Ross *et al.* 1987). It is, therefore, difficult to link cause and effect unless extensive background data on the behaviour of the fish species of interest are available or intensive surveys with control sites and sufficient replication can be carried out (Barber *et al.* 1995). The techniques described in this section are well suited to detect inter-annual changes because direct comparisons between years are valid when all other factors associated with sampling are standardised. To reduce experimental error and to make the survey as easy and meaningful as possible the following are recommended:

- Choose well-researched common species and familiarise the survey team with the chosen species' behaviour and ecology.

- Utilise survey methods that are simple, that can be undertaken routinely and where access to the sampling site is easy and reliable.
- Standardise the date and time when the survey is carried out. When annual trends are being investigated carry out the survey as nearly as possible on the same date. More importantly, surveys must be undertaken at the same state of the tide and equivalent point in the diel cycle rather than at a specific time. Dusk, for example, may be at 16.00 in winter but 21.00 in summer. Diving surveys are best undertaken during neap tides because tidal currents are weaker and their influence on fish behaviour is therefore reduced.
- Practise the survey technique (new staff should be trained on ‘dummy’ sites). Identification skills can be tested using photographs or preserved specimens and, if estimating size visually, using fish models of known length (Costello *et al.* 1995).
- Use, wherever possible, the same survey teams. This is particularly important when conducting visual surveys and manual searches, both of which involve considerable skill.
- Maintain skill continuity during personnel changes by training all members of the survey team in every aspect of the survey technique.
- If spurious results are suspected be prepared to check the fishing gear (if relevant) and possibly repeat the survey. Repeat surveys on successive days to get an indication of day-to-day variability and incorporate these data in any statistical analysis.
- Expect large variation in fish abundance. Where assessing inter-annual variability a minimum of three years data is required.

## Data products/analysis

Survey work will normally generate data on species, abundance and size. Analysis will depend on the experimental protocol and should be done using standard statistical techniques (Sokal and Rohlf 1995). Fish populations show high inter-annual variability and this must be considered before drawing conclusions regarding cause and effect. Prior to the survey, and depending on the survey objectives, it is advisable to measure the variability of the factors of interest. Carrying out surveys on successive days gives an indication of the reliability of the survey data and these data can be used to predict the number of surveys that will be required to show significant changes (Chapter 9 in Sokal and Rohlf 1995). Comparisons of abundance between species should always take into account their differing catchabilities. If the results of the survey show a significant change in fish population this may be caused by natural causes (Collette 1986; Henderson 1989; Rogers and Millner 1996). Where a significant fish population change has been shown and tentatively linked to a cause, it is recommended that additional tests be carried out, the nature of which will depend on the proposed cause. Where pollution is suspected as a significant factor the relevant authorities should be contacted (Environment Agency, England and Wales or the Scottish Environment Protection Agency).

## Health and safety

Members of staff employed to undertake diving survey work must be suitably qualified and obey the rules and regulations as stipulated by the Health and Safety Diving Operations at Work Regulations (Dean *et al.* 1997). In addition, individual organisation codes of conduct relating to fieldwork must be adhered to. When employing external diving companies to undertake diving work, your organisation will have considerable responsibilities as the diving contractor. If accessing the diving site from the shore, care must be taken to avoid slipping. Suitably qualified boatmen must be employed when accessing the site using a boat and all crew must wear appropriate safety clothing.

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# Procedural Guideline No. 4-2 Recording benthic and demersal fish in dense vegetative cover

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## Background

In temperate marine waters seagrass (*Zostera* spp.) meadows and kelp (*Laminaria* spp.) forests commonly form dense stands of vegetation. The importance of seagrass beds as nursery areas for fish is widely accepted although exceptions are reported (Jenkins and Wheatley 1998 and references therein). Kelps commonly dominate hard substrata, in both sheltered and exposed locations. They are found from the intertidal zone down to 30m (although kelp forests are generally found in shallower water) and, as such, form an important part of many marine biotopes. Sampling in dense vegetation is technically difficult (Kuslan 1984) and should only be undertaken when an assessment of the fish population in the vegetation is specifically required. If alternatives are available they are to be recommended, for example, an estimate of fish abundance within dense vegetation can be made by sampling fish outside the vegetated zone (Baelde 1990). If the kelp density does not preclude the use of divers or traps then these techniques should be used as discussed in Procedural Guideline No. 4-1 'Sampling benthic and demersal fish populations in subtidal rock habitats'. Additional methods for sampling fish specifically within kelp or other dense algal communities are not widely reported in the literature and for this reason only one method is described here.

Two spot gobies (*Gobiusculus flavescens* (Fabricus)) are commonly found among dense vegetation but move into shallow (intertidal) areas during summer. Also frequent are the territorial species goldsinny (*Ctenolabrus rupestris* (L.)) and corkwing (*Crenilabrus melops* (L.)). Three- and fifteen- spined sticklebacks (*Gasterosteus aculeatus* (L.) and *Spinachia spinachia* (L.) respectively) may also be found.

## Purpose

To provide as accurate an estimate as possible of the abundance, species richness and age structure of fishes found in densely vegetated environments.

### Applicable to the following attributes

Sampling fish populations will be appropriate for attributes concerning biotope quality in terms of species richness and the abundance of species and for detecting whether areas of impact away from point sources are expanding or contracting. Generic attributes are:

- Measure the species richness in the biotope and/or abundance of key species (rare, fragile, declining, representative) in biotopes.
- Measure the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is 'special').

Also applicable to the following baseline survey objectives:

- Establish/re-establish the species which are present in biotopes at a site including their abundance and biomass within statistical limits.

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- Establish the species present in biotopes and their density within defined statistical limits.
- Establish/re-establish the species which are present along a gradient of change away from a point source of disturbance including their abundance and biomass within statistical limits.

# Methods

Four methods of sampling are described: three for sampling in seagrass (Floorless pop net, Beach seine and Others) and one for sampling in dense kelp forests (Stipe removal and analysis).

## Floorless pop net

These simple systems offer an excellent method of trapping fish within a well-defined area. They consist of a buoyant net curtain which, when released, rises from the substratum trapping fish. Fish caught can be collected using a small seine (described below) or hand net. Hand netting may be easier if used in conjunction with the anaesthetic quinaldine (see Procedural Guideline No. 4-4 'Sampling fish in rock pools').

### *Equipment*

- 25mm diameter PVC pipe
- netting; 25m x max. water depth of sampling site, mesh size 1mm
- ballast (chain and concrete blocks)
- wire or rope
- plastic buckets
- protective clothing (gloves, waders, oilskins, etc.)

### *Personnel*

At least two staff to deploy and trigger the net.

### *Technique*

Connolly (1994) describes the following method. Using 25mm diameter PVC pipe make a square covering an area of $25m^2$. Ensure all joints are sealed. Attach a 1.4m high fibreglass net of 1mm mesh size to the pipe. At the bottom of the net attach ballast (a light chain may be suitable). In the field stake and push the bottom of the net into the substratum and neatly concertina the net under the pipe. Push the pipe down until it is flush with the substratum (or as near as practically possible). Rest concrete blocks over the pipe and leave for one tidal cycle. The objective is to make the pop net as inconspicuous as possible, thereby reducing the effect of the gear on any subsequent fish catches. On the following high tide, and using 10m long wires attached to the concrete blocks, simultaneously pull all the blocks off the buoyant pipe. The buoyant pipe then lifts the net off the substratum and traps any fish within its boundaries. A similar but smaller trap ($9.3m^2$) has been described in Serafy *et al.* (1988) and would be particularly useful where ease and speed of construction is of paramount importance. In both the above examples fish trapped in the pop-net were removed by wading out to the net and using a small seine net. Connolly (1994) removed the fish immediately after the release of the pop net while Serafy *et al.* (1988) removed the vegetation prior to fishing with the seine net. If used in deep water, the trapped fish could be collected by SCUBA diver with or without the assistance of the anaesthetic quinaldine (see Sayer *et al.* 1994 for description of the underwater use of quinaldine).

### *Cost and time*

Net construction may take several days. Intertidal deployment is rapid. Serafy *et al.* (1988) indicate 15 minutes each for deployment, vegetation removal and fish collection. This method is relatively cost-effective, especially if a home-made device can be manufactured.

### *Advantages*

- high accuracy (most fish are confined by the rising net)

### *Disadvantages*

- has only been tried in relatively shallow water (1–2m)
- may be necessary to remove vegetation prior to fish collection

## Beach seine

Seine nets consist of a wall of netting weighted at the bottom and provided with floats at the top. They can vary in length from over 100m to less than 10m. The mesh size usually decreases from the wings towards the centre of the net, which is sometimes extended into a bag to assist retention of the fish. Efficiency has been shown to vary with species, fish behaviour, fish size and the bottom type (Gibson 1999). Seines perform optimally in areas with flat, smooth substrata containing no obstacles. Samples are best taken at low tide because at this time tidal migrants are concentrated at lower levels on the beach and the net will also sample those species that do not migrate intertidally.

### *Equipment*

- seine net (Bridport Gundry, Bridport, Dorset)
- boat
- board for carrying and shooting the net
- measuring board/scales
- plastic buckets
- protective clothing (rubber gloves, waders, oilskins, etc.)

### *Personnel*

At least two staff depending on net size and deployment method

### *Technique*

Attach one length of rope to a weighted wooden pole attached to each end of the seine net and fold the net neatly onto a flat board. Secure one end of the rope to the shore (normally held by an assistant) and place the board and net in the bows if using a powered boat or in the stern if using a rowing boat. Ensure the net will run out smoothly from the boat. Propel the boat away from the shore paying out the rope behind it. When the length of rope has been paid out, turn the boat parallel to the shore and deploy one end of the net. Moving slowly parallel to the shore deploy the rest of the net. Once the full length of the net is deployed turn 90 degrees and return to the shore trailing the other length of rope. The net and rope should delineate a rectangle. If no boat is available, the net can be deployed by hand by wading out to a suitable depth and deploying the net from a board or large bin. Once set, slowly pull the ropes in and recover the net, the midpoint of which will be last to be drawn ashore and will contain most of the captured fish. During hauling the people pulling on the ropes should move gradually towards one another, slowly closing the net. It is essential that the weighted footrope stays on the bottom at all times and precedes or stays level with the head rope during hauling. Once the net begins to come ashore, and assuming four people are available, two should keep the footrope close to the ground whilst the others pull in the head rope. If only two people are available and to ensure the footrope stays close to the bottom the net should be pulled up the beach until it is completely out of the water. The length of rope and the net length determine the area swept. The area covered by a beach seine net can be calculated by following the procedure given by Kubecka and Bohm (1991) and Ross *et al.* (1987) which, together with estimates of efficiency (Kjelson and Colby 1976; Pierce *et al.* 1990; Ross *et al.* 1987; Weinstein and Davis 1980) can be used in the calculation of absolute fish densities. To increase efficiency in seagrass the footrope can be made extra heavy (Jenkins *et al.* 1997); accurately delineating the seine netting area can be achieved by fishing between poles placed in the substratum (Ferrell and Bell 1991).

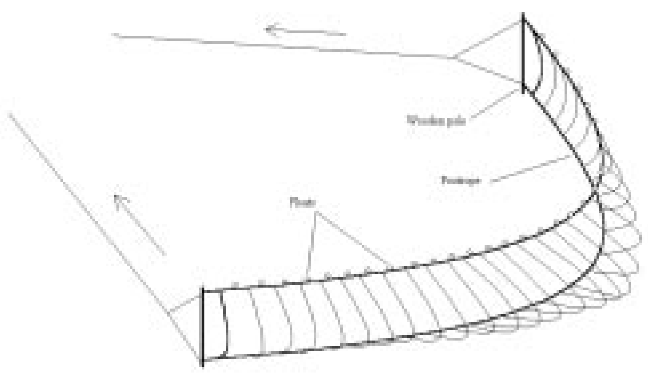


**Figure 1** Seine net during hauling

### *Cost and time*

The time required for one haul depends on the size of the net and the presence of weed fragments or obstructions on the bottom and the speed of any currents. As a rough guide, a net of 40m can deployed and recovered within 15 minutes. A 40m beach seine costs about £200 excluding the ropes for hauling. The cost of this sampling technique can be reduced when the requirement for a boat can be avoided.

### *Advantages*

- easy to operate
- faster and cheaper than a pop net (Connolly 1994)

### *Disadvantages*

- less efficient than a pop-net (Connolly 1994)
- difficult to deploy in rough conditions

## Other methods

The following methods have also been used to sample in seagrass beds but are not conventional or described in detail.

| *Technique* | *Notes* | *Reference* |
|---|---|---|
| SCUBA survey | Likely to be inefficient over dense vegetation | Jansson et al. 1985; Isaksson and Pihl 1992 |
| Drop nets | Used in the USA to sample small areas (1m2): a rather elaborate technique | Fonseca et al. 1990; Fonseca et al. 1996 |
| Gill net | A destructive technique with potential mammalian and avian by-catch problems | Pihl et al. 1994; Sogard et al. 1989 |

## Stipe removal and analysis

This technique is described by Gordon (1983) and relies on the close association that some fish species have with the bulbous holdfasts of the laminarian group of seaweeds.

### *Equipment*

- plastic/net bags
- plastic buckets
- protective clothing (boots, gloves, oilskins, etc.)

### *Personnel*

Diving unit (comprising at least three qualified divers)

### *Technique*

Divers should identify a suitable plant and carefully cut the stipe about 45cm above the holdfast. Disturbance should be minimised wherever possible. The holdfast should then be eased off the rock using a knife. As quickly as possible after removal, the holdfast should be placed inside a plastic or mesh bag and a tight knot (or cable tie) used to seal the bag around the stipe. Once the sampling has been completed all the stipes can be returned to the surface. Once on the surface the holdfast should be cut up and any fish removed. These can be measured and returned or preserved for further analysis depending on the experimental protocol.

### *Cost and time*

Each holdfast should take 5–10 minutes to bag. The total survey time will depend on the number of samples required. Laboratory work duration will depend on the experimental protocol. Costs per sampling effort can be quite high as a result of the requirement for divers (up to £500 per dive at the time of writing).

### *Advantages*

- ease of collection

### *Disadvantages*

- only samples fish that live in kelp holdfasts

## Accuracy testing

Where appropriate and where known, methods of assessing sampling accuracy are either outlined or referenced in the description of methods given above or in QA/QC (see below).

## QA/QC

High natural variability and the problems of observation and capture efficiency mean that standardisation of the techniques used to assess a fish population is essential if other sources of variation are to be minimised. Quality assurance depends on the technique chosen (see advantages and disadvantages). However, in general terms apparent changes in abundance may simply be caused by a change in catchability (Beja 1995; Costello *et al.* 1995; *Sayer et al.* 1994; Sayer *et al.* 1996) or by movements into or out of the sampling area (Allen *et al.* 1992; Claridge *et al.* 1986; Gibson *et al.* 1993; Ross *et al.* 1987). It is, therefore, difficult to link cause and effect unless extensive background data on the behaviour of the fish species of interest are available or intensive surveys with control sites and sufficient replication can be carried out (Barber *et al.* 1995). The techniques described in this section are well suited to detect inter-annual changes because direct comparisons between years are valid when all other factors associated with sampling are standardised. To reduce experimental error and to make the survey as easy and meaningful as possible the following are recommended:

- Choose well-researched common species and familiarise the survey team with the chosen species' behaviour and ecology.
- Utilise survey methods that are simple, that can be undertaken routinely and where access to the sampling site is easy and reliable.
- Standardise the date and time when the survey is carried out. When annual trends are being investigated carry out the survey as nearly as possible on the same date. More importantly, surveys must be undertaken at the same state of the tide (low tide is preferable) and equivalent point in the diel cycle rather than at a specific time. Dusk, for example, may be at 16.00 in winter but 21.00 in summer. Diving surveys are best undertaken during neap tides because tidal currents are weaker and their influence on fish behaviour may, therefore, be reduced .
- Practise the survey technique (new staff should be trained on 'dummy' sites). Identification skills can be tested using photographs or preserved specimens and, if estimating size visually, using fish models of known length.
- Use, wherever possible, the same survey teams. This is particularly important when conducting visual surveys and manual searches which involve considerable skill.
- Maintain skill continuity during personnel changes by training all members of the survey team in every aspect of the survey technique.
- If spurious results are suspected be prepared to check the fishing gear (if relevant) and possibly repeat the survey. Repeat surveys on successive days to get an indication of day-to-day variability and incorporate these data in any statistical analysis.
- Expect large variation in fish abundance. Where assessing inter-annual variability a minimum of three years data is required.

## Data analysis and products

Survey work will normally generate data on species, abundance and size. Analysis will depend on the experimental protocol and should be analysed using standard statistical techniques (Sokal and Rohlf 1995). Fish populations show high inter-annual variability and this must be considered before drawing conclusions regarding cause and effect. Prior to the survey, and depending on the survey objectives, it is advisable to measure the variability of the factors of interest. Carrying out surveys on successive days gives an indication of the reliability of the survey data and these data can be used to predict the number of surveys that will be required to show significant changes (Chapter 9 in Sokal and Rohlf 1995). Comparisons of abundance between species should always take into account their differing catchabilities. If the results of the survey show a significant change in fish population this may be due entirely to natural causes (Collette 1986; Henderson 1989; Rogers and Millner 1996). Where significant fish population changes have been shown and a cause postulated, it is recommended that additional tests be carried out, the nature of which will depend on the postulated cause. Where pollution is suspected as a significant factor the relevant authorities should be contacted (Environment Agency (England and Wales) or the Scottish Environment Protection Agency).

## Health and safety

The primary rule in any fieldwork is Never Work Alone. When working in areas covered in seaweed care should be taken to avoid slipping. Unusually large waves can catch the unwary when working near the tide line; waders can become swamped, making escape very difficult and increasing the chance of an accident. Quinaldine is unpleasant to handle and, when in use, the guidelines given in the Control of Substances Hazardous to Health (CoSHH) hazard data sheet should be followed.

Members of staff employed to undertake diving survey work must be suitably qualified and obey the rules and regulations as stipulated by the Health and Safety at Work Regulations (Dean *et al.* 1997). In addition, individual organisation codes of conduct relating to fieldwork must be adhered to and, where employing external diving contractors to undertake diving work, your organisation will have considerable responsibilities as the diving contractor.

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# Procedural Guideline No. 4-3 Sampling benthic and demersal fish populations on sediments

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## Background

Sedimentary habitats range from those in high energy, frequently shallow, environments with a coarse substratum to low energy, enclosed and sometimes brackish areas of fine mud. The dominant benthic and demersal fish species in these diverse habitats differ markedly, as do successful strategies for sampling them. In deeper water, some species such as *Lesueurigobius friesii* and *Cepola rubescens* live in burrows but most species live on the sediment surface.

On medium to coarse substrata the dominant benthic fish species in shallow water are the plaice (*Pleuronectes platessa* L.), sand goby (*Pomatoschistus minutus* (Pallas)) and the dab (*Limanda limanda* (L.)). On muddier substrata flounder (*Pleuronectes flesus* L.) and sole (*Solea solea* (L.)) may predominate

## Purpose

To provide as accurate an estimate as possible of the abundance, species richness and age structure of benthic and demersal fishes on shallow water sediments.

### *Applicable to the following attributes*

Sampling fish populations will be appropriate for attributes concerning biotope quality in terms of species richness and the abundance of species and for detecting whether areas of impact away from point sources are expanding or contracting. Generic attributes are:

- Measure the species richness in the biotope and/or abundance of key species (rare, fragile, declining, representative) in biotopes.
- Measure the quantity of particular species of conservation importance (rare, fragile, declining species – those for which the site is ‘special’).

Also applicable to the following baseline survey objectives:

- Establish/re-establish the species which are present in biotopes at a site including their abundance and biomass within statistical limits.
- Establish the species present in biotopes and their density within defined statistical limits.
- Establish/re-establish the species which are present along a gradient of change away from a point source of disturbance including their abundance and biomass within statistical limits.

## Methods

### Beach seining

Seine nets consist of a wall of netting weighted at the bottom and provided with floats at the top. They can vary in length from over 100m to less than 10m. The mesh size usually decreases from the wings

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towards the centre which is sometimes extended into a bag to assist retention of the fish. Efficiency has been shown to vary with species, fish behaviour, fish size and the bottom type (Gibson 1999). Seines perform optimally in areas with flat, smooth substrata containing no obstacles. Beach seines are less efficient at sampling benthic species than beam trawls but are preferable where only a localised area is free of obstructions and where a beam trawl could not easily operate. Samples are best taken at low tide because at this time tidal migrants are concentrated at lower levels on the beach and the net will also sample those species that do not migrate intertidally.

### *Equipment*

- seine net (Bridport Gundry, Bridport, Dorset)
- boat
- board for carrying and shooting the net
- measuring board/scales
- plastic buckets
- protective clothing (rubber gloves, waders, oilskins, etc.)

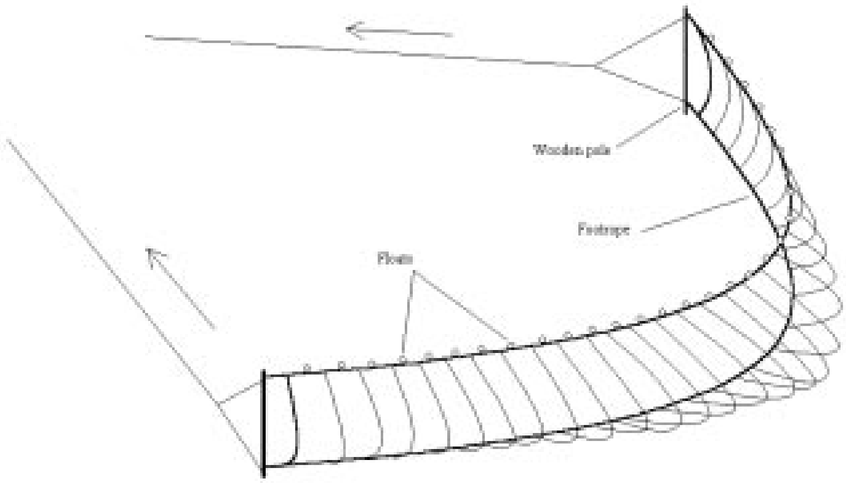


**Figure 1** Seine net during hauling

### *Personnel*

At least two staff depending on net size and deployment method.

### *Technique*

Attach one length of rope to a weighted wooden pole attached to each end of the seine net and fold the net neatly on to a flat board. Secure one end of the rope (normally held by an assistant) to the shore and place the board and net in the bows if using a powered boat or in the stern if using a rowing boat. Ensure the net will run out smoothly from the boat. Propel the boat away from the shore paying out the rope behind it. When the length of rope has been paid out, turn the boat parallel to the shore and deploy one end of the net. Moving slowly parallel to the shore deploy the rest of the net. Once the full length of the net is deployed turn 90 degrees and return to the shore trailing the other length of rope. The net and rope should delineate a rectangle (see Figure 1). If no boat is available the net is deployed by hand by wading out to a suitable depth and deploying the net from a board or large bin. Once it is set, slowly pull the ropes in and recover the net, the midpoint of which will be last to be drawn ashore and will contain most of the captured fish. During hauling the people pulling on the ropes should move gradually towards one another, slowly closing the net. It is essential that the weighted footrope stays on the bottom at all times and precedes or stays level with the head rope during hauling. Once the net begins to come ashore, and assuming four people are available, two should keep the footrope close to the ground whilst the others pull the headrope. If only two people are available and to ensure the footrope stays close to the bottom the net should be pulled up the beach until it is completely out of the water. The length of rope and the net length determine the area swept. The area covered by a beach seine net can be calculated by following the procedure given by Kubecka and Bohm (1991) and Ross *et al.* (1987) which, together with estimates of efficiency (Kjelson and Colby 1976; Pierce *et al.* 1990; Ross *et al.* 1987; Weinstein and Davis 1980) can be used in the calculation of absolute fish densities.

### *Cost and time*

A 40m beach seine costs about £200 excluding ropes for hauling. The time required for one haul depends on the size of the net and the presence of weed fragments or obstructions on the bottom and the speed of any currents. As a rough guide, a net of 40m can deployed and recovered within 15 minutes.

### *Advantages*

- easy to operate
- cost effective

### *Disadvantages*

- efficiency depends on species and size
- difficult to deploy in rough conditions or where currents are strong
- ineffective if weed and boulders are present

## Beam trawling/push netting

The beam trawl is the standard gear for sampling benthic and demersal fish on coarse substrata. The beam trawl consists of a net bag mounted between two 'runners' which are pulled across the sediment like a sledge. A wooden or metal beam connects the runners and forms a strong frame for the attachment of the top of the net. To improve efficiency for certain species one or more lengths of chain can be stretched between the runners positioned c. 15cm in front of the footrope. The chain disturbs the sediment and helps to lift the fish from the bottom where they can be gathered by the net. Commonly, the width of beam trawls used in fish surveys is c.a 2m (Kuipers *et al.* 1992; Rogers and Lockwood 1989). Small trawls can be pulled by hand in shallow water or, more commonly, towed by a boat. A push net (Potts and Reay 1987; Rogers and Millner 1996) is of a similar design to a beam trawl except it is smaller, lighter and pushed from behind by one person. Its design and construction is described by Holme (1971). As a consequence of the short trawl hauls associated with scientific sampling, fish caught are usually undamaged and in good condition, particularly if the net is emptied into a container of water.

### *Equipment*

- boat (dory type with 15–20 hp outboard)
- beam trawl (Netherlands Institute for Sea Research, PO Box 59, 1790 AB Den Burg Texel, The Netherlands; or Frithvale Ltd, Marine Sales, Battery Green Road, Lowestoft NR32 1DE)
- push net (aluminium frames manufactured by Lyte Ladders Ltd, Ballihane Industrial Estate, Ballasalla, Isle of Man)
- measuring boards
- buckets
- protective clothing (gloves, oilskins, etc.)
- deep tray or large bowl for sorting the catch

### *Personnel*

Two or three people depending on the trawl size and subsequent sorting required.

### *Technique*

With the boat slowly underway and under the direction of the boat skipper, the trawl should be lowered to the bottom ensuring the net is streaming cleanly behind the boat. The tow rope should be c. 5 times the water depth and the trawling speed should be 30–35m/min$^{-1}$ (Riley and Corlett, 1966) with trawls lasting c. 5–10 minutes. If possible the boat should slowly continue in motion while the net is being hauled. Bottom obstructions should be avoided and, where assessing change in fish populations over time and when practical, the same area should be trawled during each sampling. Even with experienced operators, towing for the same distance on replicate trawls is difficult and it is recommended that the distance is judged using appropriate marks on the shore or towing between two pre-positioned buoys.

### Cost and time

Two-metre beam trawls and push nets cost in the region of £200. Shooting and hauling the net will take aproximately 15 minutes for short hauls. Sorting the catch varies according to the amount of weed and debris present and may take up to 30 minutes.

### Advantages

- efficiencies for some species have been calculated (Kuipers *et al.* 1992; Rogers and Lockwood 1989; Wennhage *et al.* 1997)
- easy and inexpensive to operate
- fish caught can usually be returned alive if tows are short

### Disadvantages

- beam trawls require a reasonably powerful and suitably equipped survey vessel (inflatables are not recommended as they do not have sufficient 'grip' on the water)
- may cause, or be perceived as causing, damage to the substratum (may not be suitable for sampling on maerl, for example)

## Drop trapping

Drop traps are essentially bottomless boxes that are dropped onto the seabed to enclose a known area. They are suitable for repetitive sampling of small fishes in shallow water.

### Equipment

- drop trap of known area
- strong long-handled hand nets
- containers for holding the catch
- measuring board
- notebook and pencil

### Personnel

Two people are required, although if many samples are to be taken more than two will make sampling less tiring.

### Technique

The trap (usually $1m^2$) is attached to a long pole and raised above the water surface. It is then dropped onto the seabed and the enclosed animals are netted out using the hand nets. Hand netting is continued until no more individuals are caught on three successive sweeps. The technique is fully described by Pihl and Rosenberg (1982) and Wennhage *et al.* (1997).

### Cost and time

The drop traps are made from sheet aluminium which costs approximately £25 per square metre from sheet metal suppliers. It is recommended that if this technique is to be used, specially made hand nets are constructed from thick wire and strong wood as they are subject to considerable strain and wear in use. Operating the trap takes only a few minutes per drop. Sampling the contents can take up to 10–15 minutes per sample.

### Advantages

- unselective and very efficient (>90%).

### Disadvantages

- unwieldy to transport
- tiring if many samples are to be taken
- only suitable for use in shallow water (<1m)
- can only be used on clean sediment, as stones prevent the trap penetrating the sediment

## Fyke netting

Fyke nets consist of one or more leader nets which direct fish into a conical-shaped net funnel held open by metal rings. The conical net comprises a series of interconnecting nets with one-way entry doors which trap the fish (Van der Veer *et al.* 1992) (see Figure 2). Although they can be used singly, fyke nets are usually sold in pairs. Fleets of fyke nets can be joined together into a line and used to sample a much larger area. In some circumstances it may be desirable to distinguish fish that have encountered the leader net from different directions; the net described by Baelde (1990) could easily be modified to produce information on fish direction. To prevent otters entering the net and drowning, otter boards should be attached. Fyke nets are not suitable for use in areas of strong currents. Where the net is likely to be exposed to moderate currents it should be very firmly attached to metal stakes hammered into the substratum (where possible) or heavily weighted. Currents are likely to interfere with the performance of the leader net (by pushing it over) and may cause the net funnel to roll over the substratum. Fyke nets can be used for short periods, and where strong tidal currents are likely the nets should be used during slack water.

### *Equipment required*

- fyke net (Collins Nets, Bridport, Dorset) and otter boards
- boat
- shot weight (at least 10kg per pair of fyke nets )
- protective clothing (gloves, oilskins, etc.)

### *Personnel*

At least two staff (plus a boat skipper)

### *Technique*

Sew the otter boards into the mouth of the net funnel as directed by the manufacturer. Attach the shot weight to the closed end of one of the nets and then lower it to the bottom using the net (there is no need to attach an additional length of rope). When the weight reaches the bottom the rest of the fleet can be paid out as the boat slowly reverses. Most fish in the rocky subtidal move parallel to the shore, and therefore the net should be orientated perpendicular to the shore. It is useful to survey the site visually, prior to deploying the fleet, to check for obstacles. Areas with large boulders, very steep slopes/cliffs and detritus which could become entangled in the net should be avoided. If deploying the net on a steeply sloping substratum attach an extra long shot line and use a larger buoy. This layout reduces the chances of losing the net if it is deployed slightly off site and its weight pulls the marker buoy under the water. Recovery is achieved by lifting the buoyed rope and fish can be removed easily by untying the ends of the net.

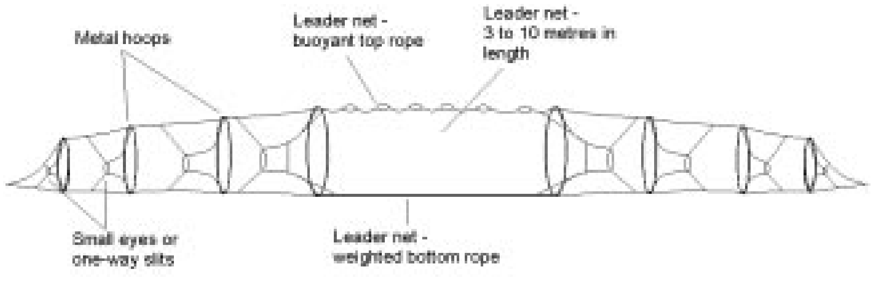


**Figure 2**. Fyke net

If the net is to be deployed intertidally stake out the net during low tide and ensure the leader nets are not tangled.

### *Cost and time*

Boat deployment and recovery takes around 5 minutes per net pair. Removing the fish takes c. 10 minutes. Fishing time depends on the survey objectives but fyke nets are commonly left in position for one day or one tidal cycle (Treasurer 1996). The net should be checked at every low tide or, if sited sublittorally, every tidal cycle. This is necessary to check for damage and to remove detritus and any trapped fish. Fyke nets cost £50–£300 depending on size (Collins Nets, telephone 013808 427352).

### *Advantages*

- cost-effective
- easy to use
- non-destructive

### *Disadvantages*

- restricted depth range (c. 15m maximum)
- sub-tidal deployment requires a boat
- the catch represents an unknown proportion of the actual population; the catching power of the net is unknown for most species and may vary with season and other factors (Darwall *et al.* 1992)
- cannot be successfully used in areas with moderate to strong currents

## Accuracy testing

Where appropriate, methods of assessing sampling accuracy are either outlined or referenced in the description of methods given above.

## QA/QC

High natural variability and the problems of capture efficiency mean that standardisation of the techniques used to assess a fish population is essential if other sources of variation are to be minimised. Apparent changes in abundance may simply be caused by a change in catchability (Beja 1995; Costello *et al.* 1995; Sayer *et al.* 1994; Sayer *et al.* 1996) or by movements into or out of the sampling area (Allen *et al.* 1992; Claridge *et al.* 1986; Gibson *et al.* 1993; Ross *et al.* 1987). It is, therefore, difficult to link cause and effect unless extensive background data on the behaviour of the fish species of interest are available or intensive surveys with control sites and sufficient replication can be carried out (Barber *et al.* 1995). The techniques described in this section are well suited to detect inter-annual changes because direct comparisons between years are valid when all other factors associated with sampling are standardised. To reduce experimental error and to make the survey as easy and meaningful as possible the following are recommended:

- Choose well-researched common species and familiarise the survey team with the chosen species' behaviour and ecology.
- Utilise survey methods that are simple, that can be undertaken routinely and where access to the sampling site is easy and reliable.
- Standardise the date and time when the survey is carried out. When annual trends are being investigated carry out the survey as nearly as possible on the same date. More importantly, surveys must be undertaken at the same state of the tide (low tide is preferable) and equivalent point in the diel cycle rather than at a specific time. Dusk, for example, may be at 16.00 in winter but 21.00 in summer. Diving surveys are best undertaken during neap tides because tidal currents are weaker and their influence on fish behaviour is therefore reduced .
- Practise the survey technique (new staff should be trained on 'dummy' sites). Identification skills can be tested using photographs or preserved specimens and, if estimating size visually, using fish models of known length.
- Use, wherever possible, the same survey teams. This is particularly important when conducting visual surveys and manual searches which involve considerable skill.
- Maintain skill continuity during personnel changes by training all members of the survey team in every aspect of the survey technique.
- If spurious results are suspected be prepared to check the fishing gear (if relevant) and possibly repeat the survey. Repeat surveys on successive days to get an indication of day-to-day variability and incorporate these data in any statistical analysis.
- Expect large variation in fish abundance. Where assessing inter-annual variability a minimum of three years data is required.

## Data analysis and products

Survey work will normally generate data on species, abundance and size. Analysis will depend on the experimental protocol and should be analysed using standard statistical techniques (Sokal and Rohlf 1995). Fish populations show high inter-annual variability and this must be considered before drawing conclusions regarding cause and effect. Prior to the survey, and depending on the survey objectives, it is advisable to measure the variability of the factors of interest. Carrying out surveys on successive days gives an indication of the reliability of the survey data and these data can be used to predict the number of surveys that will be required to show significant changes (Chapter 9 in Sokal and Rohlf 1995). Comparisons of abundance between species should always take into account their differing catchabilities. If the results of the survey show significant changes in fish abundance and population structure, these changes may be due entirely to natural causes (Henderson and Seaby 1994; Rogers and Millner 1996). Where significant fish population changes have been shown and a cause postulated, it is recommended that additional tests be carried out the nature of which will depend on the postulated cause. Where pollution is suspected as a significant factor the relevant authorities should be contacted (Environment Agency (England and Wales) or the Scottish Environment Protection Agency).

## Health and safety

The primary rule in any fieldwork is 'Never Work Alone'. When working in areas covered in seaweed care should be taken to avoid slipping. Unusually large waves can catch the unwary when working near the tide line; waders can become swamped, making escape very difficult and increasing the chance of an accident.

Members of staff employed to undertake diving survey work must be suitably qualified and obey the rules and regulations as stipulated by the Health and Safety at Work Regulations (Dean *et al.* 1997). In addition, appropriate codes of field work conduct appropriate to your organisation must be followed. Note that where employing external diving contractors to undertake diving work your organisation will have considerable responsibilities as the diving contractor.

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# Procedural Guideline No. 4-4 Sampling fish in rockpools

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## Background

Rockpools make convenient sampling units for assessing intertidal fish populations and several sampling techniques are available, all with attendant advantages and disadvantages. The most accurate methods are intrusive and involve the application of anaesthetics, whilst techniques such as visual assessment have negligible affects on the pool but lack accuracy. Mark-recapture techniques have also been used but they are not considered applicable for SAC surveys for reasons discussed below. As with all fish sampling, the strategy chosen for sampling rock pools should reflect the objectives of the survey.

The commonest fish found in UK rock pools are rock goby (*Gobius paganellus* (L.)), shanny (*Lipophrys pholis* (L.)), butterfish (*Pholis gunnellus* (L.)) and sea scorpion (*Taurulus bubalis* (Euphrasen)). Corkwing (*Crenilabrus melops* (L.)) juveniles and fifteen-spined sticklebacks (*Spinachia spinachia* (L.)) may also be common in weedy pools.

## Purpose

To provide as accurate an estimate as possible of the abundance, species richness and age structure of intertidal fishes in rock pools

### Applicable to the following attributes

Sampling to collect the cryptofauna of turfs will be appropriate to assessing quality in terms of species richness and the abundance of species. Generic attributes are:

- Measure the species richness in the biotope and/or abundance of key species (rare, fragile, declining, representative) in biotopes.
- Measure the quantity of particular species of conservation importance.

Also applicable to the following baseline survey objectives:

- Establish/re-establish the species present in the biotopes at a site, including their abundance.
- Establish/re-establish the species present in biotopes at a site, including their density within statistical limits.

## Methods

### Selection of pools for sampling

Rock pools as near to the low water mark as possible, and preferably those only exposed during spring tides, should be selected to maximise the range of species that can potentially be caught. Pool selection will depend on availability, accessibility and the estimated time the sampling will take, since sampling must be completed before the tide returns. Low pressure and onshore winds can significantly reduce the ebb tide and this factor should be considered when selecting pools. Do not select, for example, those at the bottom of the spring tide range, as under certain weather conditions they will remain covered even during spring tides.

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To reduce variability between pools those that are similar in terms of area, depth and shore level should be sampled whenever practicable. Whether the same rock pools are visited repeatedly depends on practical considerations including the frequency of sampling. In areas with relatively few convenient pools there may be no alternative to sampling the same pool. During a period of frequent sampling the sampling process is likely to affect the fish assemblage adversely. This factor should be considered when designing the sampling strategy. In general, rock pool, especially exposed pool, fish assemblages recover quickly (within weeks) from disturbance. However, the number of times the same rock pool can be sampled per unit time without affecting the survey results has not been determined experimentally and repeat sampling should be undertaken with this consideration in mind.

If sampling the same pools is the chosen strategy it is advisable to mark the pools to facilitate return visits. The nature of the marker depends on the exposure of the location and the intended length of the survey. In exposed locations where sampling will cover several years a stout metal post should be hammered into a suitable crevice. This post can be then be labelled to identify the pool. The post should not attract undue attention to the pool or pose a hazard to members of the public.

## Estimating pool volume

Rough estimates can be made by making approximate length, width and depth measurements. A simple measuring stick can be dipped into representative parts of the pool to estimate mean depth. A more accurate method is to disperse a non-toxic dye within the pool and remove a small sample. The concentration of dye in the sample can be measured photometrically and used to calculate the pool volume (Green 1971; Pfister 1995). Other methods are outlined by Gibson (1999).

## Sampling by anaesthetisation

Rock pools offer an ideal environment for the anaesthetisation of the fish they contain because flushing is often negligible during low tide and a fairly accurate estimate of the pool volume can be made. With careful use (correct concentration), and in conjunction with hand searching and netting, anaesthetics can be used to catch 80–90% or more of the rock pool fish (Gibson 1967); sampling is therefore much more accurate than many alternative techniques.

### *Equipment*

- quinaldine (2-methylquinoline (90–95%, Sigma); solution diluted 1 part quinaldine to 4 parts acetone or ethanol (by volume): methylated spirits could be substituted for ethanol
- fine mesh (knotless) 10–15cm hand-net
- ruler/measuring board, scales
- protective clothing (rubber gloves, waders/boots, oilskins)
- plastic dispenser bottle and buckets
- notebook and pencil

### *Personnel*

At least one person experienced in the use of quinaldine. Other staff as required to collect, identify, measure and record the fish.

### *Technique*

Move any overhanging weed in the rock pool to the sides of the pool to assist in the uniform dispersion of the quinaldine and the recovery of anaesthetised fish. Using estimates of rock pool volume, add quinaldine to give a final concentration of ~5–10 p.p.m. (equivalent of 25–50ml quinaldine solution per cubic metre of sea water). Quinaldine can be administered using a flexible polythene bottle (washing-up liquid or similar) with ~30cm of flexible tubing attached. The tubing can be directed under stones and into cracks and crevices. After application to any one area in the pool the water should be agitated to assist in dispersion in the immediate vicinity and to prevent the quinaldine floating to the surface. The total volume of quinaldine should be administered in this way or, where applicable, be added to water flowing into the rock pool. After addition of the quinaldine the whole pool should be thoroughly mixed (Gibson 1967). Pools lowest on the shore should be sampled first to minimise the time the fish are exposed to the anaesthetic before the pools are flushed by the incoming tide.

Fish will appear from their hiding places within 1–10 minutes after application of the quinaldine, depending on species. The pool should be searched by feeling by hand around weedy areas, under stones and in crevices. Affected fish should be carefully collected using a fine hand net and then transferred to buckets of clean sea water for recovery (in hot weather the buckets should be kept cool) or to treated water taken from the pool if continued anaesthesia is required. Any measurements should be done on anaesthetised fish. If further laboratory analysis is required fish can be preserved in alcohol or formalin. Alternatively, fish should be returned to the same pool.

### *Cost and time*

Quinaldine currently (March 2000) costs £26.60 for 0.5 litre and is available from Sigma.
Pool location and tides will dictate the amount of time available to carry out the work. As a rough guide, a pool of 2m x 1m x 0.5m would normally take approximately 15–30 minutes to sample. Reducing pool volume (by bailing) may reduce the time required to carry out the work.

### *Advantages*

- high accuracy (most fish will be collected this way)
- fish returned to clean water recover quickly and, provided the appropriate concentrations are used, mortality is negligible

### *Disadvantages*

- quinaldine is an unpleasant compound with which to work (see 'Health and safety' section)
- possibly an unacceptable technique on SAC sites
- unknown effects on other pool occupants (e.g. Crustacea)

## Sampling by bailing/hand netting

This technique is particularly applicable to pools that have a low rugosity and/or minimal weed cover or where the use of anaesthetics would be unacceptable. These techniques may also be preferable where an absolute measurement of fish number is not required and where it can be assumed that catchability is similar between years. It is not acceptable when comparing fish numbers between seasons as changes in fish behaviour rather than abundance may result in differing catches. Hand netting without anaesthetics is likely to be subject to higher investigator variance and this will make comparisons between surveys carried out by different teams less reliable. Bailing can be used to reduce the volume of water in a rockpool and thereby reduce sampling time. Bailing can be done with buckets or, if faced with a larger volume, a pump powered by a small petrol engine can be used.

### *Equipment*

- fine-mesh (knotless) 10–15cm hand-nets available from pet shops
- ruler/ measuring board
- buckets/pump and hose
- notebook and pencil

### *Personnel*

At least two, of whom one must be experienced in the capture technique.

### *Technique*

The net should be worked around the base of weed and into cracks and crevices. Two people, both using nets, are likely to be more effective in catching highly motile species. Where appropriate, stones and boulders can be turned to reveal fish concealed beneath, but these must be replaced to minimise damage.

### *Cost and time*

Minimal cost unless a pump is used. Pumps can be hired from tool hirers. Time required is dependent on the survey objectives, experimental design and rock pool location. A rough guide for a 2m x 1m x 0.5m pool is 15–20 minutes.

### *Advantages*

- low cost, easy to carry out
- no requirement for chemicals

### *Disadvantages*

- low catch efficiency, especially in cracks, crevices and dense weed cover
- comparisons between individuals/teams can be unreliable
- stone and boulder turning can damage the environment

## Sampling by visual assessment

Simple visual assessment has the advantage over all other methods in that it is non-invasive and has no impact on the pool. If the sampling objective requires only an overview of fish numbers then this technique may be acceptable. Previous research (Christensen and Winterbottom 1981) has shown that cryptic species and those inhabiting crevices were underestimated during visual surveys of rock pools (0–86% were counted). Correction factors should be calculated for every species and those that are rarely observed excluded. The correction factor will differ between observers and its calculation will require the removal and counting of all individuals from a pool using anaesthetics. In the UK, rock pools tend to be dominated by cryptic species and therefore visual assessment is only recommended where all other techniques are unacceptable. The topic has been reviewed by Gibson (1999).

### *Equipment*

Notebook and pencil.

### *Personnel*

Individuals familiar with the species likely to be encountered in the locality.

### *Technique*

Visual assessment involves careful approach to a pool and choosing an inconspicuous viewpoint. The observer should then remain still until fish emerge from their hiding places when they can be identified and counted. Additions of small quantities of bait (crushed mussels or sea urchins) can reveal the presence of previously undetected individuals.

### *Cost and time*

Minimal cost. Time required is dependent on the size and number of pools sampled.

- Advantages
- no effect on the fish or their environment
- suitable for frequent repeat sampling
- Disadvantages
- absolute abundance estimates are not possible
- observation is difficult when the surface of the pool is disturbed by windy weather

## Sampling by mark and recapture

This technique involves the marking and subsequent release of individual fish. After a given time the release area is fished again. The number of marked fish recaptured can be used to give an indication of fish population size (Pfister 1996) but has more commonly been used to determine fish movement and refuge fidelity (Moring 1976; Koop and Gibson 1991). The problems caused by the potential movement of marked fish, the relatively short life span of some rockpool species (making interpretation of data more difficult) and the time needed to conduct the research adequately mean that this technique is not recommended. For a review of this technique see Potts and Reay (1987) and references therein.

## Accuracy testing

Where appropriate, methods of assessing sampling accuracy are either outlined or referenced in the description of methods given above.

# QA/QC

High natural variability and the problems of observation and capture efficiency mean that standardisation of the techniques used to assess a fish population is essential if other sources of variation are to be minimised. Apparent changes in abundance may simply be caused by a change in catchability (Beja 1995; Costello *et al.* 1995; Sayer *et al.* 1994; Sayer *et al.* 1996) or by movements into or out of the sampling area (Claridge *et al.* 1986; Ross *et al.* 1987, Allen *et al.* 1992; Gibson *et al.* 1993). It is therefore difficult to link cause and effect without extensive background data on the behaviour of the species of interest or without carrying out intensive surveys with control sites (Barber *et al.* 1995). The techniques described in these Guidelines are suitable for detecting inter-annual changes because direct comparisons between years are valid when all other factors associated with sampling are standardised. To reduce experimental error and to make the survey as easy and meaningful as possible the following points are recommended:

- Choose well researched common species and familiarise the survey team with the chosen species' behaviour and ecology.
- Utilise survey methods that are simple, that can be undertaken routinely and where access to the sampling site is easy and reliable.
- The timing of sampling is critical and when populations are to be compared between years, samples should always be taken at the same time of year and during similar weather and tide conditions. Equally importantly, surveys must be undertaken at the same state of the tide and equivalent point in the diel cycle rather than at a specific time. For example, in midsummer sampling at 16.00 would be in daylight, whereas sampling at the same time in winter would be at dusk; apparent differences in population size may simply reflect diel behavioural changes.
- Standardise the time spent searching unit volume of water and adhere to this time even when searching could continue.
- Practise the survey technique (new staff should be trained on 'dummy' sites). Identification skills can be tested using photographs or preserved specimens and, if estimating size visually, using fish models of known length.
- Use, wherever possible, the same survey teams. This is particularly important when conducting visual surveys and manual searches which involve considerable skill.
- Maintain skill continuity during personnel changes by training all members of the survey team in every aspect of the survey technique.
- If spurious results are suspected be prepared to repeat the survey. Repeat surveys on successive days to get an indication of day-to-day variability and incorporate these data into any statistical analysis.
- Expect large variation in fish abundance. Where assessing inter-annual variability a minimum of three years data is required.

# Data analysis and products

Survey work will normally generate data on species, abundance and size. Analysis will depend on the experimental protocol and should be done using standard statistical techniques (Sokal and Rohlf 1995). Fish populations show high inter-annual variability and this must be considered before drawing conclusions regarding cause and effect. Prior to, and depending on the survey objectives, it is advisable to measure variability between rockpools in whatever factor is of interest. The measure of variability can be used to predict the number of pools (replicates) that will be required to detect changes in the fish population statistically (Chapter 9 in Sokal and Rohlf 1995). The abundance of rockpool fish is normally expressed as number of fish per unit area (the area of the pool surface) or volume. However, rockpools with differing rugosities will have differing submerged surface areas, reducing the validity of comparisons based on either surface area or volume. Comparisons of abundance between species should always take into account their differing catchabilities. If the results of the survey show a significant change in fish population this may be due entirely to natural causes (Collette 1986). Where significant changes in abundance or assemblage structure have been demonstrated and a cause postulated, it is recommended that additional tests be carried out, the nature of which will depend on the postulated cause. Where pollution is suspected as causing significant changes in fish populations the relevant authorities should be contacted (Environment Agency (England and Wales) or the Scottish Environment Protection Agency).

## Health and safety

Never do field work alone. When working in areas covered in seaweed care should be taken to avoid slipping. Unusually large waves can catch the unwary when working near the tide line; waders can become swamped, making escape difficult and increasing the chance of an accident. Quinaldine is very irritating to the eyes and skin; rubber gloves must be used and face protection is advisable when handling the quinaldine concentrate. Quinaldine splashes should be washed off skin immediately. Shores are often exposed and general precautions against the cold, wind and sun should be taken.

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# Procedural Guideline No. 6-1 Positioning using a differential Global Positioning System (GPS) in near-shore tidal waters

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## Background

The aim of this document is to provide a set of generic guidelines appropriate for the non-specialist for site location (positioning) and relocation in near-shore tidal waters and lagoons using the Global Positioning System (GPS). All positioning aspects and options discussed relate to the waters surrounding the UK. However, the principles can generally be applied to all GPS systems throughout the world and are also suitable for land-based positioning.

### Overview of the Global Positioning System (GPS)

GPS is a space-based positioning system whereby a position can be instantaneously determined anywhere on the surface of the earth by measuring range from a ground-based receiver to at least four satellites from a constellation of 24 which continuously orbit the earth. The system is operated by the US Department of Defense which monitors the satellites and uploads information defining their position and status. This information is then constantly broadcast via a coded signal towards the earth's surface. A ground-based receiver is able to track the satellites via these signals and so calculate ranges to all tracked satellites. In essence this is done by measuring the time of travel of the coded signal. The transmitted signal also provides current satellite orbit information, thereby enabling the ground-based receiver to calculate its current position.

- In general, the user can expect horizontal positional accuracies of around 10–15m (with 95% probability), using a single stand-alone receiver.[2]
- Improved positional accuracies are available by expanding on the basic technique outlined above. This document discusses one of those techniques, differential GPS, which results in possible horizontal positional accuracies of up to 1 metre.
- Other techniques, of which there are many, e.g. RTK (Real Time Kinematic) or rapid static, are beyond the scope of these guidelines. Real Time Kinematic GPS is in the main used for precise surveying where accuracies at 10mm level are required. The technique involves the use of more advanced GPS equipment and local radio transceivers, i.e. user operated. From an operating point of view this technique is similar to user established dGPS systems as outlined later in this document. Commercial RTK correction services are not available at this time

### Overview of differential GPS (dGPS)

The accuracy of the basic GPS positioning technique is limited by several factors. One significant factor is that the signals transmitted by the satellite are degraded as they pass through the atmosphere. A

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2 Prior to 1 May 2000 the US used SA to degrade the instantaneous positioning accuracies to 100m 95% of the time. On that datethey switched SA off and so now all receivers will yield an instantaneous position of around 10–15m 95% of the time.

second factor is due to the uncertainties of the broadcast satellite position. Errors arising from these factors affect the ranges but can be considered equal between any two points at the same time and in the same locality. In the differential global positioning system technique the errors in the ranges are measured at a predetermined location (base station) in the locality. Corrections to the ranges are then broadcast for use by any local GPS receiver (rover station).

Accuracy achievable with dGPS is typically 1–5m (horizontal position) at the 95% confidence level. The actual accuracy achievable is dependent on factors such as:

- the frequency with which the range correction is received.
- the number of common satellites being tracked by the rover and the base station.
- the number of base stations providing the corrections (several of the commercial operators who provide dGPS corrections improve the quality of their corrections by averaging the corrections from several base stations).
- effects of Multipath; this is the error caused by GPS signals being reflected from local surfaces (sea, buildings, etc.) to give an incorrect, greater range.
- the distance between the base and rover GPS receivers; typically this would be within 500km.
- the dGPS corrections need to be received by any user in (near) real-time – typically within 1–10 seconds.

Several commercial companies broadcast dGPS corrections as a standard service. These corrections can be broadcast via either satellite or ground-based communications. The international standard for the digital format of the correction signal is RTCM SC-104 version 2.1 (Radio Technical Commission for Maritime Services Sub Committee 104).

### The dGPS deliverables

The dGPS technique yields a series of point locations, described by co-ordinates, of the rover receiver antenna.

- The horizontal point position so determined will define the location of a site.
- A typical GPS receiver has built in functions allowing real-time navigation along a predetermined route via waypoints. These functions will aid the user to navigate a vessel to relocate a site.
- The basic dGPS technique provides co-ordinates in a worldwide co-ordinate reference system (WGS84) not typically used for near-shore mapping. These co-ordinates can usually be transformed within the receiver into any other co-ordinate reference system. It is essential that the co-ordinate output is compliant with the project requirements. See co-ordinate reference systems section.
- Many receivers have the facility to export the point locations for integration into software packages including attribute mapping devices (geographical information systems (GIS)) and other dedicated marine monitoring systems.

## Equipment

Figure 1 shows the basic configuration of a dGPS system that comprises a base station, some form of range correction transmitting equipment and one or more roving GPS receivers. At present there are three main system configurations utilised for dGPS positioning, namely user-established, satellite-based and ground-based systems.

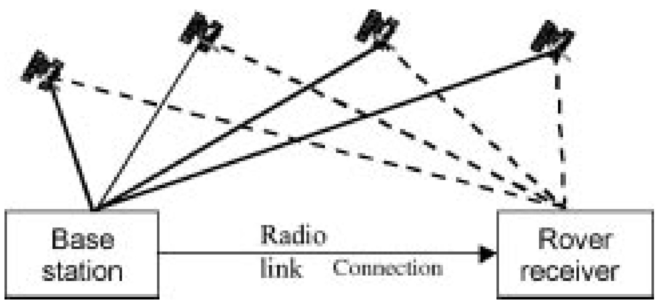


**Figure 1** Basic components of a dGPS system

The basic equipment for a roving receiver comprises a GPS positioning receiver and antenna and a dGPS range correction receiver and antenna, power systems and appropriate cables. Other peripheral devices such as a data logger may be required depending on project specifications. Current trends are for a combined solution with the GPS positioning receiver and dGPS correction receiver situated in the same physical case utilising a combined antenna. A typical terrestrial equipment configuration is shown in Figure 2.

**Figure 2** Typical dGPS rover configuration[3]

Further product information specific to individual manufacturers can be obtained by visiting the websites provided at the end of this document.

## User-established systems

The equipment required for the establishment of a base station is a GPS positioning receiver with antenna located at a known, fixed location, dGPS range correction computation software, a correction transmitter, power systems and appropriate cabling. Such equipment is available from all the major GPS receiver manufactures. The following should be taken into consideration with respect to such a system:

### *Advantages*

- flexibility to establish base station at an optimal location for the proposed project
- no dGPS service subscription fees

### *Disadvantages*

- a substantial increase in expense with the need for a second GPS receiver, processing software and corrections transmitter at the base station
- security and monitoring of base station equipment
- possible radio licence costs
- interference of radio signal used to transmit the dGPS corrections; current Department of Trade and Industry (DTI) radio frequency regulations provide very little bandwidth over which dGPS corrections can be transmitted: this may lead to conditions where the correction signal is overpowered by alternative signals and is rendered useless.

A preferable approach is the utilisation of a commercial dGPS service. Such services remove the requirement for the user to establish a base station. This has obvious advantages with respect to the simplicity of system configuration. Depending upon the nature and duration of the project it will be necessary to investigate the suitability of each of these solutions.

As previously stated, commercial dGPS service providers fall into two categories based on the method by which the dGPS correction is transmitted to the user.

## Satellite-based systems

- Provide corrections to position with an accuracy of about 1 metre horizontal, due to the use of a network of base stations.
- Coverage available for 95% of the earth.

3 Copyright for this image resides with RACAL Landstar for which no permission has been obtained.

- Correction service is provided on a subscription basis additional to the purchase of rover receiver equipment.
- Correction service charges are often dependent upon duration and coverage required.
- Equipment can often be specific to the project terrain. For instance, a system may be designed for use on land, and at a certain distance out to sea software associated with the equipment will prevent its use. Therefore, an alternative system would be required for offshore work. This is primarily a service supplier's answer to preventing offshore oil and gas companies using the less expensive land systems. The range at which this cut-off occurs is subject to change by each manufacturer

## Ground-based systems

- Provided in the UK by the General Lighthouse Authorities and Trinity House under the guise of the Marine Differential GPS Service (MDGPS)
- In general, positions based on these corrections are less accurate (approximately 5m horizontal) as the corrections are calculated and delivered to the rover receiver from a single user-selected radio beacon. Usually this will be the beacon providing the strongest reception.
- There is currently no subscription charged for these corrections, once rover receiver equipment has been purchased.
- The system is designed to maximise coastal and offshore coverage.
- Due to its intended use as a marine navigation aid this system has very limited use on land.

Figure 3 shows the distribution, range and frequency of dGPS stations around the UK and Ireland.

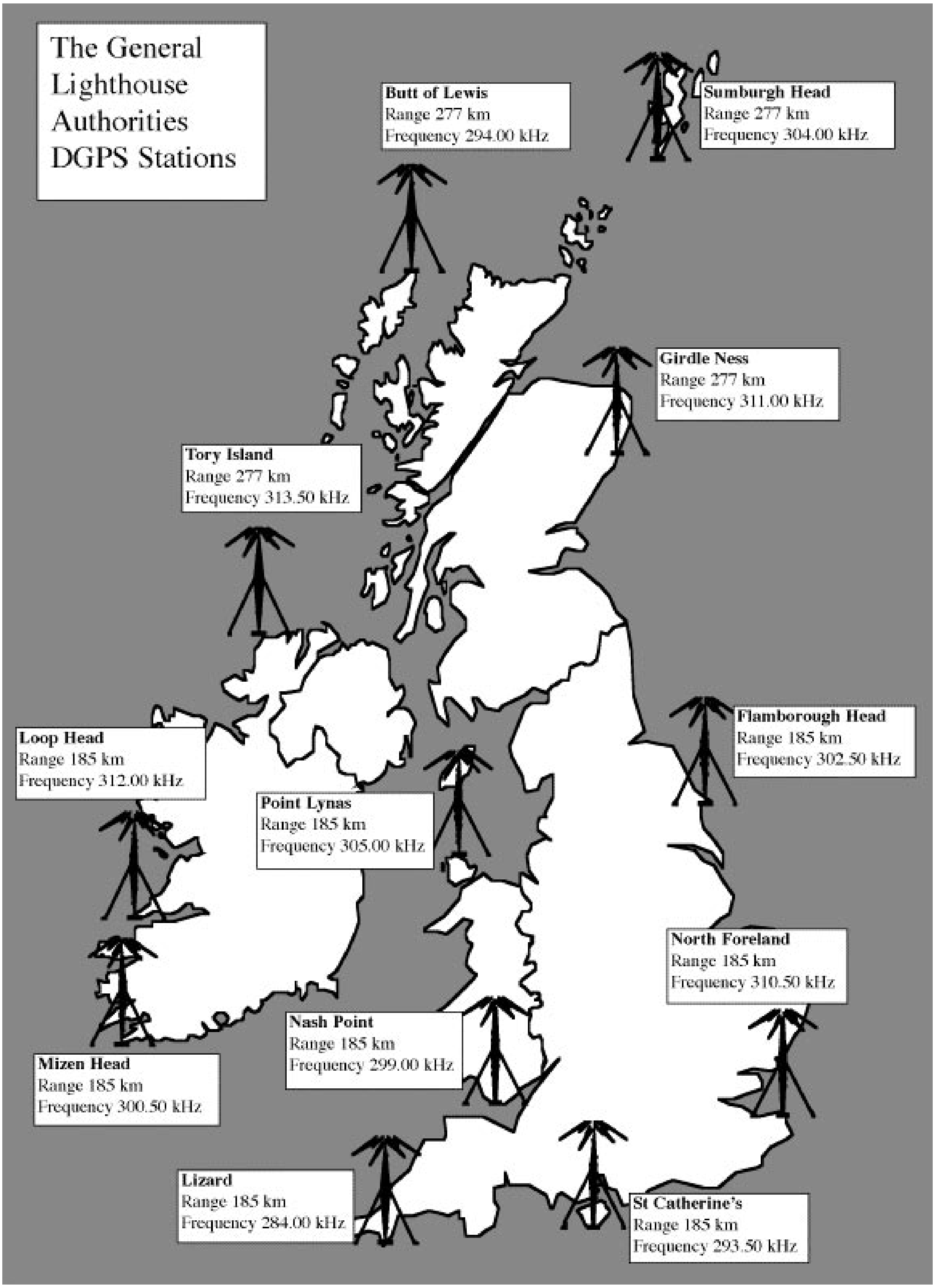


**Figure 3** The location and frequency of dGPS beacons around the United Kingdom and Ireland[4]

The table below provides a summary of dGPS options.

4 Data on the status of these beacons may be found at **http://www.effective-solutions.co.uk/beacons.html**

| *Service provider* | *Type of link* | *Anticipated accuracy* | *Approximate cost of correction service* |
|---|---|---|---|
| MDGPS | Ground-based | ≈3–5m | Equipment ≈ £600–£2000 |
| User system | Ground-based | <3m | Equipment ≈ £5000 |
| Satellite system | Satellite-based | <1m | Equipment – integrated unit ≈ £3000 |
| | (spot beam) | | Correction only ≈£1200–£2500 |
| | | | UK correction service ≈ £800–£1000 pa |

## Equipment procurement – factors to consider

Assuming a need for dGPS positioning, the specific choice of equipment will be very much dependent upon: (a) the required accuracies for site location/relocation; (b) the location of the project; and (c) the costs involved. For example, a commercial dGPS correction service might not be available in the project area and therefore it may be necessary to implement a user-established dGPS system.
Prior to the procurement of equipment the following additional factors should also be considered:

- Existing equipment availability. It may be possible to upgrade an existing GPS receiver with the addition of a compatible dGPS correction receiver.
- Purchase versus hire of equipment.
- Location and duration of project *vis-à-vis* the costs of using a commercial satellite-based correction service and the service availability within a specific project area. (Areal coverage with respect to commercial dGPS correction availability varies between the different service providers.)
- Financial budget.
- Specific equipment requirements as regards actual dGPS deliverables and extra functionality, e.g. navigation, data collection, site relocation, etc.
- Methods of mounting the equipment on a vessel. Receivers designed for recreational use, e.g. hiking, are not usually ideal for secure mounting on a vessel.
- Backup equipment. When it is vital that data is obtained at a specific time then reliance on a single dGPS system is not ideal. In such situations a multi-system approach is appropriate, whereby a second and ideally independent dGPS system is employed. This provides both a means of monitoring individual system integrity and automatic system swapping should a failure occur in one system. The degree of equipment backup required will vary with specific project requirements. However, it is recommended that wherever possible all equipment should be duplicated.
- Final co-ordinate reference system requirements. The default co-ordinate reference system for all GPS positioning is WGS84 (World Co-ordinate System 1984), see co-ordinate reference system section. This may not be consistent with the project co-ordinate reference system.
- Operator training requirements. Whilst GPS and dGPS positioning is in the main a *black box* technique, users may require specific training in a particular manufacturers equipment, e.g. setting datum and setting co-ordinates.

## Technical information of a typical receiver

GPS equipment specifications contain a variety of technical information that is also applicable to dGPS receivers, and the user should be aware of some of the terminology. See also the Glossary of terms (Appendix A).

- Number of receiver channels – this determines the number of satellites that can be tracked at any one time: typically 6 in a lower specification system and 12 in higher order models.
- GPS measurements and frequencies – the coded GPS signal is broadcast on two carrier frequencies called L1 and L2. The L1 frequency carries a modulated code known as the C/A (coarse acquisition) code. Both L1 and L2 frequencies also contain a precise (P) code. In its most basic form a GPS receiver will track only the L1 carrier frequency and use the C/A code to calculate ranges. Advanced GPS receivers are capable of tracking both L1 and L2 and through this gain access to the precise codes, thus improving accuracy by an ability to correct for atmospheric errors.
- Position recording rate (max. per second) – typically this is selectable and might vary from 0.2–60 seconds.

- Latency – particularly important in relation to dGPS, the latency of a system describes the lapsed time since the last dGPS correction was received.

# Personnel

Prior to project commencement a number of personnel will be required to rig and test all dGPS equipment on the monitoring vessel. However, once installed, under normal modes of operation only one person is required to operate each GPS receiver. Specifically, it is necessary to monitor only the GPS output (see QC section) values and communication links to other data capture devices and software.

# Method

All GPS manufacturers' equipment has variations in set-up functions and user interface. It is therefore essential that the user ensures that the manual for each piece of equipment within the specific system has been read and understood. For example, failure to correctly enable the dGPS correction facility on the rover receiver will result in positioning being performed only at the basic 15m level (horizontal position).

## Installation of equipment

### *Antenna location*

The location of the rover receiver antenna on board the monitoring vessel is important. Depending on the nature of the project and required accuracies the following should be taken into consideration:

- Clear view of the sky – the antenna should be located such that it is free from obstructions for 360 degrees above the horizontal plane of the antenna (for example, on top of vessel's mast).
- Interference from other communication sources and electrical fields – GPS and dGPS correction signals are typically weak in comparison to other licensed communication signals, e.g. shipping radio transmissions. It may be necessary to locate the antenna away from other antenna arrays.
- The human/animal interference – this should be minimised. For example, it may be necessary to employ a specialist cover to prevent seabirds sitting on antennae.
- Offset from other measurement devices, e.g. echo-sounding transponder – it should be noted that the movement of the vessel in terms of heading, pitch and roll will have an effect on the position of the GPS antenna with respect to other measurement devices. For example, with an antenna situated 10m up a mast 5 degrees of pitch will introduce ~0.9m of offset.
- Antenna mount – this should be sufficiently robust for the project conditions and the antenna must not move independently of the vessel to which it is attached.

### *Power supply*

GPS receivers from separate manufacturers have differing power requirements. It is therefore essential that attention is paid to the specific requirements of the equipment used. In particular the following key issues should be addressed:

- Most GPS receivers and correction receivers operate on a 12v supply using specialist batteries. The user should check whether alternative voltages are available.
- If it is not possible to replace batteries without powering down the system and the receiver is not operating on an external power supply, e.g. mains adapter, then the user should ensure that recharging facilities are available if project duration is likely to exceed 80% of the stated battery life.
- It may take some time to get a fix after power loss.

### *Cabling*

Depending on configuration individual dGPS systems can require many cables. Moreover the loss of any one cable will generally render the whole system inoperable. Inadequately maintained cables can often be a cause of system failure – avoidable, yet difficult to detect. Implementation of the following recommendations significantly reduces system failure due to cabling problems.

- Ensure each cable is correctly and clearly identified.
- Ensure the complete system is verified before any antennae are fixed in normal operating locations.
- Ensure sufficient coaxial cable is available for proposed antenna location. Maximum antenna cable lengths are dependent upon the thickness of cable and the quality of the end connectors. Thick cable (RG214) has a maximum length of 60m, whilst thin cable (RG58) has a length of 10m. In general antenna cable should not have more than 17db signal loss.
- Ensure cable runs follow paths that are away from areas where personnel or equipment regularly move.

### *Storage/transportation*

All GPS and dGPS equipment designed for use in the field is generally enclosed in rugged waterproof casings. However, the complex electronics housed inside are both sensitive and very expensive to replace and the equipment should be treated with due respect at all times.

When in use, all equipment should be secured and the user should ensure that any mounts used are sufficiently robust for the project conditions.

Ensure that equipment is stored in carrying cases when not being used.

Ensure all cables are carefully stored to prevent damage.

## System settings

Once the equipment is correctly installed and prior to the commencement of the project it is necessary to verify that all system components are operating correctly. Specifically **the user must check that all hardware and software parameters have been correctly selected**. The following are identified as the minimum parameters that must be set.

### *Hardware settings*

- Ensure that communication parameters of the rover receiver and the dGPS correction receiver are compatible. Parameters such as baud rate (speed of communication) will be quoted in the manufacturer's manual.
- Ensure that communication parameters of the rover receiver and any other device receiving the output are also compatible.
- Ensure that the correct antenna type is selected. The use of the incorrect antenna type will introduce a bias in the determined position of the rover receiver.

### *Software settings*

- Set the co-ordinate reference system for the position output appropriate for the project. See section on co-ordinate reference systems.
- Ensure rover receiver is set to accept dGPS corrections.
- Set the frequency of position determination – the update rate at which a position is calculated. An appropriate value is 1 second.
- Set the PDOP threshold (Positional Dilution of Precision, a QC measure of the suitability of the current satellite geometry – see QA/QC section). Above the PDOP threshold positions are not calculated. An appropriate value is 5.
- Set elevation mask – a QA measure to improve PDOP value by filtering out signals from low elevation satellites. An appropriate value to set is 15 degrees above the horizon.
- Set the minimum number of satellites to be tracked. The minimum requirement is 4.

# QA/QC

For the majority of marine monitoring projects dGPS has now become a cost-effective method of position fixing. However, as with all measurement processes perfect measurements are not possible. No matter how sophisticated the associated technology, errors will still remain in the measured ranges and will have an effect on computed positions. The detailed aspects of how these errors can be quantified and assessed is beyond the scope of this report [3]. However, there are various simple functions available to the user, during dGPS operation, that can be monitored to ensure system integrity.

- DOP (Dilution of Precision) - DOP is a measure of the suitability of the geometry of satellites.

Expressed as a number from 1 to infinity the DOP value represents the geometric contribution to the error in the position fix. A value of 5 and below generally regarded as acceptable. In particular, the PDOP (Positional Dilution of Precision) value is generally used as an indicator of good observing satellite geometry. GPS and dGPS positioning should not be undertaken during periods of high PDOP, i.e. >5. If PDOP rises above 5 the user should consider suspending operations until observing conditions improve, i.e. PDOP value <5. In practice this will entail the user either waiting until the GPS satellite geometry changes or moving the vessel to facilitate such a geometry change.[5]

- Number of satellites to be tracked – both the base and rover receivers need to be tracking at least 4 satellites to maintain accuracy. More importantly for dGPS positioning the base and rover receiver must track, as a minimum, 4 common satellites. If this is not achieved then Positioning in the dGPS mode cannot be performed. This can usually be monitored via an output on the rover receiver. However, with the GPS constellation now complete this should not be a problem for receiver with a clear view of the sky.
- Reception of differential corrections – the loss of dGPS corrections for periods of greater then 10 seconds will lead to degradation in accuracy of position fix. The longer the period without the correction signal the greater the degradation of accuracy. See also technical information section – *latency*.

## Accuracy testing

Any position derived from a GPS receiver should only be accepted if it has satisfied the QC factors stated above. Whilst in operation these QC functions provide the only measure of accuracy and it is important that they are monitored. Positions that do not satisfy all of the criteria should be rejected. This can be achieved either automatically or manually depending upon the GPS receiver specification. In order to ensure that QC factors are being met a number of simple accuracy tests can be performed before project commencement. These include:

- Set up the rover receiver according to manufacturer's guidelines and leave the rover antenna stationary for a long period of time (e.g. 1 hour) and monitor the output positions. The average position should not exceed manufacturer's stated system accuracy for 95% of the measured positions. This test should be performed in good operating conditions, i.e. clear view of sky and low multipath. The user should be aware that a hostile environment is likely to reduce system performance.
- Set up the rover receiver according to manufacturer's guidelines and locate the rover antenna over a known co-ordinated point (e.g. Ordnance Survey control point or clearly identifiable point from a local plan). Compare the output positions with the known co-ordinate values. Great care should be taken to **ensure that the co-ordinates of the known point and the dGPS output are in the same co-ordinate reference system** – see co-ordinate reference systems section.
- If a multi-system approach is being used, i.e. two or more independent dGPS systems, then a simple comparison of individual receiver co-ordinate outputs can provide a useful QC test. If this approach is adopted then consideration should be given to the **receiver output co-ordinate reference systems and antenna offsets for each GPS receiver**.

## Co-ordinate reference systems

The standard output from a GPS receiver is a single co-ordinated position in the WGS84 (World Geodetic System 1984) co-ordinate reference system. However, many maps and charts used in the monitoring of marine environments are not referred to this system. It is therefore vitally important that all potential users of GPS and dGPS understand the basic concepts and options concerned with transforming GPS positional output into alternative co-ordinate reference systems (Figure 4). In particular:

- The WGS84 co-ordinate datum has been established for common positioning throughout the world.

5 It is not possible to put a general figure on the decrease in accuracy caused by high PDOP as it is totally dependent on the satellite geometry as observed above the user's local horizon. Obviously this well vary from place to place.

- Position output will often be required to comply with the project base mapping, e.g. Admiralty datum (OSGB36 geodetic).
- The principal co-ordinate system in the UK is based on the Ordnance Survey's National Grid, which is a realisation of the Ordnance Survey Great Britain 1936 datum (OSGB36). All points in the UK and within near-shore waters can be expressed in either geodetic co-ordinates (latitude and longitude) or plan co-ordinates (easting and northing).
- There are a number of different transformation methods, e.g. Helmert, available for transforming WGS84 co-ordinates to OSGB36 or another datum. The user should be aware that each method will, in general, yield slightly different values for the same WGS84 position and the specific choice of transformation is important.
- GPS and dGPS receivers can usually be set to output in a local co-ordinate system, e.g. OSGB36. However, the coordinates output are in the main based on a generalised set of transformation parameters and may not always be appropriate. The user should therefore ensure that the transformed positions are to the required accuracy.

**Note.** There are slight variations to WGS84 that may be referred to in technical documentation, e.g. ETRF89. For this type of project such variations can be regarded as WGS84.

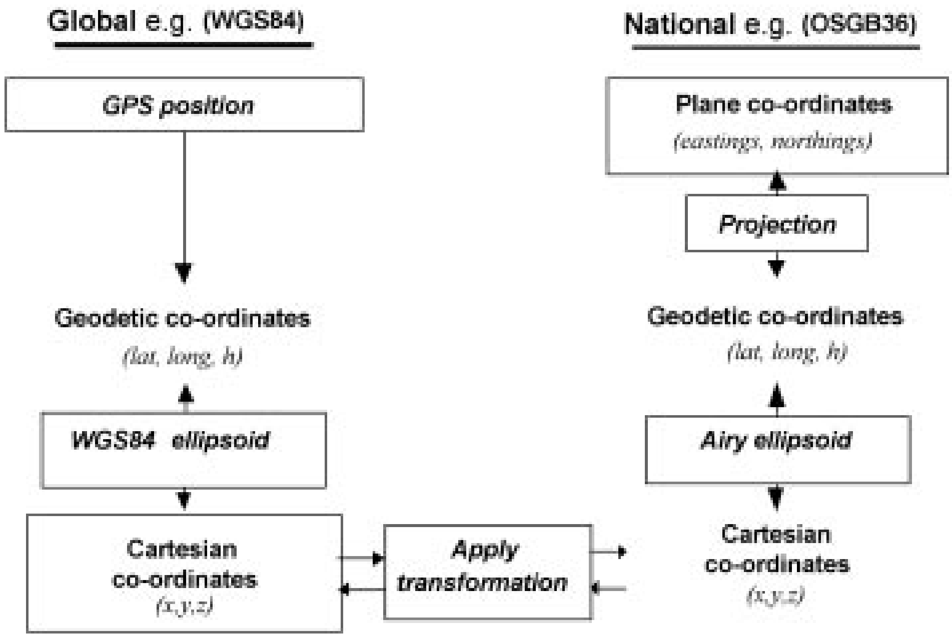


**Figure 4** The interrelationship between the WGS84 and OSGB36 co-ordinate reference systems

# Data output formats

In the vast majority of marine monitoring projects site location and relocation, whilst fundamental to the task in hand, are not the fundamental objective. The position output from dGPS often forms one of the inputs to another system, e.g. GIS, echo-sounder, etc. It is therefore essential that users understand how data strings can be extracted from a GPS receiver and fed into other scientific applications.

## NMEA

The NMEA data format comprises a series of structured messages containing information from the GPS receiver. These messages can be used as an alternative method of interacting with a GPS receiver. The majority of GPS and dGPS receivers use the NMEA format as a communication format allowing interface with other non-proprietary software and data logging devices. The current NMEA standard for interfacing with marine electronic devices is NMEA 0183. The reader may find the following NMEA messages useful:

- GLL
- GGA – GPS position (WGS84 geodetic), time and a measure of quality of that position

- GSA – QC information, such as number of satellites being tracked and PDOP

### Export to GIS format

As mentioned above, dGPS positional information is often utilised within a third party software package such as a GIS. This might simply be for navigational purposes or it might comprise other attribute information attached to an information block that can be subsequently recorded and displayed in a GIS. The reader should be aware that export facilities, for GIS formats, are usually only available if the data is processed in proprietary software supplied with the GPS receiver, after the data has been captured. However, some GIS manufacturers now provide add-on modules that allow the direct input of GPS data from many sources. Such packages usually require NMEA output from the GPS receiver, e.g. MapInfo uses Geotracker™ for 'live' GPS input to base maps.

## References

Leick, A (1995) *GPS Satellite Surveying*, 2nd ed. Wiley, New York.
DGPS http://www.colorado.edu/geography/gcraft/notes/gps/gps_f.html
UK Offshore Operators Association (Surveying and Positioning committee) (1994) *Guidelines for the use of Differential GPS in Offshore Surveying*, Issue Number 1.
Ordnance Survey (1999) *A guide to co-ordinate systems in Great Britain.*
National Marine Electronics Association (1998) *NMEA 0183 Interface Standard, version 2.30.*

### Useful websites

| | |
|---|---|
| Ashtech | **www.ashtech.com** |
| Commissioners of Irish Lights | **www.cil.ie/** |
| Fugro OmniSTAR | **www.omnistar.nl** |
| Leica | **www.leica-geosystems.com** |
| National Marine Electronics Association | **www.nmea.org** |
| Northern Lighthouses Board | **www.nlb.org.uk/** |
| Ordnance Survey | **www.ordsvy.gov.uk/services/gps-co/geo6.htm** |
| Racal LandStar | **www.racal-landstar.com** |
| Trinity House Lighthouse Service | **www.trinityhouse.co.uk** |
| Trimble | **www.trimble.com** |

## Glossary

| | |
|---|---|
| dGPS | Global Positioning System used in differential mode |
| DOP | Dilution of Precision of computed position |
| PDOP | Positional Dilution of Precision |
| HDOP | Horizontal Dilution of Precision |
| VDOP | Vertical Dilution of Precision |
| Ephemeris | Message broadcast from GPS satellite giving the user information on the health and position of the satellite |
| Rover Station | Term used to describe the moving component of the dGPS system, e.g. the vessel |
| Base Station | Term used to describe a fixed station at which corrections to ranges are computed and then broadcast to the Rover Station |
| Multipath | This is caused by GPS signals being reflected from local surfaces (sea, buildings, etc.) onto the GPS receiver's antenna: this can cause errors in the computed range |

# Procedural Guideline No. 6-2 Relocation of intertidal and subtidal sites

Rohan Holt and Bill Sanderson, Countryside Council for Wales[1]

## Background

Relocating sites on the shore or seabed can be very difficult given the nature of the marine environment in temperate waters. Underwater visibility is often restricted to a few metres and weather, sea state and other sea users can make marking a site with permanent marker buoys impractical in the long term. Hiscock (1996) outlines a selection of well-tried methods available for accurately marking and relocating sites on the shore and underwater: variations of these and others utilising recently developed technologies are described below

## Purpose

This guideline deals with the following issues:

- marking and relocating shore and nearshore sites adjacent to surface features (mainland, islands and off-lying rocks)
- marking and relocating offshore sites
- documentation of monitoring sites

### Applicable to the following objectives

Accurate position fixing is a fundamental choice in the design of the monitoring strategy for a given attribute. Position fixing has been used in the monitoring of population and community composition attributes as well as the integrity/structure of populations. It is also conceivable that site marking could be used directly or indirectly (as a georeference point) in the measurement of extent.

Also applicable to the following baseline survey objectives:

- subtidal rock and sediment biology requiring sampling/repeat sampling at exact locations by a variety of different methods
- establishing fixed-point monitoring stations
- locating and relocating structures/communities/species of conservation importance.

### Advantages of marking sites

- Greater precision in detecting changes by being able to return to the same location.
- Ability to examine localised structures, communities or even individuals of one species.
- Accurate position fixing reduces valuable field work/dive time looking for a site.
- Possible health and safety implications – accurate information about a site allows for pre-dive planning and the whereabouts of divers on the seabed are also known.
- Time-series data are secure when anyone can use the information to return to the site (i.e. not reliant on individuals).

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1 Plas Penrhos, Ffordd Penrhos, Bangor, Gwynedd, Wales, LL57 2LQ.

- Permanent site markers such as the 'pyramid' design can be used as a fixing point for other scientific equipment as necessary, such as temperature, current, light and salinity meters.

### Disadvantages of marking sites

- Maintenance commitments and costs involved in the deployment and upkeep of a fixed site.
- Frequent visits to a fixed site can result in localised disturbance (e.g. trampling, silt disturbance, diver's bubbles, mechanical damage to delicate species, behavioural changes in some species of fish).
- Markers may attract unwanted attention from other sea/shore users.

## Logistics

### Diving operations

*All diving operations will be carried out using conventional* ***scuba equipment*** *following the procedures in the current agency diving regulations (Holt 1998).*

### Equipment

#### *Marking shore and near-shore sites*

#### *Recording facilities*

Establishing accurate positions on or close to the shore can make best use of a 'low-tech' approach and still provide accurate position information down to less than one metre. The alignment of natural features ('transit marks' – see Figure 1, Figure 3, and Figure 4) will need to be recorded as sketches (*waterproof paper/slate*) supplemented with *photographs* taken with a standard or short telephoto lens (e.g. 35 to 70mm focal length zoom on a 35mm SLR camera would probably suit most situations).

Artificial markers can be used on the shore or underwater bearing in mind that human disturbance and natural weathering processes can result in their loss and therefore necessitate site maintenance.

#### *Support vessel*

A *support boat* is required for most diving operations and should be equipped with an *echo-sounder* that will allow a seabed profile to be viewed and accurate depths recorded. Current time and date should be recorded to allow for recalculation of depth relative to chart datum using an appropriate tidal correction.

#### *Pitons and bolts*

Easily recognisable natural features on the shore or the seabed can be supplemented with *pitons* (Figure 2) hammered into cracks using a 2kg lump hammer. Rock type (i.e. its friability, the availability of cracks for bolts and pitons and its softness, if drilling bolt holes) and exposure to wave action and weather (with respect to corrosion) must be taken into account. Regular replacement or maintenance should be considered perhaps every 2–3 years.

*Stainless steel eye-bolts* (Figure 2) fixed with rawplugs or *epoxy resin* into the rock also make suitable attachment points for marker tapes and lines. A battery- or petrol-driven portable drill (with 'hammer action') can be used on the shore to bore suitable bolt-fixing holes or making *marker holes*. Only a few tools such as a *compressed air drill* or *bolt gun* can be used underwater. A small air drill with a masonry bit, driven by compressed air from a large diving cylinder via a standard first stage of a diving regulator, will bore holes in *soft* rock. Allow approximately one 12L cylinder for 2–3 holes drilled at 10–20m water depth (Sanderson *et al.* 2000). However, very few air-powered tools available to the scientific diver will make much of an impression on hard limestone and granite and only result in the diver and the drill consuming large quantities of compressed air. Bolt guns work on the principle of driving a steel pin into the rock using a small explosive charge from a 'blank' starter pistol cartridge (M. Bates, Port Erin Marine Laboratory, pers. comm.). Again, such devices are best used on relatively soft rock and require careful use with regard to health and safety.

Small bolts and pitons can be quickly overgrown by turf-forming plants and animals. Finding them by eye can be difficult, even if the location down to the last square metre is known. *Fluorescent tape* (Figure 5) or coloured cable-ties attached to the head of a piton will clearly highlight its position although the tape itself can become detached or have a scouring effect on the flora and fauna at turbulent sites. *Submersible metal detectors* that emit an audible tone when passed over a metal object can help relocate a lost piton or bolt, although this could be very time-consuming if a large area has to be searched. Alternatively, documentation of distances from nearby highly conspicuous natural or man-made features can assist in finding bolts and pitons with a measuring tape (Figure 6).

### Resins and glues

*Resins and glues* that set underwater (e.g. quick-setting epoxy resin) are a less labour-intensive method of fixing markers into crevices (although additional drilling may be required). On very hard flat surfaces, where drilling might be impracticable, small markers, for example to indicate where a repeat quadrat sample should be positioned, can be stuck directly to the rock surface. The rock surface must be thoroughly cleaned of any encrusting algal or animal films using an abrasive wire brush or similar to ensure a firm bond is achieved.


**Figure 1** Drawings of marks and transit features. On the left, when the paint marks (P1 & P2) on a foreground boulder and background cliff face are correctly aligned will indicate the correct location in terms of position and distance offshore. On the right, the transit features are correctly aligned when the tooth-shaped rock appears in the 'V' of the hillside.

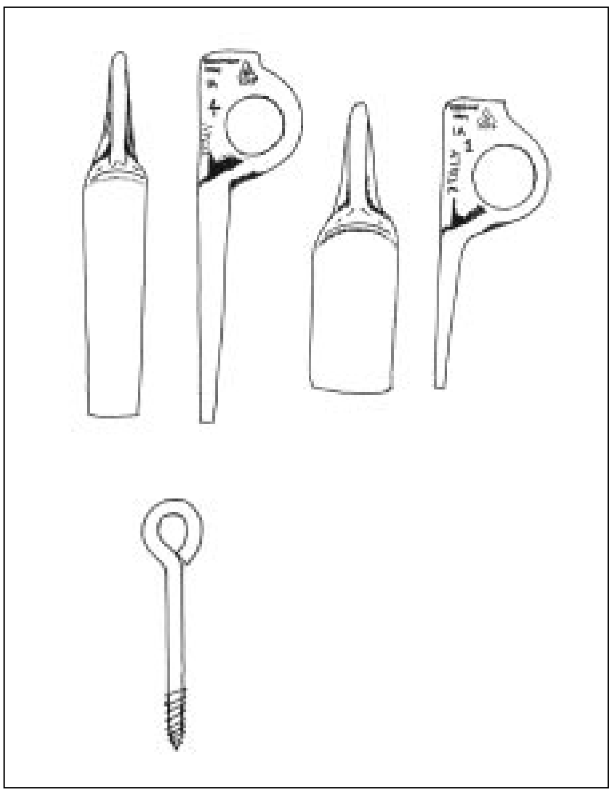

**Figure 2** Examples of typical pitons and an eye bolt used to mark positions on rocky monitoring stations

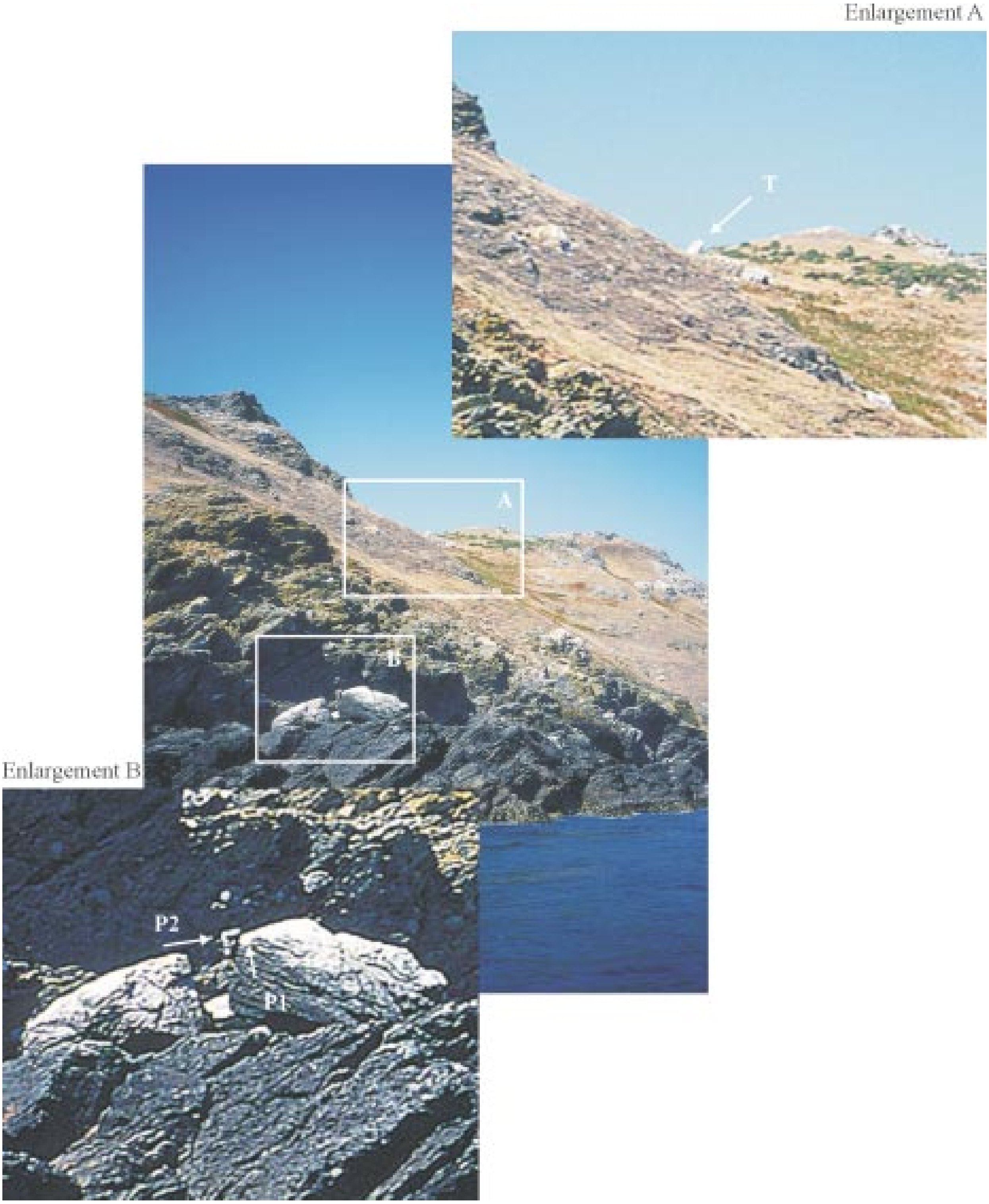


**Figure 3** Photographs of the marks at Pen Cristin on the east side of Bardsey Island. Enlargement A shows the detail of the tooth-shaped rock (T). Enlargement B shows the detail of the paint mark on the boulder (P1) in alignment with the inverted 'L' shaped mark (P2) on the short cliff face.

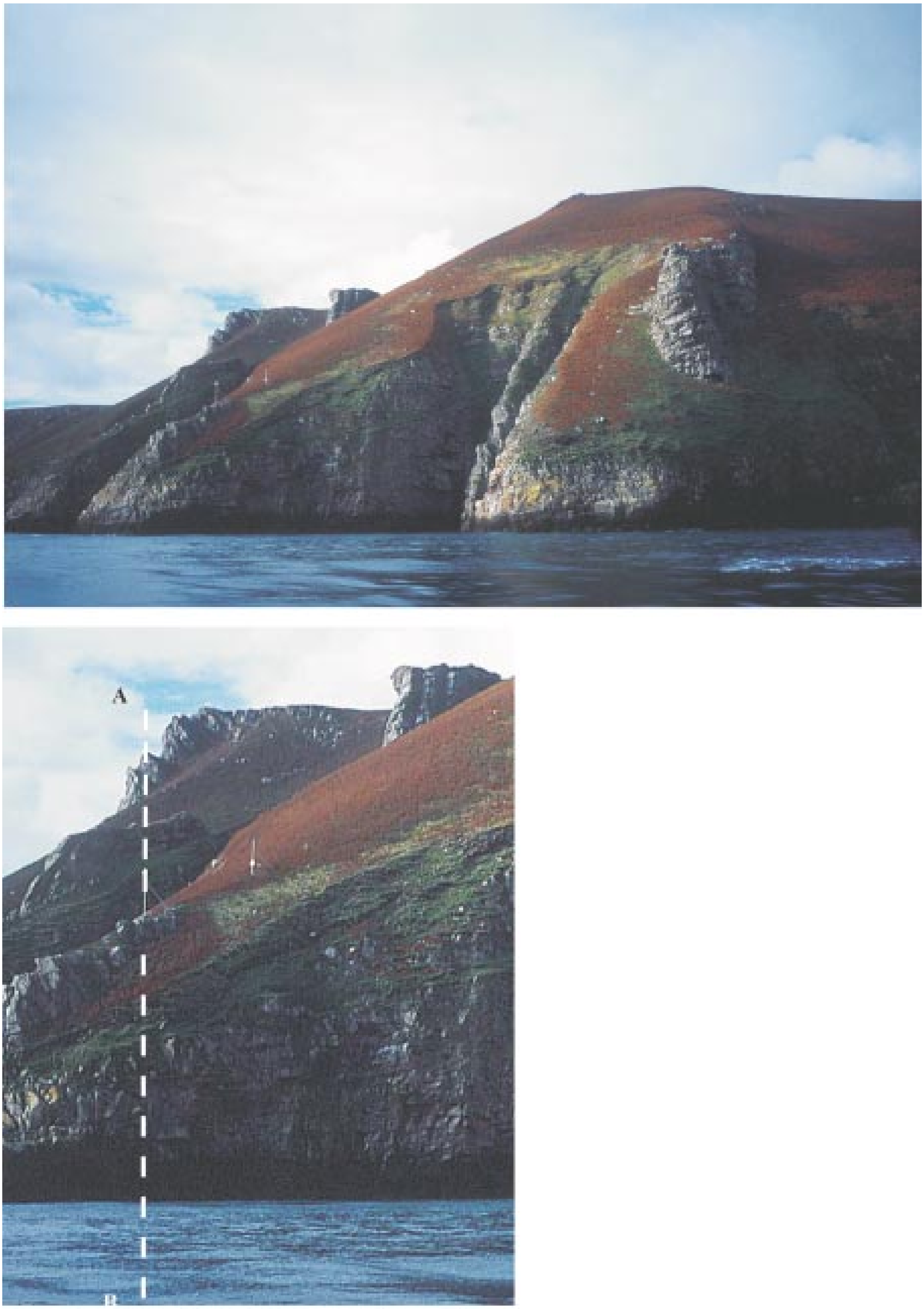


**Figure 4** General view and enlarged view of features used as part of the transit marks on east Lundy at the Knoll Pins monitoring site. Line A–B shows the alignment of the cable marker with one of the peaks in the background (Photographs by W. Sanderson).

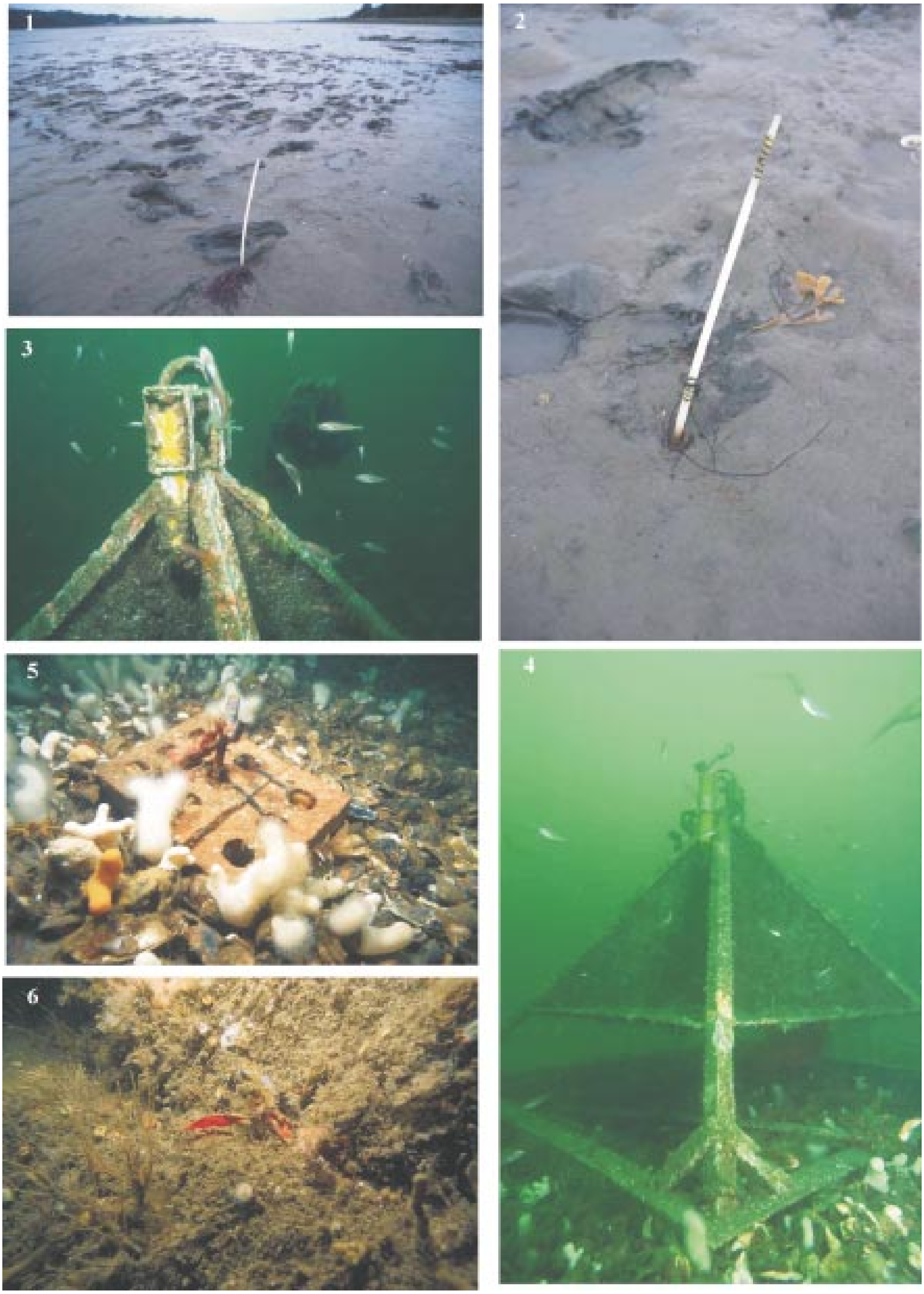


**Figure 5** Images 1 and 2 show plastic whips attached to sub-sediment surface blocks or stakes to mark the perimeter of an experimental plot. Images 3 and 4 show an acoustic transponder beacon placed on the apex of a pyramid marker on a *Modiolus modiolus* bed used to guide a diver to the marker even in poor visibility. Image 5 shows a bundle of bricks tied with cable ties fastened securely to the seabed with a 'road pin' that allows for the attachment of guidelines. Image 6 shows a piton hammered into a crack in a rock face almost obscured by epibiotic turf except for its fluorescent tape to show its whereabouts. (Photographs by Rohan Holt)

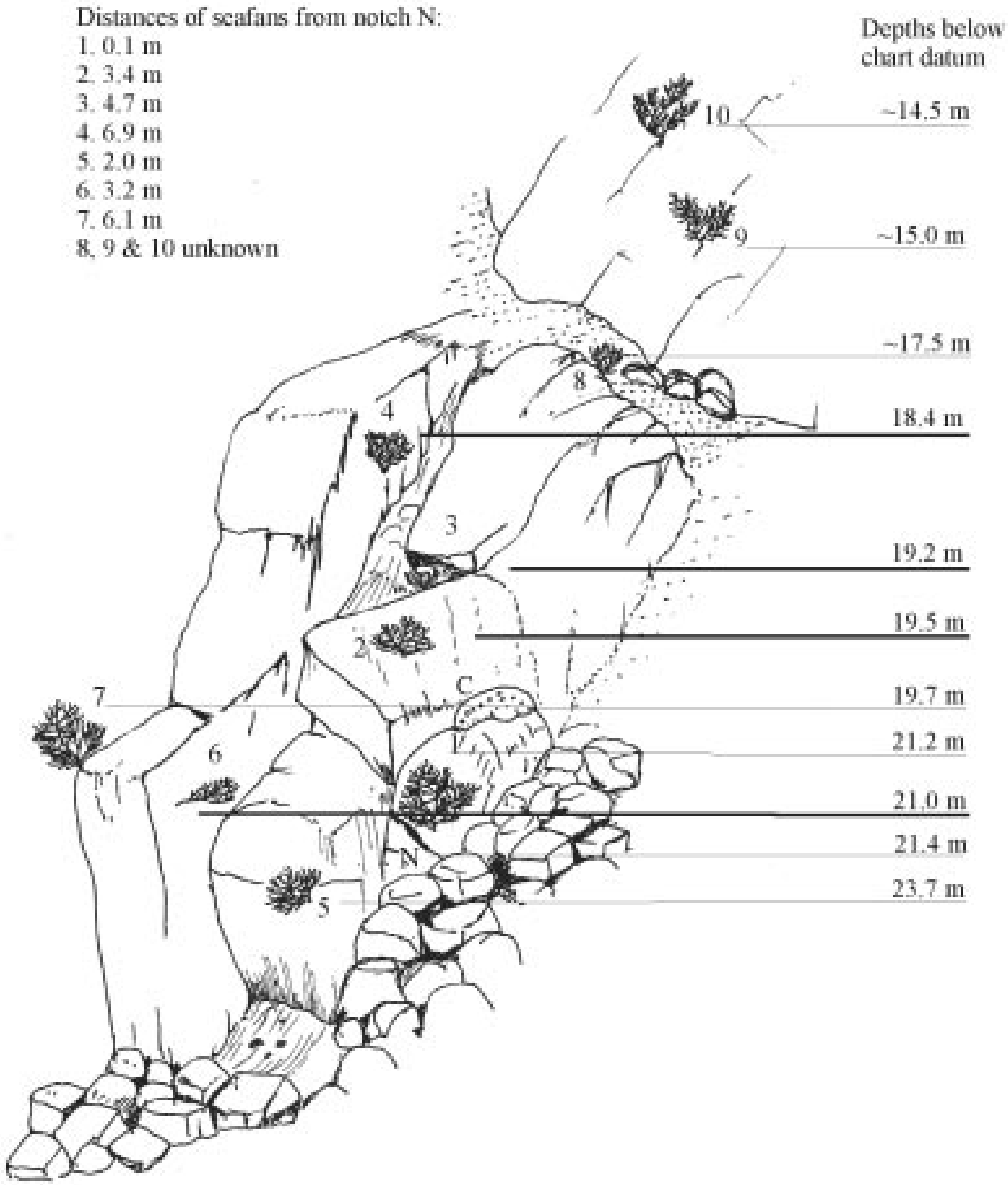


**Figure 6** A diagrammatic representation of the main features at the *Eunicella verrucosa* monitoring site at North Wall, Skomer showing the layout of the seafans in relation to a distinctive notch (N), and a conspicuous colony of the sponge *Cliona celata* (C). (Drawing by Rohan Holt adapted from drawings by K. Lock, Skomer Marine Nature Reserve)

## *Marker posts and stakes*

Sediment shore and seabed sites can be marked with a combination of *stakes, pegs* and '*cairns*' of boulders or bricks (Figure 5). Steel '*road pins*' can be driven into the sediment with a lump hammer and '*cork-screws*' (made from steel reinforcing rods wound round a post to make helix-shaped markers about 50cm long with an eye bent into the top section) can be screwed into sandy/muddy sediments. With such systems of marking, consideration needs to be given to the rate of corrosion of the markers or whether the habitat is sufficiently mobile to cover over the marker. In some circumstances it might be desirable to avoid having large conspicuous posts or rods protruding from the sediment surface, particularly in unstable or soft sediments where such markers are vulnerable to being pushed over or where they might attract unwanted attention. A 'whip' of *thick nylon line* or flexible plastic rod attached to an anchor point, such as a wooden stake or concrete block buried below the surface of the sediment, will adequately mark a position on, for example a sandy or muddy shore (Figure 5).

### *Paint marks*
Rocky substrata on the shore can be marked with oil-based paint to aid location of spot-positions or transit lines (Figure 3). Fresh coats of paint will be required periodically – perhaps each year in areas where weathering has a significant effect.

### *Guide ropes and lines*
Ropes and lines laid down on the seabed to aid diver navigation are particularly useful in the short term (e.g. during a few days of work at a site) but are prone to being snagged by fishing gear or anchors and can attract unwanted growths of fouling organisms that could influence the natural state of the site. Ropes and lines should therefore be treated as a temporary fixture which if damaged or lost will not result in losing the site. It is therefore best to consider retrieving any lines at the end of a task unless other users only rarely visit the site.

### *Distance measurements*
A tape measure can be used to accurately record distances between features on the shore or seabed and can also serve as a guide line. Very accurate distance and approximate direction can therefore be recorded if the tape is used in conjunction with a *diver's compass*. Ideally measurements should be taken from an easily identifiable reference point such as a piton or an obvious and robust natural feature such as a crevice or well-defined bedrock outcrop. This method is perhaps the best way to record the whereabouts of and relocate small features such as bolt/piton markers or individual organisms/colonies on the seabed or on the shore. An example of using tape measurements to illustrate the layout of *Eunicella verrucosa* seafans at a monitoring station at the North Wall on Skomer is shown in Figure 6 (K. Lock, Skomer MNR, pers. comm.). Waterproof diagrams of the layout of a site such as this are essential for rapid relocation of individual colonies.

## Marking and relocating offshore sites
Marking and relocating offshore sites uses many of the principles applied to inshore sites described above. The differences usually concern the increased scale of the operation due to the remoteness of the location offshore, sometimes greater depth of water and generally more exposed situations. The choice of location for an offshore site and where to place a marker depends on finding out as much as possible about the area beforehand. In water of 30–40m depth deployment of remote survey techniques (see Procedural Guideline Nos PG 1-3 for Acoustic Ground Discrimination System (AGDS), PG 1-4 sidescan sonar and PG 3-5 remote video techniques) is advisable before any expensive and time-consuming diving operations take place.

### *GPS or dGPS*
Transit marks can be used as a rough guide to bring a vessel into an approximate area, although poor surface visibility can negate their usefulness. Global Positioning System (GPS), combined with a differential signal receiver (dGPS) can provide sub-metre accuracy (see dGPS Procedural Guideline 6-1).

### *Seabed positioning using dGPS*
GPS radio-wave signals do not pass through water and therefore GPS/dGPS units cannot be modified for underwater use. Acoustic signals do, however, pass through water very well. By converting GPS radio signals into ultrasound frequency acoustic signals and vice-versa, divers deployed from a boat carrying the appropriate acoustic positioning system (APS) can be tracked on the seabed. Three transducers housed in one unit on the side of the support boat and one located immediately under the boat's dGPS antenna interrogate an acoustic beacon attached to the diver. The position of the diver is indicated on a screen in front of the diving supervisor who can mark on the same screen the exact co-ordinates of specific locations on the site. It is then straightforward to guide the diver to a precise feature on the seabed, even in poor visibility. The beacon can also be used to track the true position of towed fish during remote sensing operations and removes the need for layback calculations during post-processing of the data. Such systems can be accurate to as little as 10mm over a range of 100m. The drawback of such systems is that they are relatively expensive (£4K+), although valuable in-water time can be saved by not having to use multiple tape measurements over long distances.

### *Seabed markers: general considerations*
Structures placed on the seabed can be used to mark the precise position of an area of interest or act as a reference point on areas of seabed with few distinguishing features nearby. This avoids expensive and

time-consuming searches by divers looking for a particular feature. Factors to consider when placing a marker on a site are:

- How and where is it to be deployed? Very large objects (100kg or more) to be deployed several kilometres out to sea will require a substantial (15m+?) vessel with heavy lifting gear. What is the maximum physical size and weight of an object that can be lifted by the deck-mounted crane?
- Alternatively, can the object be constructed on the seabed?
- Is it large enough and/or conspicuous enough to be found by divers operating in poor visibility? If not, can acoustic beacons be used to aid relocation on the seabed?
- Can it be detected remotely by AGDS/sonar/echo-sounder?
- Will it move/be damaged by the worst sea conditions expected at the site? Will it require attaching to the seabed or will it stay in position if free-standing?
- If fishing gear, or similar, is deployed regularly in the area will this disturb/displace the object?
- Will its presence alter/affect the natural situation (physical and/or chemical) in such a way as to disturb the habitats and communities under investigation? How far away from the area of study will the marker have to be?
- Does the object require any form of regular maintenance?
- Is permission required (e.g. from the Crown Estate) before the marker is placed on site?
- Do other sea users need to be made aware of the presence of a marker/experimental site (e.g. through the Sea Fisheries Committees or the Hydrographic Office)?

### *Seabed marker construction*

Different working groups have constructed various designs of seabed marker in the past. They have been constructed from objects as simple as scrap engine blocks, rail carriage wheels and bundles of bricks to more elaborate structures built for a specific purpose. Many use concrete poured into old tyres (from car-sized to large tractor tyres) with a steel loop embedded into the concrete to attach ropes and lines; but note that greater volumes of concrete are required to achieve the same mass as a steel structure.

Examples of seabed markers are shown in Figure 5 (images 3, 4 and 5). The Countryside Council for Wales and the School of Ocean Science, Menai Bridge (University of Wales, Bangor) used the ‘pyramid’ design to mark sampling stations on Sarn Badrig Reef and a *Modiolus modiolus* reef off Pen Llyn, North Wales. These heavy steel ‘stations’ were constructed specifically for the attachment of the two types of *acoustic relocation devices* and were also designed to investigate whether they could provide an acoustic target for sidescan sonar.

The structures were built with a 2 x 2m square base of 15 x 8cm channel bar steel upon which a pyramid-shaped, angled steel construction stood 1.75m tall. The whole structure was weighted with an old 6-inch anchor chain bolted between mountings on the square base making the overall structure weigh approximately 500kg in air. The weighting was considered necessary to prevent the object moving with tide or wave action. The stations also had mounts for two types of acoustic beacon and a surrounding ‘cage’ for protection. The whole structure was pyramidal in design to enable fishing gear to pass over without snagging. The nature of the base was expected to enable the structure to ‘bed-in’ to the partially mobile sediment.

The stations were painted using high visibility colours to assist with initial diver relocation and each side of the structure painted with a letter to facilitate orientation when in use (although the paint was soon obscured by marine life). A sacrificial zinc anode was fitted to each station in order to retard corrosion in seawater and rope loops were secured to each corner from which distance lines could later be deployed.

### *Acoustic position markers*

*Acoustic beacons* (7815 Miniature Marker Transponders – Sonardyne International Ltd) were attached to the top of each of the ‘pyramids’ described above, although such devices could easily be attached to other structures or even pitons/bolts directly hammered into rock. Divers using the hand-held Homer-Pro *diver relocation unit* (Sonardyne International Ltd) were guided to the target beacons that emitted sound pulses in the HF frequency band from 35–55 kHz.

Once activated the Sonardyne acoustic beacons were designed to be permanently ‘on’ and listen for encoded ‘interrogation’ signals from the diver’s unit. In this mode the battery life span of the beacons was estimated to be 2 years (Sonardyne technicians, pers. comm. 1998), although lithium battery packs with double this life span are now available at a greater cost (£180 as against £17). The diver unit was designed to send out an encoded interrogation signal to the specific transponder (each has its own 'address' signal) to which the beacon was designed to reply automatically. The diver unit would then calculate the distance and direction from the beacon and display this information to the diver. The manufacturers recommended that the beacons were positioned in a vertical orientation one metre off the seabed in order to improve performance by facilitating a straight-line acoustic path between the beacon and the diver. In trials the acoustic beacons were detected from the surface at over 100m away.

Using similar acoustic technology it is also possible to set up an 'acoustic net' by positioning a network of transponders on the seabed. A receiver unit carried by a diver or submersible decodes the signals from three or more transponders simultaneously several times per second to obtain a precise position on the seabed. Such systems were developed in the offshore oil and gas industry and for marine archaeologists[2] but could be applied to seabed monitoring work where spatial orientation between features is important.

### *Maintenance implications*

The 2 kg zinc sacrificial anodes lasted only 18 months on the seabed and therefore require periodic replacement.

The transponders require periodic battery replacement. In order to avoid a situation where the marker station is left on the seabed without a transponder, and to avoid having to do more than one dive to retrieve and replace a transponder, it is important to have a fully charged spare.

## Personnel

### *Inshore/near-shore sites*

Placing marks on the shore requires only one or two people. One person can position markers on a site, although a second might be required to check the correct alignment of relevant features or help record measurements and compass bearings.

Accurate recording of subtidal site positions is normally accomplished as part of a diving or remote sampling survey. Teams of four people are usually required for diving surveys, although one person can accomplish the tasks of positioning the survey vessel over the site while another makes observations. Divers working on the seabed might have to guide the boat crew to a precise location through the use of surface marker buoys and/or underwater communication systems. Teams of four, the standard size of a diving team recommended by the Health and Safety Executive (HSE) for diving work, can co-ordinate this task.

The diver's qualifications can be an issue in this matter. Diving under the Scientific and Archaeological Approved Code of Practice (ACOP) allows for use of light tools, but heavier engineering tasks such as fixing large, heavy frameworks to the seabed might have to be carried out by divers trained to work under the Inshore Commercial Approved Code of Practice. The ACOP for commercial divers includes the requirements of suitable qualifications in the use of lifting gear and heavy engineering tasks which are not normally part of a scientific diver's training.

### *Offshore sites*

There are a number of tasks that require specialist skills:

- Constructing the markers – the 'pyramids' described above were constructed by engineering technicians. Alternative designs, such as concrete-weighted tyres, require less technical ability to construct but are nonetheless heavy.
- A suitable vessel and crew are required for the deployment of heavy objects offshore (the survey vessel *Prince Madog*, used to deploy the pyramid markers in Wales, is 28m OAL and 182 GRT. The A-frame has a 4 tonne SWL.
- 'Heavy engineering' on the seabed requires divers working under the HSE Inshore Code of Practice. This can be avoided by deploying a completed structure from a boat.
- The diving team should comprise at least four personnel. Working at depths of 30–50m requires highly experienced divers used to carrying out tasks in deep water.

2 The Archaeological Diving Unit internet site - **http://www.st-andrews.ac.uk/institutes/sims/Adu/adu.htm** provides information on acoustic and manual methods of surveying seabed features, including links to acoustic survey techniques.

## Best time of year

### *Shore and near-shore sites*

Calm weather is required for diving and is an important health and safety issue for personnel working on steep rocky shores and from boats. Summer weather tends to be more reliable, although there may be occasions where disturbance is best kept to a minimum by deploying markers during the winter. If bolts and pitons must be put in position during the winter months, it is important to consider whether dense algae or faunal turfs will obscure them during the summer.

### *Offshore sites*

Calm weather is required for diving and is an important health and safety issue for boat crews working with heavy loads suspended from winches and cranes. Because there is a significant amount of work required in preparation for deployment of most large marker structures, such an event is best planned away from periods when the weather is likely to be unsettled, such as at the equinoxes when high winds and strong currents are most likely. Deployment and diving operations are best carried out during neap tides when tidal streams are at their weakest.

## Survey brief

To record the layout of natural features and/or artificial markers and record positions above and below sea level as required.

The level of detail should be sufficient to determine the accurate whereabouts of sub-surface features to allow personnel with *no experience of the site* to find the exact location: a long-term monitoring strategy reliant upon the know-how of one or a few staff members is inherently flawed.

# Method

## Marking and relocating shore/near-shore sites

### *Intertidal sites*

The specific requirements of a monitoring exercise and the layout of a site will largely dictate the methods used to record the exact location of features. The following summarises options that should be considered (assuming the whereabouts of a feature of interest is known from previous survey information).

(1) Relate the exact location of the feature of interest to other easily recognised and permanent features on the shore, such as rocky outcrops (preferably bedrock features), very large boulders that are unlikely to move in any weather conditions or ‘permanent’ man-made features by:
   (a) taking fixed point photographs of the shore from an identifiable and repeatable position;
   (b) recording a combination of transits, distance and compass bearing measurements of the feature from a known reference point;
   (c) drawing sketches to highlight the main features.
(2) Mark the feature with a suitable tag or marker (see above) whether on a rock or sediment shore and map/photograph its exact location using methods outlined in 1 above.
(3) Use dGPS to locate a precise location on an extensive shore where nearby natural/man-made features are too far away or indistinct to use as transit marks or where positions relate to co-ordinates chosen from a map. Combine with positioning a suitable marker if possible or necessary.

### *Subtidal sites*

There are many specific ways of marking and relocating a subsurface site near to shore using combinations of the above equipment. In general terms the following tasks should be accomplished to record the positions of a site and then tested to ensure that the information is sufficiently accurate for someone with no experience of the site to return to the exact spot. The following scenario assumes that the approximate whereabouts of a feature of interest is known from previous survey information. If this is not the case, systematic underwater search techniques may have to be deployed.

(1) Divers, carrying a surface marker buoy, locate the feature underwater and tighten the buoy line so that the buoy is as perpendicular to the feature as possible. At a pre-arranged signal from the divers (e.g. pulling on the buoy line a specified number of times) the boat carefully moves into position and the surface support crew notes the GPS/dGPS position, echo-sounder depth, date and time.

(2) Sketches and/or photographs of two, preferably three, transit marks are made. Transit marks are straight lines adjoining land-based features that intersect over the position of the site (see Figure 1, Figure 3 and Figure 4). The greatest accuracy is obtained by having the intersecting lines between 60 and 120 degrees apart. For example, looking north a line drawn from the apex of a gable end of a house in the far background might line-up with a prominent rock in the foreground. This line intersects another line from the west where a triangulation point and a prominent tree are also in line. Transit marks can also be sufficiently accurate at close quarters to gauge distance along the line;. for example, when lining up an object with a mark on a cliff close behind it (see Figure 1 and Figure 3).

(3) Compass bearings to features on the nearby shore should also be recorded to supplement the transit marks. The effect of poor visibility on distant transit line features should be considered, particularly along areas of coast where low cloud or fog might regularly obscure such features.

(4) The divers should make sketches (e.g. Figure 5) supplemented with photographs of the layout of the seabed around the feature of interest, concentrating on distances, using a tape measure if appropriate, and compass directions between features that aid navigation in poor underwater visibility. The divers should also note the relative positions of fragile parts of the site (e.g. large sponge or seafan colonies) so that subsequent deployments of a shot line (i.e. a line just longer than the depth of water anticipated with a heavy weight at one end and a buoy at the other) will miss them.

(5) Guide ropes and lines can be deployed around the site to mark the whereabouts of various features and improve the efficiency of moving around the site underwater. Guide ropes can also be considered as safety features where divers can maintain physical contact with a reference point and with one another if working as a pair along a guideline.

(6) Once the first pair of divers has completed their dive, a shot line should be deployed at the site to test the accuracy of the transit marks and supporting information gathered so far.

(7) The next pair of divers descends the shot line and adjusts the position of the shot weight to its ideal position relative to the feature of interest. The surface crew can then adjust the transit marks and GPS/dGPS positions if necessary. The divers can affix bolts, pitons etc. tagged with fluorescent tape and/or coloured cable ties or labels to mark the positions of specific features or so that divers unfamiliar with the site can confirm that they have arrived in the right area in the future.

(8) As a supplement to, or instead of transit marks, patches of rock on the shore in positions that line up with other convenient features can be marked with a conspicuous coloured oil-based paint. A piton, bolt or marker post can further supplement this where paint marks are not expected to last long. Details should be added to the sketches of the transit marks and bearings taken to the paint marks/pitons on the shore from the buoyed site (Figure 1and Figure 2).

(9) Video recordings can also be taken of the underwater features as an aid to navigation.

### *Accuracy/data format*

The information gathered from the above process should be presented in such a way as to provide sufficient detail so that someone with no prior knowledge of the site can return to the precise location. In general a 'zooming-in' approach is probably best, starting with a general map of the area, then GPS or dGPS positions, transit marks and photographs of surface features, and finally a set of illustrated instructions on how to reach the feature underwater and what it looks like when you get there. The final approach should be sufficiently detailed to find a feature with dimensions of a few millimetres if required (see 'Documentation' section below).

### *Time required*

Working as a team of four, and providing the approximate position of the site is known sufficiently well to locate on one dive, most of the work can be completed in one day. Extra time should be allowed for fixing bolts and pitons and any other task that requires a moderate amount of manual work. As a rough guide, it may take more than one dive to drill holes for placing bolts in hard rock, and several (3–5?) pitons may be fixed in place in one dive if there are sufficient appropriately shaped cracks and crevices.

## Marking offshore sites

The following describes the specific order of events required to deploy and relocate the 'pyramid' described above, assuming that a target position has already been determined via other survey methods. Variations of this method can be adapted to suite other situations and marker types.

(1) The vessel carrying the marker approaches the pre-determined position using dGPS with the aerial positioned as near as possible to the crane used to deploy the structure.
(2) The acoustic beacon is fixed in position on the marker and tested to ensure it responds to the homing device (in air).
(3) Once over the target position the marker is deployed on a running cable/rope to allow recovery of the rope. A dGPS position is taken as soon as the marker is set down on the seabed.
(4) With the vessel still on site the homing device and acoustic beacon are tested by holding the homer over the side of the boat to momentarily activate the beacon to obtain a distance and direction reading.
(5) At a later date the dive team return to the recorded dGPS position.
(6) The homing device is used to activate the acoustic beacon and the boat moved to find a position as near to the beacon as possible (< 80m is acceptable in 33m of water).
(7) A weighted shot line is deployed slightly off position, so as to avoid damaging the monitoring stations, and the first pair of divers descend down it to the seabed carrying a coil of rope (length equal to the depth of water plus a half) and an inflatable lifting bag/buoy.
(8) The homer is used to guide the divers to the marker. The rope is then attached to the apex of the marker and the free end sent to the surface under the inflatable marker buoy.
(9) The surface crew attach a more substantial buoy to the rope and then record an updated position for the buoy with the line pulled as taut as possible.
(10) Transit marks are recorded for the site, backed up with photographs taken with a short telephoto lens.
(11) The marker buoy is used to allow easy site access during work at the site but once the survey work has been completed at the site the buoy line is detached from the marker.

### *Time required*

The entire process can be split into several phases:

- Manufacturing the markers can take several days to cut, weld and paint the steel sections as required. Concrete-filled tyres require at least 48 hours for the concrete to set sufficiently.
- Positioning a marker on the seabed from a suitable vessel requires travel time plus deployment time. Two ‘pyramid’ markers, as in the example above, were deployed in one day.
- The initial phase of relocating the structure by diving should take one dive. The number of dives that can be carried out during one day depends on the duration of slack water (on tide-swept sites) and the depth (with respect to decompression limits of a dive).

# Accuracy testing

It is perhaps prudent to allow some time after marking the site to return with new personnel to test the accuracy of the information. This tests the accuracy of the written record rather than the short-term memory of the personnel involved.

Once the recorded information has been used once to successfully return to a site further visits should be equally problem-free. Future visits by personnel new to the area should be possible without having to carry out extensive searches unless, for example, the acoustic beacons on the offshore structures fail for any reason.

# QA/QC

## Documentation of monitoring sites

For condition monitoring of a designated site for management purposes the duration of the work is potentially infinite. It is therefore important to provide sufficient information for, in the worst case, a competent, unfamiliar worker to be able to locate monitoring sites and stations without the assistance of a worker who is familiar with the site. Monitoring programmes that are reliant on the knowledge of individuals are insecure and the historic investment in the gathering of previous data is potentially wasted if they cannot be continued when individuals become unavailable. At Skomer Marine Nature Reserve documentation has taken the form of a file that systematically lists all the details necessary to find a site and conduct the work at them. This model is outlined here with examples drawn from several monitoring stations throughout Wales and England.

### Level 1

The first level of information for the documentation of monitoring on designated sites is a table of the different monitoring locations. At this level the table can be detail metadata such as those given in the example below (Table 1).

**Table 1** Level 1 metadata for site documentation taken from Skomer MNR (SMNR staff pers. comm. 2000)

| *Site name* | *Buoy/acoustic beacon* | *Position* | *Bearings* | *Distance from shore* | *Depth* | *Slack water times* | *Notes* |
|---|---|---|---|---|---|---|---|
| Mewstone | None | 51°43'.630N<br>5°17'.504W | 262° – Grassholm<br>179° – Skokholm Lthouse | 4–5m offshore | 15m bcd | Slack @ LW + 2.5 or HW + 3.5–4 hours | Site first marked 1994 |
| etc… | … | … | … | … | … | … | … |

### Level 2

A hard copy of the relevant chart is included showing where the monitoring station is within the designated site. Surface features and transit marks for the site are shown on drawings and photographs (e.g. Figure 1 and Figure 3).

### Level 3

In CCW each monitoring project is documented with a Conservation Management System (CMS) planning code, a description of the objective for that monitoring project and the months when the monitoring should be conducted. See Table 2 below.

**Table 2** An example of Level 3 details

| *Skomer Marine Nature Reserve* ***Eunicella verrucosa*** *population monitoring RM23/01 Feature Monitoring* | |
|---|---|
| Start date | August 1993 |
| End date | Ongoing |
| Frequency of data collection | Annual |
| Data sets collected | 6 (by 2000), no data collected in 1999 |
| Costs met by other organisations | None |
| Partner organisations | None |
| Purpose | Schedule 5 species monitoring |
| Coverage | Single cluster of sites |
| Project status | Active and ongoing |
| Project background | Monitor *Eunicella verrucosa* populations integrity. Since the Bunker survey in 1985, the population monitoring technique has been reassessed |
| Status | Six sites have been mapped in detail and are mono-photographed annually. |
| Site 1. Waybench (1993) | The Waybench site connects with the Sandy Seafan Gully site, although the gap between them requires mapping. This site also referred to as Waybench East in previous surveys. 12 colonies present on the Weybench monitoring route (although No. 9 missing since 1995). |
| Site 2. Sandy Seafan Gulley (1994) | 9 colonies monitored currently numbered 13–21. |
| Site 3. Bernie's Rocks (1993) | Includes both the Eastern (2 *Eunicella*) and Western reefs (7 *Eunicella*). |
| Site 4. The Pool (1997) etc… | … |

Level 3 details should also include details of changes to work practices, locations of files with images of, for example, each seafan colony and where slides or other images are stored (with a filing/CMS code).

It is also appropriate to include an equipment list (can be very specific to a particular task) and details of the protocol for each site, noting any peculiarities or difficulties, for example, in finding particular individual seafan colonies. Unfinished work, for example if a GPS position is required for a certain site or a particular seafan requires re-photographing through equipment failure, should also be noted here.

### *Level 4*

The finest level of detail can be presented as illustrations to facilitate navigation and lay-out of transects, travel lines or other such materials for monitoring tasks as well as indicating exactly where, for example, frame-photographs should be taken.

Collectively these levels of information should be capable of guiding unfamiliar competent persons to exact locations and to perform appropriate monitoring tasks.

## Health and safety

Diving health and safety issues are covered for diving activities in the joint agencies diving regulations (Holt 1998). All diving operations are subject to the procedures described in the Diving at Work Regulations 1997[3] and must follow the Scientific and Archaeological Approved Code of Practice[4].

3 The Diving at Work Regulations 1997 SI 1997/2776. The Stationery Office 1997. ISBN 0 11 065170 7
See: **http://www.hse.gov.uk/spd/spddivex.htm**

4 Scientific and Archaeological diving projects: The Diving at Work Regulations 1997.Approved Code of Practice and Guidance - L107. HSE Books 1998. ISBN 0 7176 1498 0.
See: **http://www.hse.gov.uk/spd/spdacop.htm - a**

There are advantages of work diving on a fixed station on the seabed as mentioned above – the dives can be planned in detail as the target depth and likely duration of the dive is known. Hence appropriate breathing gas mixes (nitrox as opposed to air if working at less than 34 m) can be tailored to the target depth to improve the decompression regime. The surface support crew also knows exactly where the divers should be during the dive. Slack water times can also be easier to predict for a small fixed site rather than a general area.

# Summary table

**Table 3** Summary of methods used to mark and relocate positions on the shore and seabed

| *Marker/ method* | *Substratum* | *Littoral (L)/ Sublittoral (S)* | *Effort of deployment – High, Medium, Low* | *Anticipated life-span* | *Accuracy of position fix – comments* |
|---|---|---|---|---|---|
| Piton | Rock | L and S | M | 2–5 years | Exact point location, although position dictated by availability of suitable cracks. |
| Eye bolts (drilled) | Rock | L and S | M | 2–5 years (more if stainless steel) | Exact point location, although difficult to fix in very hard rock. |
| Eye bolts (epoxy resin fixed) | Rock | L and S | L | 2–5 years + | Exact point location dictated by availability of suitable cracks and crevices or ability to drill. |
| Glued-on markers | Rock | L and S | L | 1–2 years | Exact point location. Prone to being dislodged. |
| Drilled holes | Rock | L and S | M | 10 years + depending on size | Exact point location. Technically simpler on shore than underwater. Can fill up, erode or be overgrown |
| Paint marks | Rock | L and S | L | 2–3 years | Exact point location or used as part of transit mark. Requires regular maintenance. |
| Wooden/ plastic/ metal Posts and 'corkscrews' | Sediment | L and S | L | >2–3 years | Small posts can be used to mark exact location (e.g. quadrat position). Larger posts used in marking transit lines or adjacent to sampling points. Not suitable for highly mobile sediment. |
| Sub-sediment anchored markers | Sediment | L and S | L | ? >2 years | Exact point location, but disturbance of sediment required to put in place. Mark out quadrat positions in sediment. Not suitable for highly mobile sediment. |
| Ropes and lines | Any | L? and S | L | Temporary Depends on battery life (2 years +) | Used for guidance to exact location. |
| Acoustic beacons | Need fixing in place | S | M | ? >5 years with regular maintenance | Exact point location, although requires stable anchor point. |
| Steel seabed marker, e.g. 'pyramid' | Best on sediment | S | H | | Exact location, although sampling points best positioned away from main structure. Best used in conjunction with acoustic beacon + dGPS. Potential attachment point for other instrumentation. |

| *Marker/ method* | *Substratum* | *Littoral (L)/ Sublittoral (S)* | *Effort of deployment – High, Medium, Low* | *Anticipated life-span* | *Accuracy of position fix – comments* |
|---|---|---|---|---|---|
| Concrete blocks | Best on level seabed | S | H | ? >10 years | Exact location, although sampling points best positioned away from main structure. Best used in conjunction with acoustic beacon + dGPS. Potential attachment point for other instrumentation. |
| Boulder/ brick cairns (may be pinned in position) | Best on level seabed | S | L | ? >1 year depending on depth and disturbance | Exact location, although sampling points best positioned ~ 0.5 m away. |
| Transit marks | Any | L and S | L | Considerable if features used are permanent | Can be accurate to approximately 2m x 2m depending on distance from transit features |
| Photographs and drawings of features | Any | L and S | L | Considerable if features used are likely to stay in position. | Exact location or simply to indicate that the surveyor is in the proximity of the sampling site. |
| GPS | Any | L and sea surface | L | Life span of the satellite system? | Sub 15m or less for non-differential unit |
| dGPS | Any | L and S | L | Life span of the satellite system? | Sub 1m or less. For S, an acoustic link to submersible position finder is possible. |

# References


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# Procedural Guideline No. 6-3 Specimen collection, preservation and storage

Emily Strong[1] and Caroline Turnbull[2]

## Background

A reference set of specimens for each SAC will provide an important permanent record of the species recorded. Specimen collections provide an important quality control mechanism to ensure consistent identification. Specimens preserved should include any unusual or rare species, species found outside their known distributional limit, specimens of doubtful identification and species of uncertain taxonomic status. A collection of the more common species would also be useful for training and familiarisation of field staff on repeat visits.

## Purpose

To provide a consistent, permanent record of species from a site and a reference for future work. This can aid the monitoring of long-term changes in community structure.

### Advantages

- Provides a permanent record of species at a site
- Provides a reference collection to refer and monitor long-term change
- Can be done alongside other faunal collection, e.g. quantitative sampling of sediment biotopes

### Disadvantages

- Requires a high level of expertise in identification
- Requires room for storage and cataloguing
- Hand sorting of animals from sediment and debris is time-consuming and can result in damage of specimens
- Uses toxic chemicals
- To gain a comprehensive list of species for an area will require a considerable amount of time and money since the task is quite labour intensive

## Logistics

### Equipment

Table 1 gives a general list of equipment that will be needed for specimen collection and preservation. However, further specialist equipment may be needed depending on the type of substrata being surveyed, and whether the site is intertidal or subtidal.

1 English Nature, Northminster House, Peterborough, PE1 1UA.
2 Joint Nature Conservation Committee, Monkstone House, City Road, Peterborough, PE1 1JY.

| *Field* | *Laboratory* |
|---|---|
| Containers: bottles, tubes and bags | Chemicals for relaxing, fixing and preserving |
| Collecting instruments | Compound microscope |
| Sediment corers | Dissection microscope |
| Dishes | Mounted needle/tweezers |
| Lenses | Labelling material |
| Photography equipment | |

For further details on equipment please refer to Lincoln and Sheals (1979).

### Personnel

Personnel will need specialist identification skills and may need to be accredited, e.g. NMBAQC for sediment specimens.

## Method

### Field collection

#### *Intertidal macrofauna collection*

Collections should be made during a spring tide. Care should be taken to examine the shore thoroughly as many organisms retreat into crevices at low tide, especially when this coincides with daylight.

Procedures for rock substrata:

- Non-sessile animals which are large enough to see by eye or hand lens are picked off by hand or blunt forceps
- Sessile animals should be taken with the small piece of rock or seaweed to which they are attached
- Displace the seaweed to reveal motile fauna
- Turn over boulders to expose the fauna beneath them
- Collect a variety of seaweed to be examined thoroughly at the laboratory
- Animals in rock crevices may be induced to release by squirting with a weak solution of formalin, or if necessary obtained by breaking open the crevice with crowbar
- Collect fauna in rock pools using a fine meshed hand net and a wide-bore pipette
- Use a long handled scrape net for steep rock faces and other relatively flat surfaces

For further information on collecting fish in rockpools see Wilding *et al.* (2000a).
Procedures for sediment substrata:

- Turn over larger cobbles and boulders to expose the fauna beneath them
- Dig out or core sections of sediment for sieving back at the laboratory
- Use cores collected for community sampling to eliminate repetition and reduce the quantity of material removed from the shore

Puddle sediment in sieves as swirling of sediment will damage delicate specimens.

#### *Meiobenthic infauna collection*

Sediment substrata:

- When tide is out dig a small pit in sediment (2–3m)with a number of channels radiating from it for a distance of 2–3m. Allow water to accumulate in the pit and then filter off free swimming animals with a fine sieve (62μm pore diameter)
- Take a small core of sediment to sample less active and sessile meiofauna. A number of techniques can be used for separating the animals (see Lincoln and Sheals 1979 for details)

### Subtidal benthic fauna collection

*Rocky substrata* The same methods as detailed above for intertidal rock substratum can be used by divers to remove fauna and flora from submerged rock. The use of anaesthetic to displace organisms may be widely employed in the subtidal zone since time is of greater importance and this may facilitate faster collection. Divers may also wish to use a 'slurp gun' (Lincoln and Sheals 1979) to suck fauna out of crevices.

*Sediment substrata* Divers may employ suction sampling to collect sediment infauna (see Rostron 2000). Epifauna and flora can be hand-collected but the diver will be limited to flora and relatively slow-moving or sessile fauna.

Dredging and trawling can be employed to collect epifauna remotely (see Wilding *et al.* 2000b) although individuals are often damaged by mechanical abrasion.

Grabs and corers can be employed to collect infauna remotely (see Thomas 2000).

### Plankton collection

To ensure that a cross-section of the plankton community in an area is sampled, sampling should occur at several different depths. If a thermocline is present then sampling should occur both above and below the thermocline. Either a tow-net or Hansen net can be used to collect a general plankton sample. Consideration should be given to the mesh size of the plankton net with regard to what minimum body size of plankton is to be sampled.

### Special considerations for algae collection

It is important to collect a representative sample of specimens (seasonally), being careful to collect the entire plant (including holdfast) as well as representative plants from various habitats, noting information about the habitat for the label.

Crustose coralline algae should be taken with the rock they are attached to, so as to prevent damage to the specimen (further information on coralline algae collection can be found at **http://www.botany.uwc.ac.za/clines/** ).

## Laboratory preservation of fauna

Many fauna are highly contractile and need to be relaxed with an anaesthetic before death and fixation. Anaesthetisation should not be prolonged since it can cause tissue breakdown.

The process of fixation stabilises the proteins in tissue so that after death and subsequent treatment, the tissues generally retain the form they held when alive. The required fixative varies between organisms and also depends on what the tissue will be used for. The treatments given below are for specimens which are to be preserved whole and held in a collection.

Preservation by fluid allows the material to be stored indefinitely without seriously distorting the specimen or destroying the tissue. It is not a substitute for fixation and should be considered as a post-fixation process.

Table 2 summarises typical treatments for invertebrate anaesthetisation, fixation and preservation; for a more comprehensive list of taxa and further information see the National Museum of Natural History, Smithsonian Institution (**http://nmnhwww.si.edu/iz/usap/usapspec.html**)

**Table 2** Typical treatments for invertebrate anaesthetisation, fixation and preservation

| *General taxa* | *Specific taxa* | *Relaxing agent* | *Fixative solution* | *Wash solution* | *Final solution preservative* |
|---|---|---|---|---|---|
| Porifera | – | n/a | 10% formalin sea water buffered by methenamine | 70–80% EtOH change twice | 70–80% EtOH |
| Cnidaria | Anthozoa | $MgCl_2$ (c. 7%) | 6–10% phosphate buffered formalin | 30%, 50%, 70% EtOH | 70%EtOH |
| | Hydrozoa | $MgCl_2$ (c. 7%) | 4% phosphate buffered formalin | 30%, 50%, 70% EtOH | 70% EtOH |
| Bryozoa | – | $MgCl_2$ (c. 7%) | 5% phosphate buffered formalin | 30%, 50%, 70% EtOH | 70% EtOH |
| Annelida | Polychaeta, Oligochaeta and Hirudinea | $MgCl_2$ (c. 7%) | 10% phosphate buffered formalin in seawater | 30%, 50%, 70% EtOH | 70%EtOH |
| Crustacea | Decapoda and other larger crustaceans | $MgCl_2$ (c. 7%) or oil of cloves | 5–10% phosphate buffered formalin in seawater or 75% EtOH | 50%, 70% EtOH | 70%EtOH |
| | Ostracoda, Copepoda, Branchiopoda and Amphopoda | $MgCl_2$ (c. 7%) | 4–10% phosphate buffered formalin in sea water or 70% EtOH (Ostracoda only) | – | 70% EtOH |
| Mollusca | Bivalvia | $MgCl_2$ (c. 7%) | 10% phosphate buffered formalin or 70% EtOH | 30%, 50%, 70% EtOH | 70% EtOH |
| | Gastropoda | $MgCl_2$ (c. 7%) | 10% phosphate buffered formalin | 30%, 50%, 70% EtOH | 70% EtOH |
| | Polyplacophora and Monoplacophora | $MgCl_2$ (c. 7%) | 10% phosphate buffered formalin | 30%, 50%, 70% EtOH | 70%EtOH |
| Echinodermata | Ophuiroidea | $MgCl_2$ (c. 7%) | 70–75% EtOH | n/a | 70% EtOH |
| | Holothuroidea, Asteroidea and Echinoidea | $MgCl_2$ (c. 7%) | 70–75% EtOH | n/a | 70% EtOH |
| | Crinoidea | $MgCl_2$ (c. 7%) | 90% EtOH (hold arms downwards) | – | 70% EtOH |
| Urochordata | Ascidiacea | $MgCl_2$ (c. 7%) | 10% phosphate buffered formalin | n/a | 70% EtOH |

### Preservation of flora

Specimens can be preserved either through desiccation and pressing or by placement in a preservative solution. However, the first two steps are the same for both procedures.

- Fixation: colour of specimens is best preserved by fixing in 3–5 % buffered formalin seawater away from direct sunlight. Deterioration of algae occurs quickly and therefore it is best to carry out fixation in the field.
- Preparing the specimen: specimens should be rinsed free of any sand/debris using tap water, artefacts removed which are not part of the specimen, and holdfasts split if they are too thick to be pressed.

#### *Drying specimens*

- Pressing fleshy seaweeds: spread seaweed out in a tray of fresh clean seawater. Note details in pencil of location, collector, date and identification if possible, on stiff white cartridge paper of suitable size. Float specimens onto paper, arrange plant and remove paper from tray, allowing excess water to drain away. Cover plant with an absorbent liner, and place between dry blotting paper or newspaper and compress in a seaweed press. Change drying paper after 24 hours and again after 2–3 days. Specimens should be dry after about 1 week.
- Coralline algae: soak fixed specimens in 40% glycerin in 3% buffered formalin seawater. Then dry and place in box.

#### *Preserving specimens in liquid*

- Fleshy specimens should be preserved in 70% EtOH after the fixative has been rinsed off with tap water.
- Coralline algae should be preserved in 70% ethanol and 10% glycerol.

The National Museum of Natural History, Smithsonian Institution (**http://www.nmnh.si.edu/botany/projects/algae/Alg-CoPr.htm**) comprehensively covers further information on the different preservatives and general information on algae collection and preservation. For specific information on coralline algae preservation refer to **http://www.botany.uwc.ac.za/clines/colpres.htm** .

## Data analysis

Use standard taxonomic guides.

## Accuracy testing

The accuracy of the collection depends on the correct identification of the specimens. This in turn depends on the experience of the identifier and also the care taken with preparing specimens. Quality of specimens can be affected by the method of extraction, transportation and laboratory processing.

## QA/QC

To ensure that the quality of specimens collected is high, collectors should be made aware of the importance of removing an intact specimen. To this end, sufficient training should be given in the use of equipment for the removal of specimens, e.g. the ‘slurp gun’. Care should be taken when sieving fauna from sediment and large rocks and fauna should be removed before the sediment is agitated. This should reduce damage to specimens.

Correct use of chemicals is important for the preservation of intact specimens. Workers should be aware that fixative solutions that are too weak will not protect tissue adequately and similarly preservative solutions must be strong enough to prevent rotting. Containers should be checked to ensure that they are airtight since neglect of this can cause specimens to go dry and rot.

Identification of specimens and labels should be checked by an experienced individual. If the identifier is unsure which species the specimen belongs to, this should be noted on the label and sent to someone who can identify it.

### Labelling

Specimens should be labelled directly with name and code. All specimens returned to the MNCR for deposition in museums should be properly labelled, in indian ink and on paper suitable for storage in alcohol. Temporary field labels should be retained with the specimen.

- Species name and authority (according to Howson and Picton 1997)
- Determinor
- Date determined
- Collector
- Date collected
- Location (site name)
- Area (including county or region)
- OS grid reference or latitute and longitude
- Height or depth collected (in metres from chart datum)
- Habitat details (e.g. under boulder; clean shell gravel)

Where possible, specimens should be identified to species level. Where the identification is uncertain, this should be indicated, with notes on the label where appropriate.

## Storage

Wet specimens are best kept in glass airtight containers, although glass jars with ground glass stoppers, or Copenhagen glass jars with plastic caps are very expensive. Small specimens can adequately be stored in glass soda vials with airtight plastic caps. Larger specimens can be stored more cheaply in polystyrene screw cap jars (particularly suitable for fieldwork, as these are light and non-breakable), though alcohol tends to evaporate from these with time.

## Health and safety

The use of chemicals in the field should be limited and COSHH procedures should be followed. Many of the chemicals used in the preservation process may be listed as environmentally hazardous. It is suggested that all work with chemical solutions should be conducted in a fume cupboard, and that lab personnel wear appropriate eye protection, gloves and a chemical apron. Follow COSHH procedures.

## References

Howson, C M and Picton, B E (1997) *The species directory of the marine fauna and flora of the British Isles and surrounding seas.* Ulster Museum and The Marine Conservation Society, Belfast and Ross-on-Wye.

Lincoln, R J and Sheals, J G (1979) *Invertebrate animals – Collection and Preservation.* British Museum (Natural History) and Cambridge University Press.

### References to other procedural guidelines in this volume

Procedural Guideline No. 3-9: Thomas, N (2000) Quantitative sampling of sublittoral sediment biotopes and species using remote-operated grabs.

Procedural Guideline No. 3-10: Rostron, D M (2000) Sampling marine benthos using suction sampling.

Procedural Guideline No. 4-3: Wilding, T A, Gibson, R N and Sayer, M D J (2000) Sampling benthic and demersal fish populations on sediments.

Procedural Guideline No. 4-4: Wilding, T A, Gibson, R N and Sayer, M D J (2000) Sampling fish in rockpools.

## Related websites

**http://www.botany.uwc.ac.za/clines/** Coralline algae – methods of preservation and collection

**http://www.nmnh.si.edu/botany/projects/algae/Alg-CoPr.htm**) National Museum of Natural History, Smithsonian Institution – algae collection and preservation techniques

**http://nmnhwww.si.edu/iz/usap/usapspec.html** National Museum of Natural History, Smithsonian Institution – invertebrate specimen processing procedures

**http://www.nhm.ac.uk** Natural History Museum, London

**http://www.ulstermuseum.org.uk** The Ulster Museum – see reference to Howson and Picton above.