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Marine Monitoring Handbook
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UK Marine
SACs Project

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5 Advice on selecting appropriate monitoring techniques

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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.

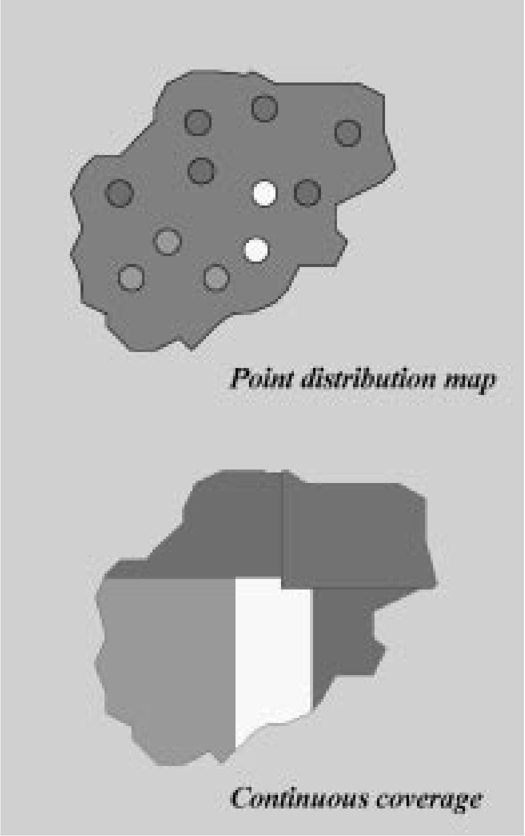

Figure 5-1 Diagrammatic representation of point distribution and continuous coverage maps of the biotopes present within a sandbank

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.

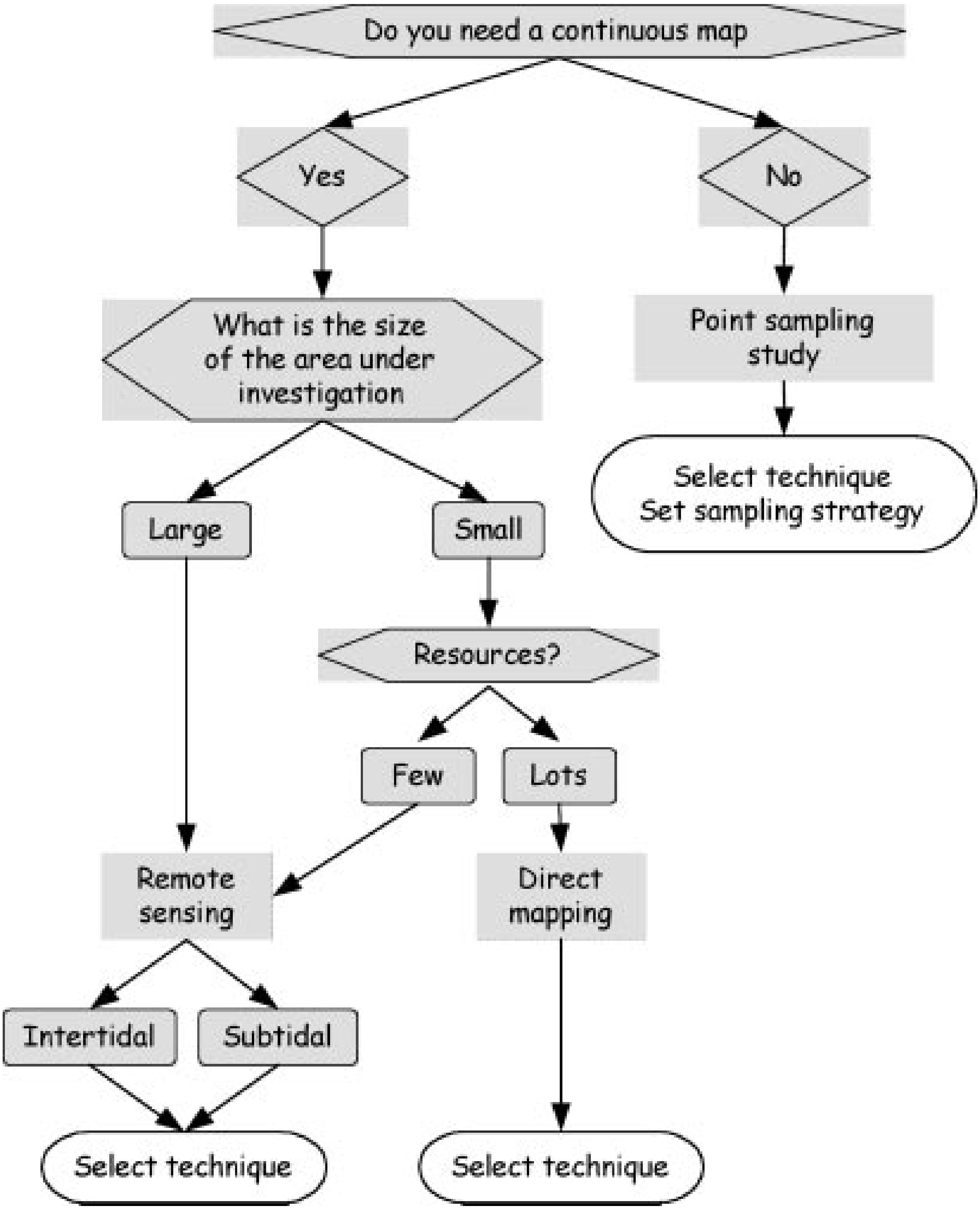

Figure 5-2 A decision tree outlining some important questions to determine the appropriate techniques for a spatial investigation

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 4 – IKONOS	8–21 spatial 24-96 hyperspectral	1	1

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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) 1:50,000 (SPOT) 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) 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. Penetration through water is affected by the prevailing turbidity and tidal state.	Prevailing atmospheric conditions affect imagery and will compromise automated classification. 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. 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. 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. An understanding of the ecosystem under investigation is helpful. 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. An understanding of the ecosystem under investigation is helpful. 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. An understanding of the ecosystem under investigation is helpful. 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. Operators must have a basic understanding of geographic information systems for digitising and analysis.
Key points	Penetration through water is dependent on prevailing conditions. At present, satellite-based remote sensing does not provide a reliable method for monitoring changes in marine habitats. Field validation is essential for accurate classification. Satellite imagery can be used for broad intertidal feature mapping. Image capture may not correspond to low water. 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. The use of airborne MSS for monitoring has not been fully evaluated. Field validation is essential for accurate classification. The digital, multispectral nature of the imagery offers the potential for other analyses – for example, vegetation changes. Image capture and associated field visits must occur at the same time of year.	Penetration through water is dependent on prevailing conditions. Good quality, overlapping, vertical, colour photographs recorded at low water are essential. Image capture and associated field visits must occur at the same time of year. Digitising pictures is a slow and complex process. 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. Surveyors must work to a consistent standard to ensure accuracy and repeatability between field visits. Field visits must occur at the same time of year, particularly when using aerial photographs. 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. Broad-scale subtidal habitat/biotope complex mapping. Providing information to stratify more detailed sampling.	Rapidly assessing the habitat over a large area. Establishing a detailed baseline for monitoring large areas. Monitoring changes in habitat extent.	Rapidly assessing the habitat resource over a large area. Establishing a baseline for monitoring. Monitoring broad scale changes in habitat and broad biotope extent. Monitoring changes in bathymetry/topographical structure.	Establishing a baseline for monitoring. Monitoring changes in habitat and broad biotope extent. Identifying the location of boundaries between habitat/biotope classes.	Providing a relatively rapid inventory of biological resources in an area. Establishing a baseline for monitoring. Monitoring broad scale changes in biotope distribution. Identifying the relative proportions of biotopes throughout an area.
Rate of coverage[r,6]	Broad scale survey: 10km^2/hr 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'. Inter-operator subjectivity creates problems for repeat studies.	Automated classification possible but improved with input from an 'expert eye'. Data are qualitative and this inter-operator subjectivity creates problems for repeat studies.	Automated classification possible but improved with input from an 'expert eye'. Inter-operator subjectivity creates problems for repeat studies.	Reasonable provided the surveyors are adequately trained in sample classification and mapping techniques. Inter-operator subjectivity creates problems for repeat studies.	Reasonable provided the surveyors are adequately trained in sample classification and mapping techniques. Inter-operator subjectivity creates problems for repeat studies.
Spatial resolution	'Along track' resolution varies with depth/speed: typically 2–3m. 15° beam will insonify 7m radius circle at 30m depth. Overall realistic minimum is 20 x 20m. Measurement area (30m) 200m^2	Frequency/range dependent[7] –10cm at 50m range (100m swath); 30cm at 150m range. Along track – typically 2-3m. Measurement area 10–1000m.	Frequency/range/distance from vessel dependent: typically 30cm at nadir (below vessel) Along track – typically 0.3m. Measurement area 10–1000m.	'Along track' resolution will be <10cm within the field of view. Measurement area 0.25–20m^2.	Dependent on sampling density but unlikely to be <20 x 20m. Individual sample resolution will depend on the sampling device – typically 0.1 m^2.

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[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. Boat speed affects sonar signal. Features between track lines will be missed – data interpolation will give a misleading image. 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. 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. Features between track lines will be missed – data interpolation will give a misleading image. 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. Small, rare habitat types can be over/under estimated if areas are calculated from maps using sampling techniques. Features between samples points will be missed.
Expertise	Experienced field operators are required although training is straightforward. Data analysis requires detailed knowledge of computer hardware and software. An understanding of the ecosystem under investigation is necessary.	Experienced field operators with a high degree of technical competence are required. Image classification requires detailed knowledge of computer hardware and software. An understanding of the ecosystem under investigation is necessary.	Experienced field operators with a high degree of technical competence are required. Image classification requires detailed knowledge of computer hardware and software. 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. 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. Track-based approach – inter-track spacing will affect resolution. Coverage is not 100% and interpolation is necessary to predict inter-track areas. Ambiguous sample classification will degrade the quality of the final maps.	The uses of side scan sonar for monitoring has not been fully evaluated. Qualitative data requiring expert interpretation. Can achieve 100% coverage giving near photo-quality images under optimal conditions. Select the appropriate frequency for depth/spatial resolution. No bathymetry information. Field validation is essential for accurate classification.	Provides detailed bathymetric data for topographic mapping. The use of swath sonar for monitoring has not been fully evaluated. Can achieve 100% coverage. Outputs include detailed bathymetry and topographic models. Inferometric systems also give side scan output. Select the appropriate frequency for depth/spatial resolution. Field validation is essential for accurate classification.	Gives a positive identification of seabed features. A slow technique only suited to small areas. Many problems with towing a camera across the seabed: risk damage from rock outcrops, the camera can damage fragile habitats/communities Track-based approach – inter-track spacing will affect resolution. Coverage is not 100% and interpolation is necessary to predict inter-track areas.	Gives a positive identification of seabed features. Sample classification must work to a consistent standard to ensure accuracy and repeatability between field visits. 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).

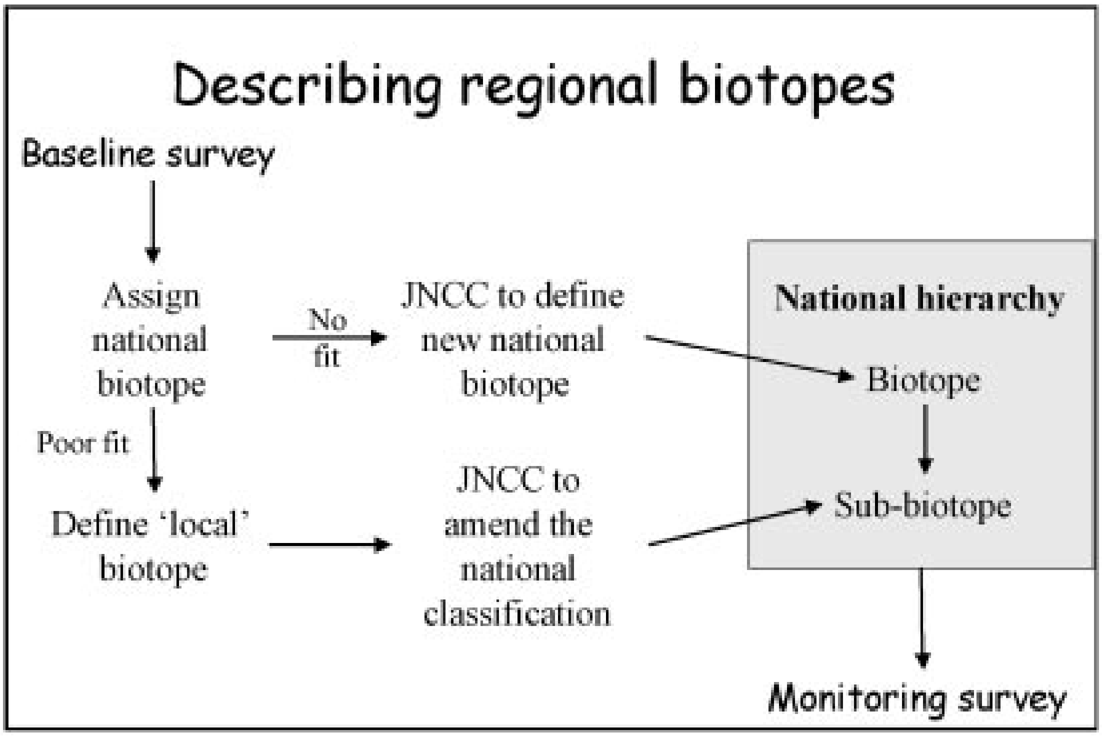

Figure 5-3 An approach to achieve consistency in defining regional biotopes

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.

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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 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	

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

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[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 Post-survey identification costs are limited Limited identification of sediment biotopes Provides quantitative information on species abundance or species richness Using photographs and/or video can provide a permanent record	A rapid method for monitoring at low cost No post-survey identification costs Limited data recorded and biotope assignment relies on the experience of the surveyor *In situ* identification QA/QC problems, and no option for future reanalysis of results Limited identification of certain sediment biotopes	Relatively slow rate of coverage but high accuracy Post survey costs high; also a three stage method of survey, identification and interpretation Provides quantitative information on species abundance, species richness and sediment structure 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 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) Operating in restricted or hazardous environments such as caves	Identifying biotopes at all depths on unconsolidated sediments Collecting samples for sediment analysis and enumeration of infaunal communities	Identifying sediment biotopes at all depths Identifying epibenthic species on a level seabed 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 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 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. Ideal towing speed is 0.3–1km/hr^{-1} Scoring the video takes approximately 2½ times the length of the recording	A two-person team (plus boat and crew) can complete 15 sites per day. Flight time depends on data required[20] 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] 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 Ideal towing speed is <3kmhr^{-1}, each tow should last a minimum of 10 mins 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) Standardise recording method Can determine position on the seabed	Difficult to standardise sampling area Difficult to accurately determine position on seabed without expensive ancillary equipment	Can standardise area if 'field of view' is known Can take many random samples from single tow Difficult to accurately determine position on seabed without expensive ancillary equipment	Can standardise area if the flight technique is calibrated over a known area Difficult to accurately determine position on seabed without expensive ancillary equipment	Accurately standardise sampling area Standardise recording method Can determine position on the seabed	Can standardise the area sampled Standardise recording method Difficult to accurately determine position on seabed without expensive ancillary equipment

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

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[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] dGPS positioning device, preferably with a 'current position'[26] recording function	Vessel suitable for local sea conditions, preferably with winch Power supply dGPS navigation system with continuous logging[27]	Vessel suitable for local sea conditions, with winch, and capable of towing at slow speed Power supply dGPS navigation system with continuous logging[27]	Vessel suitable for local sea conditions, dry working area Power supply dGPS positioning device, preferably with a 'current position'[26] recording function	Vessel suitable for local sea conditions, with 'A' or lifting arm and winch dGPS positioning device, preferably with a 'current position'[26] recording function 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 dGPS navigation system with continuous logging[27]
Key Points	Identification of some sediment biotopes requires infaunal data Relatively slow rate of coverage but high accuracy Can record quantitative information on species abundance or species richness Using a video can provide a permanent record	Permanent record of each sample Expensive equipment Digital video systems offer improved resolution and freeze frame capability Must synchronise time on video with survey time Risk of damage in rugged habitats Speed of camera over the seabed is critical to the final resolution Can damage fragile habitats	Permanent record of each sample Very expensive equipment Limited choice of vessel and environment: can only be used on a level seabed, free from obstructions Established technique that can provide quantitative data Can damage fragile habitats	Permanent record of each sample Very expensive equipment Pilot must be trained for biological recording 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] Can record quantitative information on species abundance or species richness, and sediment structure Processing and analysis of samples can be expensive and time-consuming Cameras can be attached to the grab to record epibenthic organisms	Data are not quantitative Difficult to link epibenthic species to a biotope Dredges can take a deeper 'bite' into sediment than grabs and so sample deep burrowing and/or larger organisms

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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[z] 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

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[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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