JOINT NATURE CONSERVATION COMMITTEE

Marine Monitoring Handbook
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Edited by Jon Davies (senior editor), John Baxter, Martin Bradley, David Connor, Janet Khan, Eleanor Murray, William Sanderson, Caroline Turnbull and Malcolm Vincent

UK Marine SACs Project

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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.

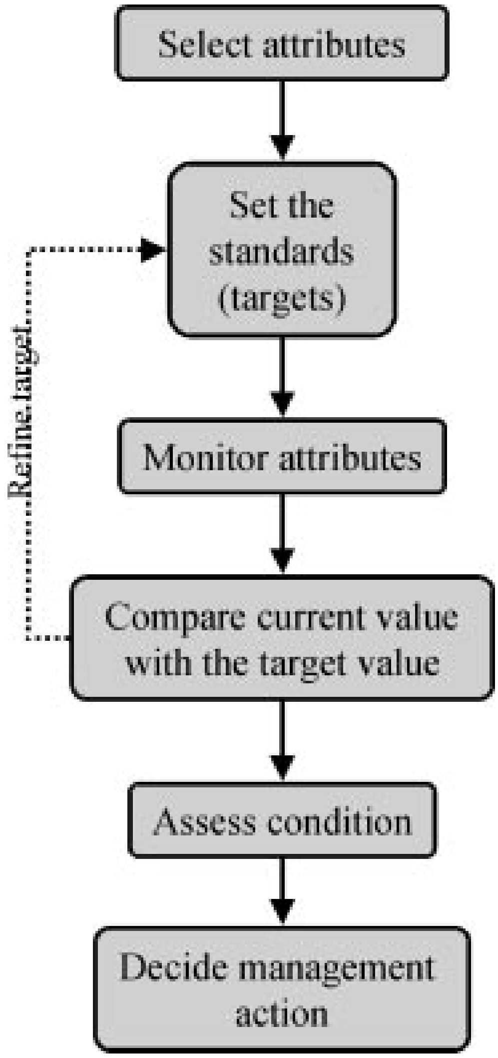


Figure 2-1 Summary of the SAC monitoring process

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.

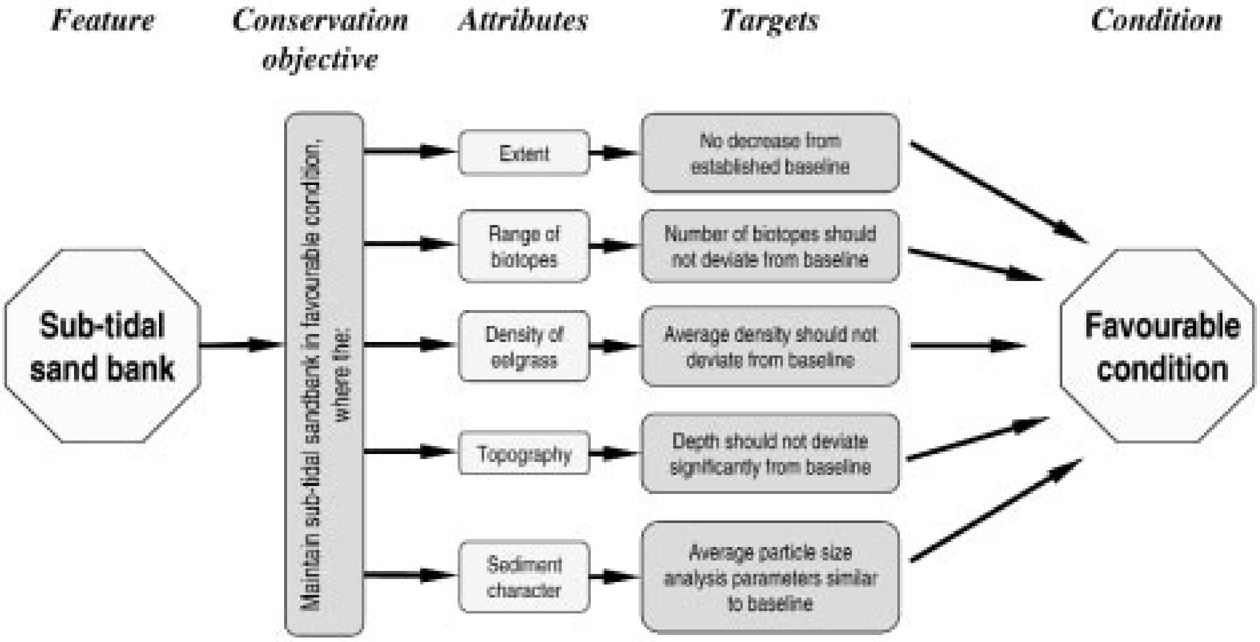


Figure 2-2 A hypothetical example of a feature and its conservation objective, showing the attributes and targets (adapted from Ecoscope 2000a).[c] This diagram will also apply to a sub-feature (see Section 1).

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.

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]

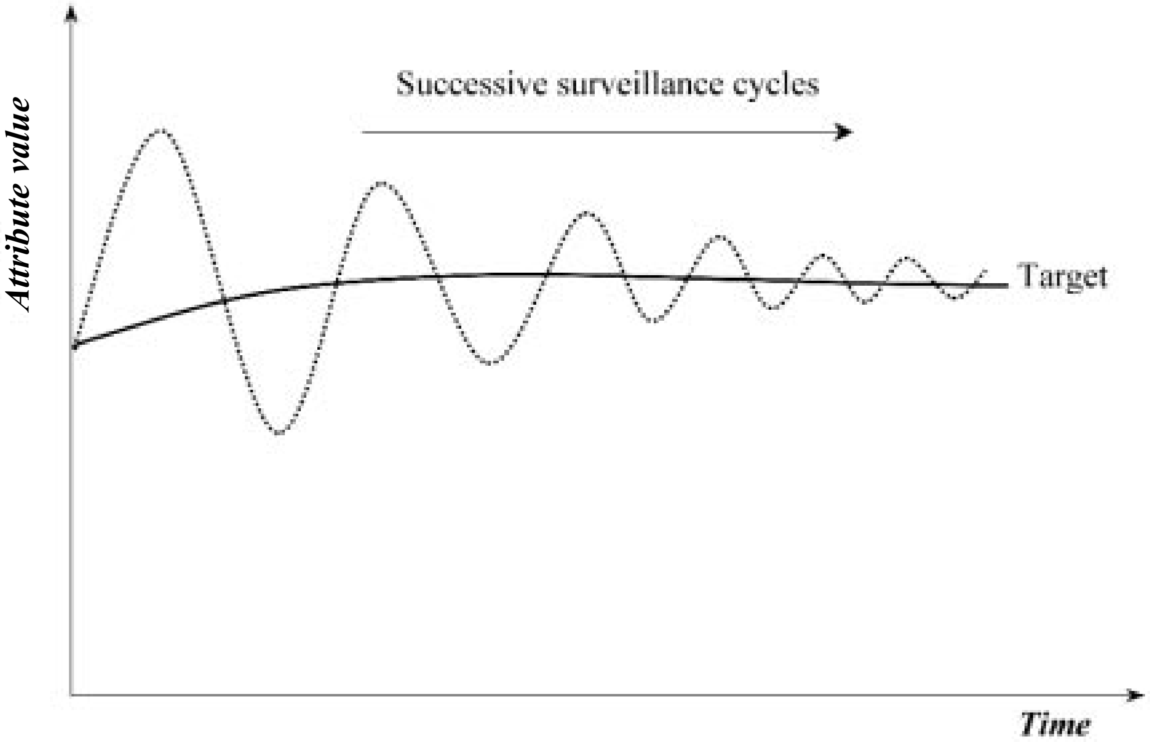


Figure 2-3 Hypothetical example of how an attribute's target value may be refined over time. If the value fluctuates, successive surveillance (or possibly monitoring) cycles enable a more accurate determination of the confidence limits (dashed line) and hence the target value (solid line). Clearly, it 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.

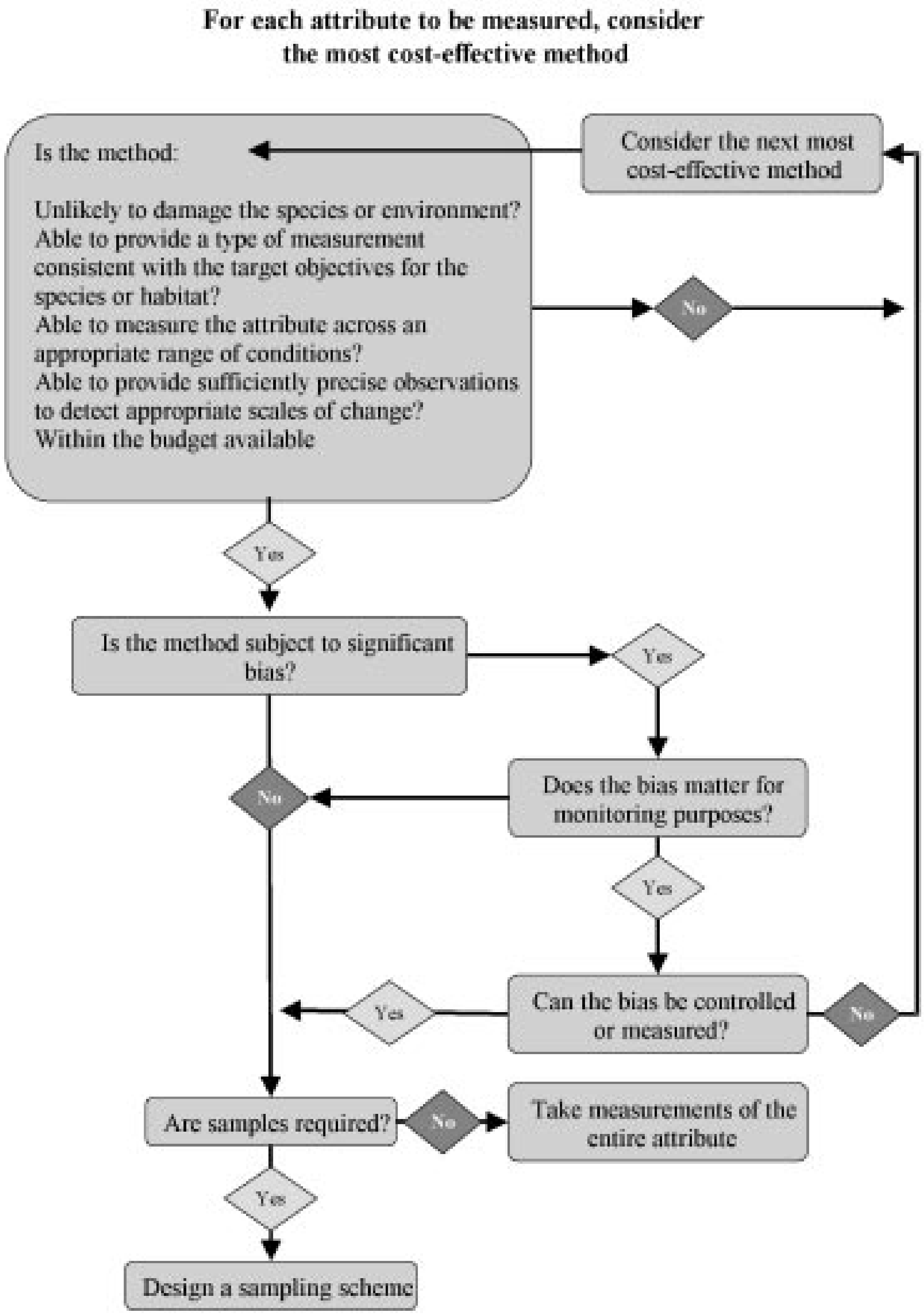


Figure 2-4 Suggested decision tree for the selection of methods for monitoring each attribute (from Ecoscope 2000a)

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.

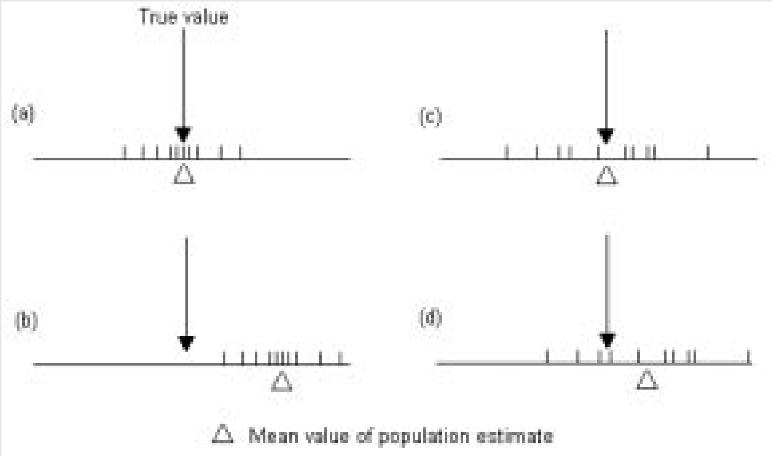
While a uniform approach to assigning a single technique to each attribute across the entire site series would standardise data collection, this approach may not be practicable for a range of operational and economic reasons. Shaw and Wind (1997) concluded that a degree of flexibility in the selection 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.

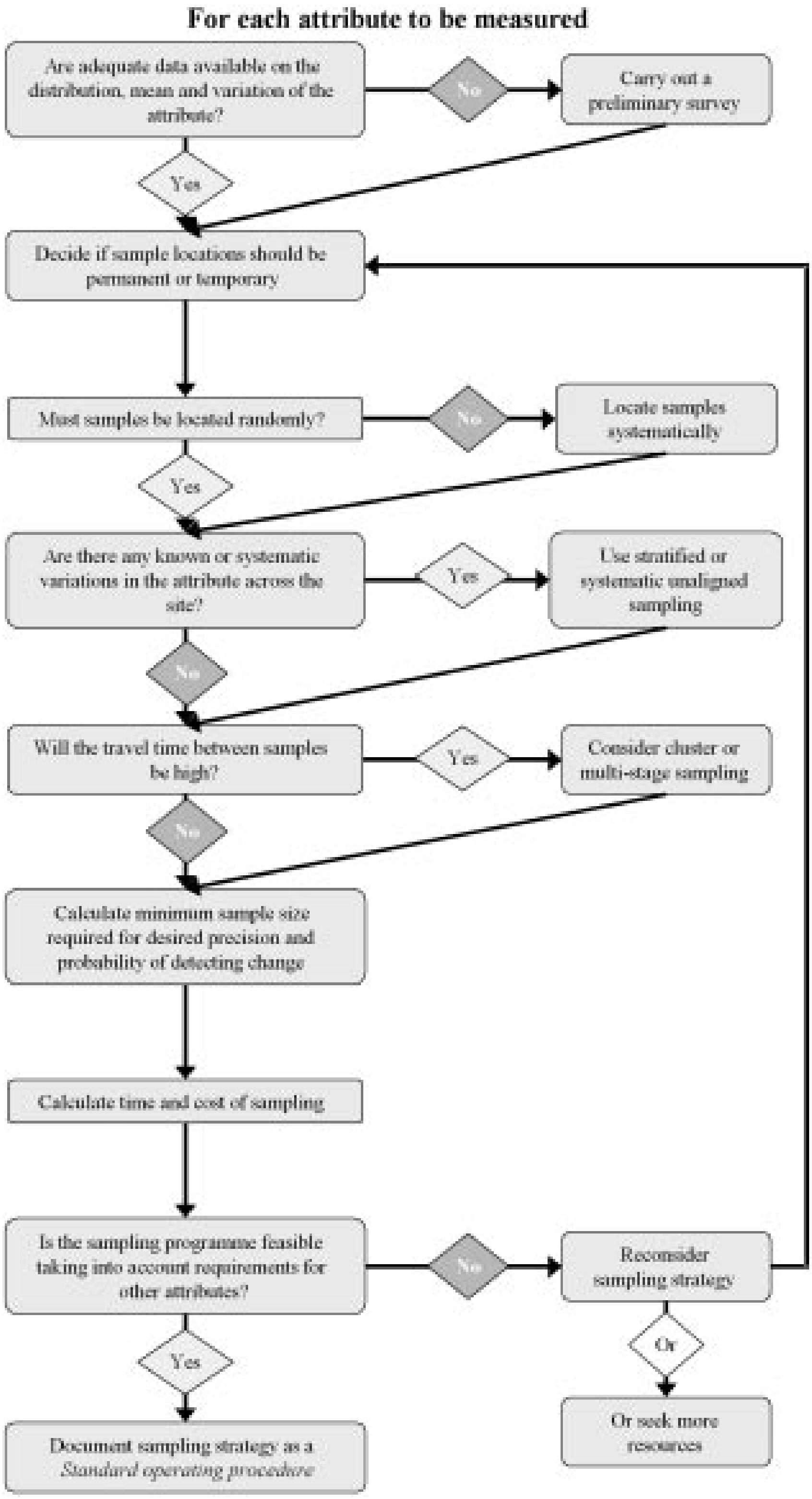


Figure 2-5 Issues to consider when designing a sampling strategy (after Ecoscope 2000a)

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]

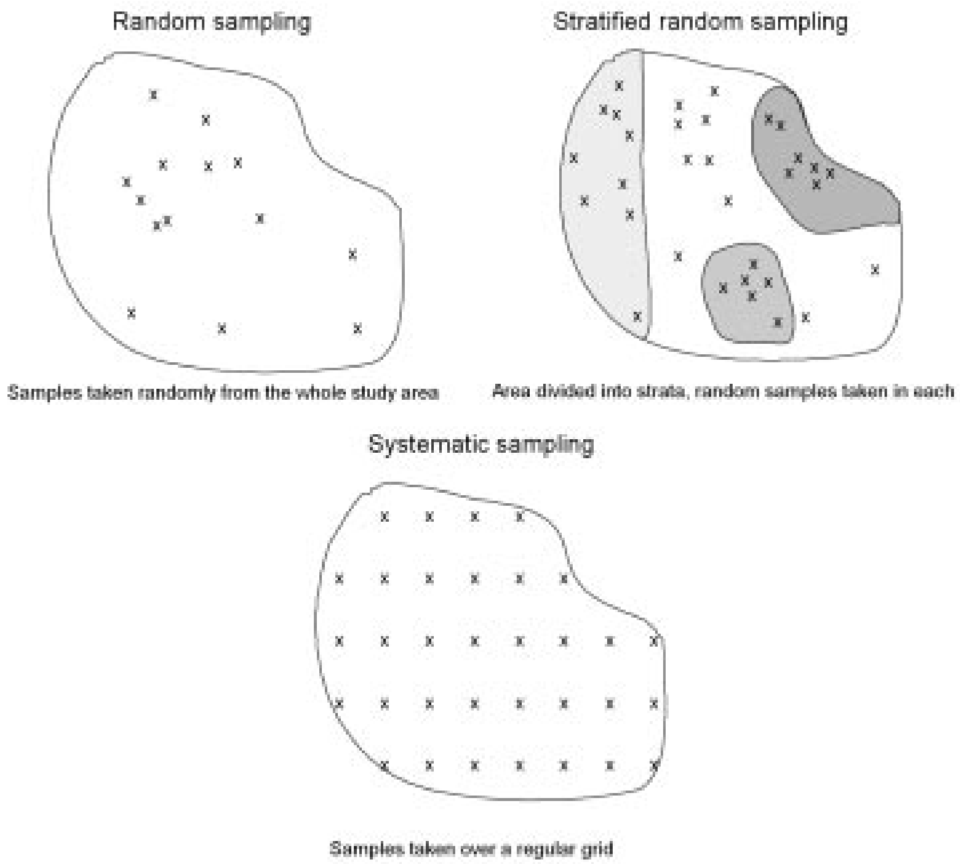


Figure 2-6 Three common types of sampling strategy (after Ecoscope 2000a). Note: *judgement or selective sampling is not shown.*

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. 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. 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. Statistical analysis is not valid and errors are unknown.	Efficient but dependent on quality of prior knowledge. 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. Free of possible classification errors. Easy to analyse data and compute errors.	Locating sample observations can be time-consuming. Often larger errors for a given sample size than with systematic sampling. May not monitor what is required	Only useful when a feature is spatially homogeneous throughout the SAC 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). Characteristics of each stratum can be measured and comparisons between them can be made. 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. 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. 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. 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 subsample 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'.

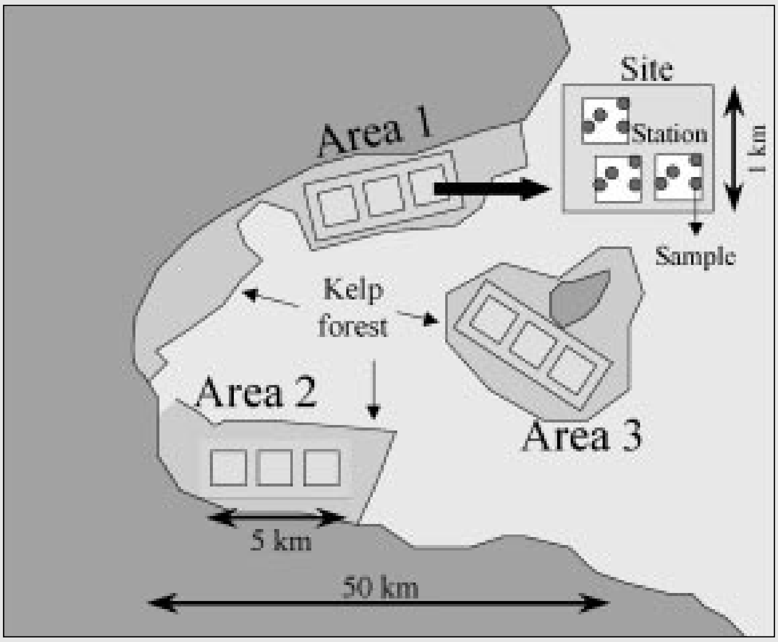
Recommendation. Monitoring Annex I features of a SAC should use a stratified random sampling strategy for locating sampling stations, except where an estimation of spatial pattern/extent is required when a systematic/grid sampling strategy should be adopted.

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])

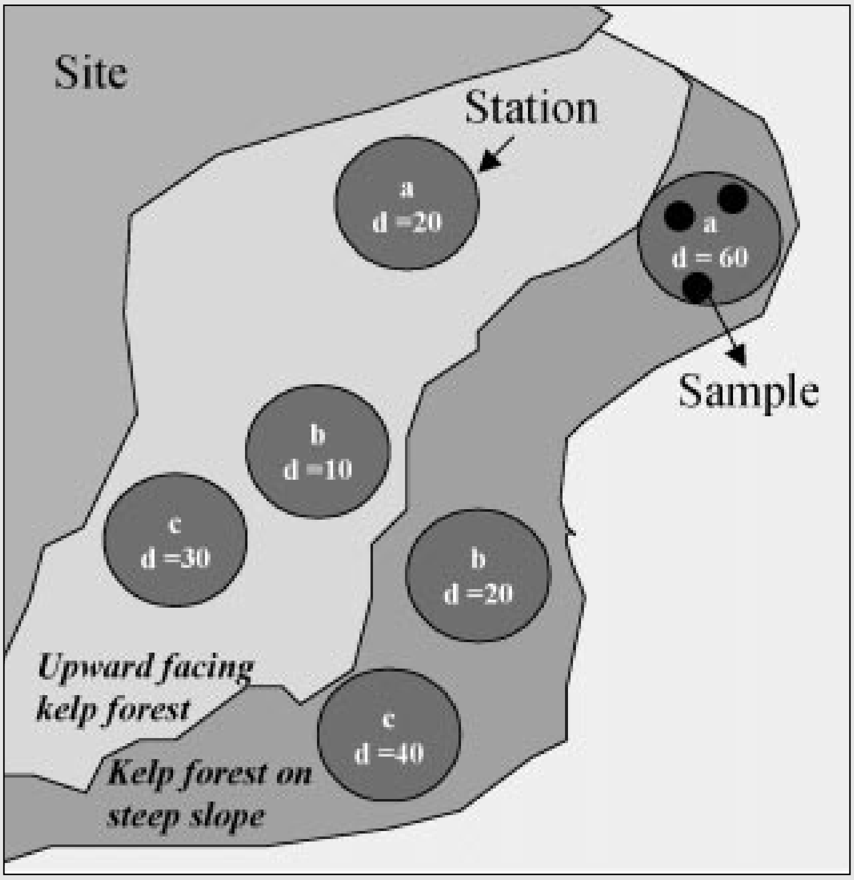


An example of a nested sampling design showing three areas at the whole SAC level. Sites are allocated in each area, stations are located randomly within the site, and samples are randomly positioned in each station. This sampling design can evaluate the difference in kelp cover between three areas,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



Scenario	*Comparison* Upward facing rock	Steep rock slope	*Conclusion*
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.

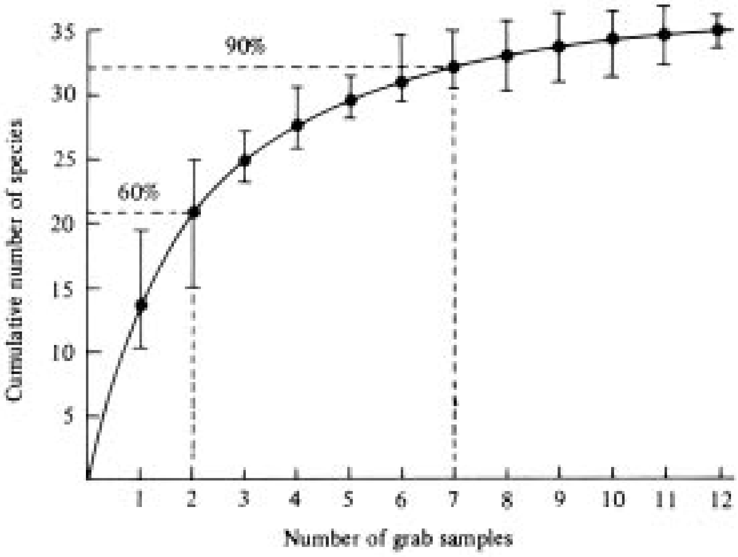


Figure 2-7 Species/area curve used to indicate the proportion of the fauna being collected with increasing numbers of grab samples and traditionally used to identify a minimum sampling area (from Gray 1981[u]).

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

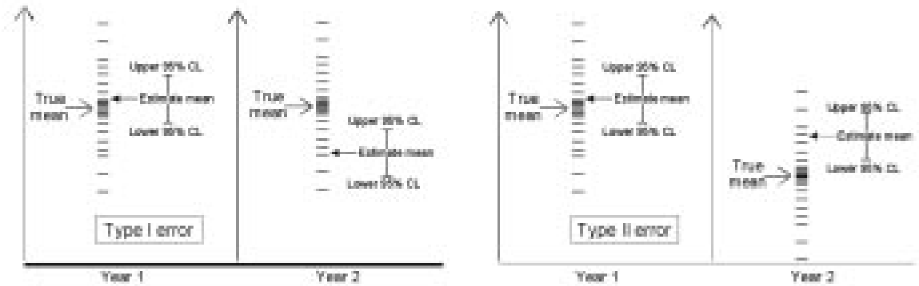
Statistical *power* is the probability of getting a statistically significant result given that there is a real biological effect in the population under investigation. In statistical terms, *power* is defined as 1 – ß, where ß is the probability of wrongly accepting a null hypothesis when it is actually 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*.

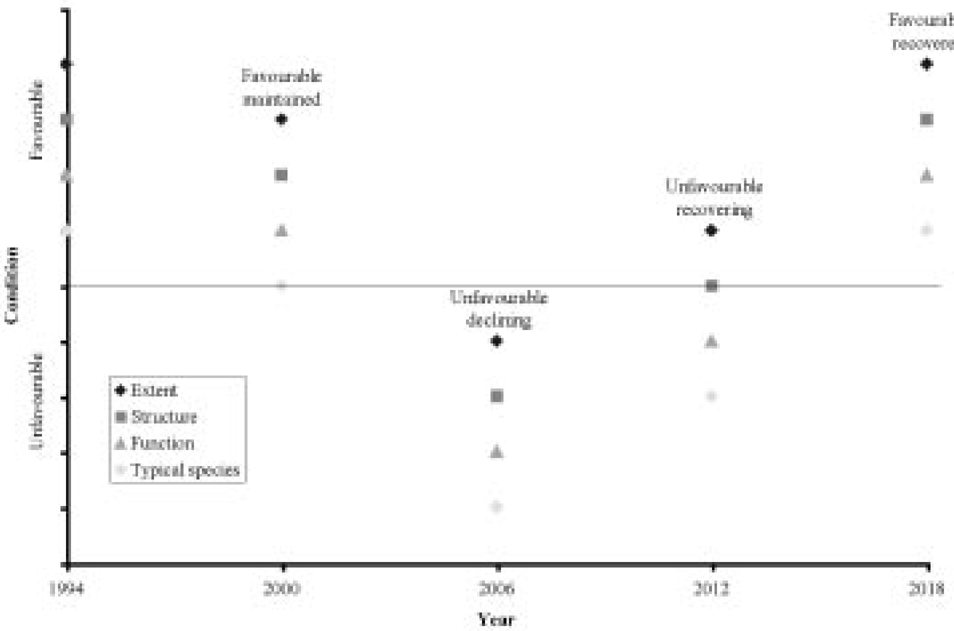


Figure 2-8 A modified version of the original common standards model (Rowell 1993)[y] proposed by Brown (2000).[s] The vertical axis shows the condition or state of the feature over the period shown on the horizontal axis. The horizontal line defines favourable condition (= the formulated standard) of 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).

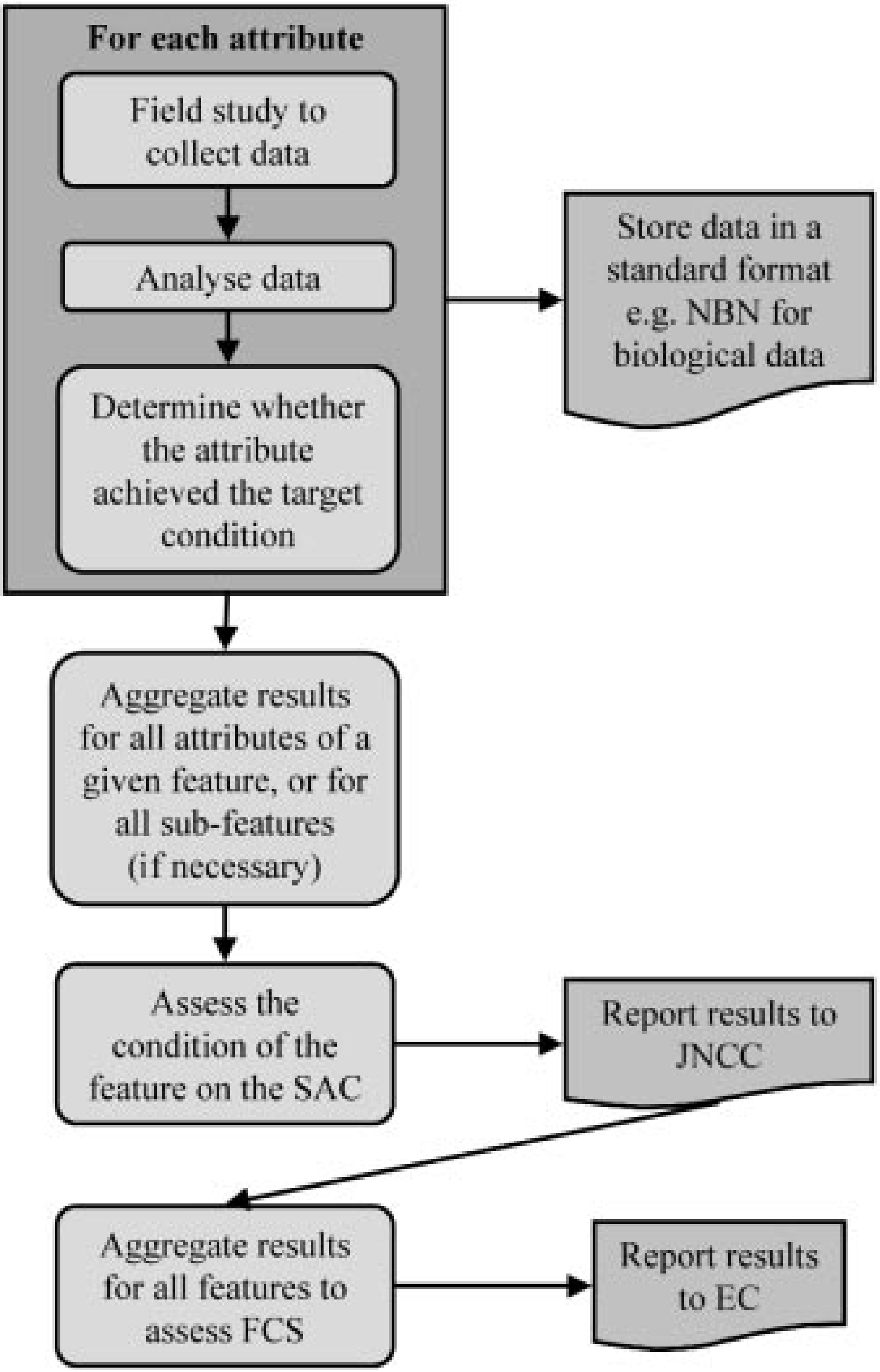


Figure 2-9 A summary of the anticipated process of assessing the condition of SAC features. The National Biodiversity Network (NBN)[19] has developed a data model that provides a *standard format* for biological data.

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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