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Marine Monitoring Handbook
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3 Advice on establishing monitoring programmes for Annex I habitats

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Introduction

Aim

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

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

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

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

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

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

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

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

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

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

Reefs

Definition

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

Introduction to the feature's interest

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

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

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

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

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

1 A ria is a drowned river valley.

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

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

Typical attributes to define the feature's condition

Generic attributes

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

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

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

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

Suggested techniques for monitoring reef attributes

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

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

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

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

Specific issues affecting the monitoring of reefs

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

Seasonal effects

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

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

Meteorological changes

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

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

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

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

Access

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

Sampling issues

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

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

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

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

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

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

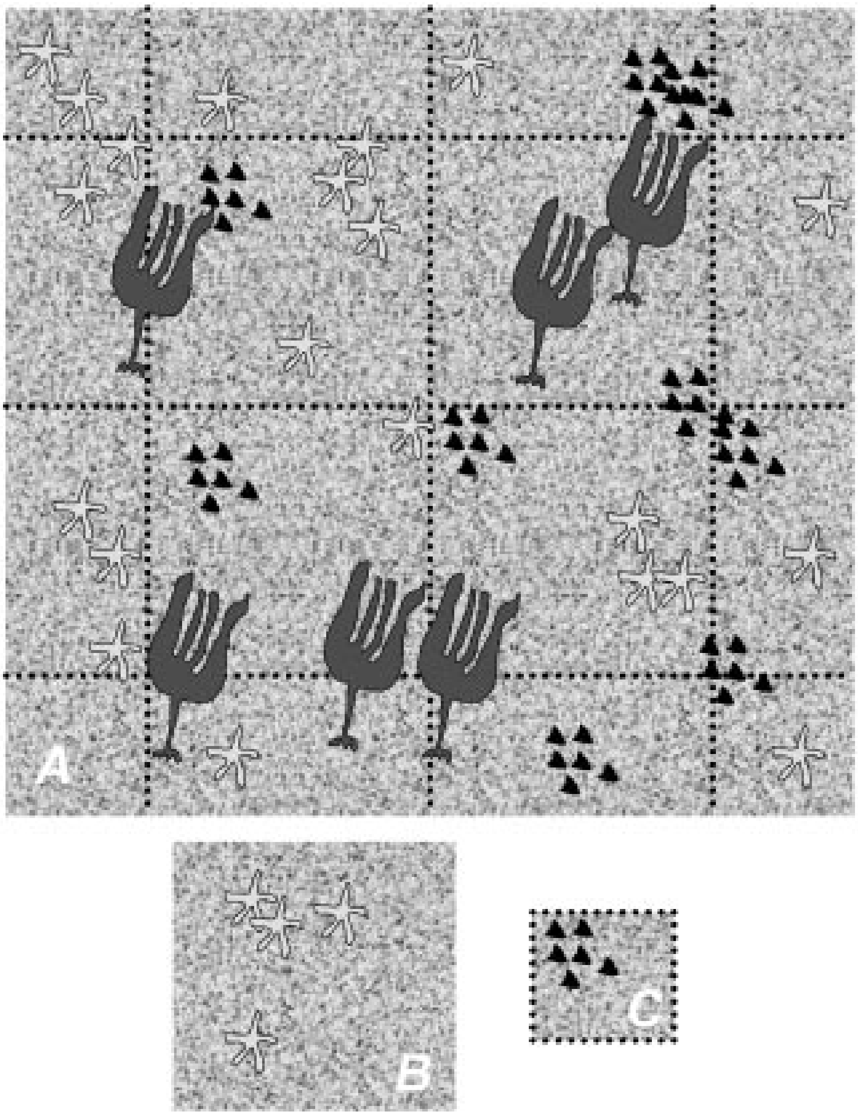

Figure 3-1 Illustration of a nested quadrat to record different sized organisms occurring at different spatial scales. Quadrat A is subdivided into 9 quadrats of size B and 36 quadrats of size C. Quadrat size will affect frequency estimates: 'starfish' frequency is 8/9 = 0.89 for quadrat B, but 15/36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

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

Site marking and relocation

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

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

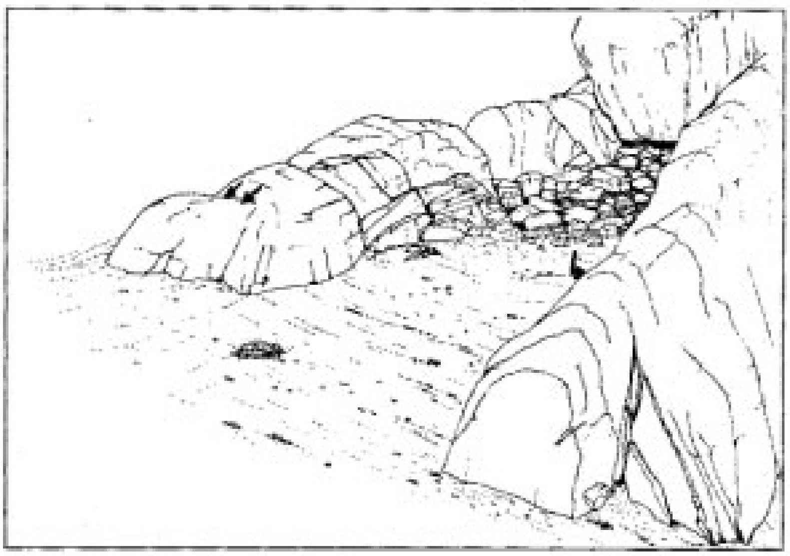

Figure 3-2 A drawing of the conspicuous underwater scenery to aid the relocation of a sample station[h]

Health and safety

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

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

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

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

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

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

Estuaries

Definition

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

Introduction to the feature's interest

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

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

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

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

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

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

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

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

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

Typical Attributes to define the feature's condition

Generic attributes

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

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

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

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

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

Suggested techniques for monitoring estuary attributes

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

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

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

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

Specific issues affecting the monitoring of estuaries

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

Seasonal effects

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

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

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

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

Meteorological changes

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

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

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2 See Section 5 for an explanation.

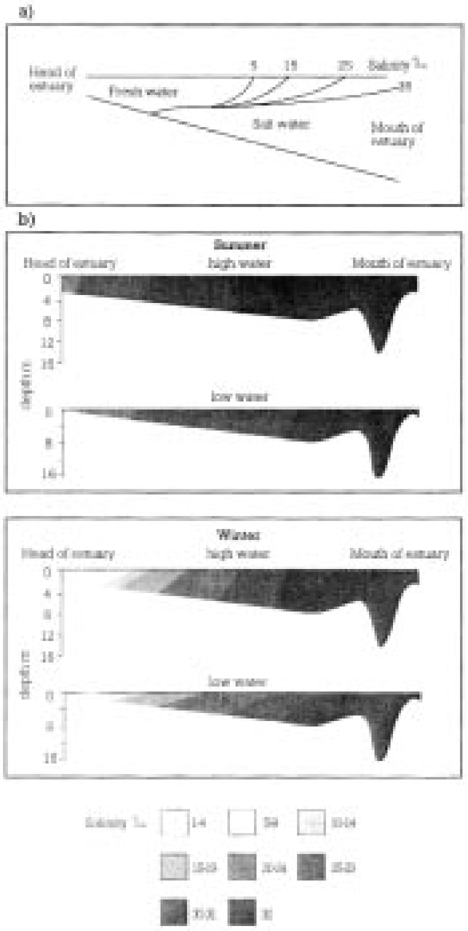

Figure 3-3 Seasonal changes in salinity in an estuary (from Davidson *et al.* 1991)

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

Access

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

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

Sampling issues

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

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

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

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

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

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

Site marking and relocation

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

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

Health and safety

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

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

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

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

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

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

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

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

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

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

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c Patterson, D M, Wiltshire, K H, Miles, A, Blackburn, J, Davidson, I, Yates, M G, McGrorty, S and Eastwood, J A (1998) Microbiological mediation of spectral reflectance from intertidal cohesive sediments. *Limnology and Oceanography*, **43**, 1207–1221.

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h Baker, J M and Wolff, W J (1987) *Biological surveys of estuaries and coasts*. Cambridge, Cambridge University Press.

i Kramer, K J M, Brockman, U H and Warwick, R M (1994) *Tidal estuaries: manual of sampling and analytical procedures*. Balkema, A A, Netherlands, 1-340.

j Yates *et al.* (2000) *Littoral sediments of the Wash and North Norfolk Coast SAC. Phase I: the 1998 survey of intertidal sediment and invertebrates*, draft confidential report from Institute of Terrestrial Ecology (Natural Environmental Research Council) to English Nature.

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

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

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

Sandbanks which are slightly covered by seawater all the time

Definition

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

Introduction to the feature's interest

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

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

(i) gravelly and clean sands

(ii) muddy sands

(iii) eelgrass *Zostera marina* beds

(iv) maerl beds

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

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

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

Typical attributes to define the feature's condition

Generic attributes

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

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

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

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

Suggested techniques for monitoring sandbank attributes

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

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

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

Specific issues affecting the monitoring of sandbanks

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

Seasonal effects

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

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

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

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

Meteorological changes

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

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

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

Access

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

Sampling issues

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

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1 See Section 5 for an explanation

utes relating to biological description.

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

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

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

Site marking and relocation

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

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

Health and safety

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

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

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

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

2 See Procedural Guideline 6-1 on dGPS guidance.

3 See Procedural Guideline 6-2 on site marking

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

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

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Mudflats and sandflats not covered by seawater at low tide

Definition

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

Introduction to the feature's interest

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

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

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

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

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

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

Typical attributes to define the feature's condition

Generic attributes

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

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

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

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

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

2 Settlement of juvenile mussels onto the seabed.

Suggested techniques for monitoring attributes of mudflats and sandflats

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

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

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

Specific issues affecting the monitoring of mudflats

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

Seasonal effects

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

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

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

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

Meteorological changes

Meteorological changes that may affect intertidal flats include:

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

Access

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

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

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

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

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

Sampling issues

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

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

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

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

Site marking and relocation

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

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

Health and safety

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

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

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3 See Procedural guideline No 6-1.

Large shallow inlets and bays

Definition

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

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

Introduction to the feature's interest

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

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

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

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

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

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

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

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

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

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

Typical Attributes to define the feature's condition

Generic attributes

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

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

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

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

Suggested techniques for monitoring attributes of inlets and bays

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

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

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

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

Specific issues affecting the monitoring of inlets and bays

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

Seasonal effects

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

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

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

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

Meteorological changes

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

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

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

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

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

1 See Section 5 for an explanation

Access

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

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

Sampling issues

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

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

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

Site marking and relocation

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

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

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

Health and Safety

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

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

2 See Procedural Guideline 6-1 on dGPS guidance.

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

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

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

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

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

Submerged or partly submerged sea caves

Definition

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

Introduction to the feature's interest

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

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

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

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

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

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

Typical attributes to define the feature's condition

Generic attributes

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

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

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

Suggested techniques for monitoring attributes of sea caves

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

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

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

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

Specific issues affecting the monitoring of caves

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

Seasonal effects

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

Meteorological changes

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

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

Access

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

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

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

Sampling issues

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

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

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

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

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

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

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

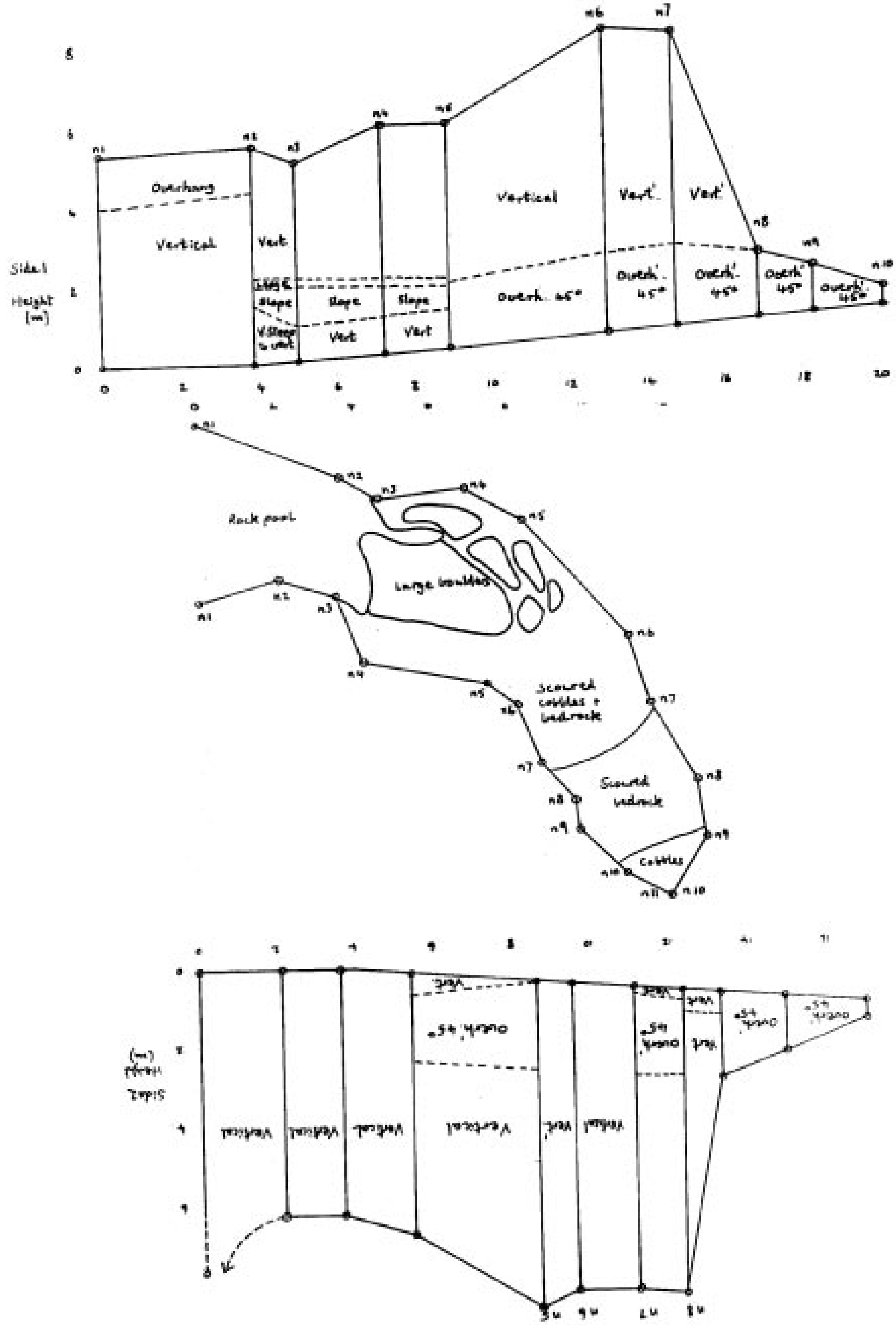

Figure 3-4 An example of a cave diagram showing the 'nodal' points of the system.[a]

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

Site marking and relocation

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

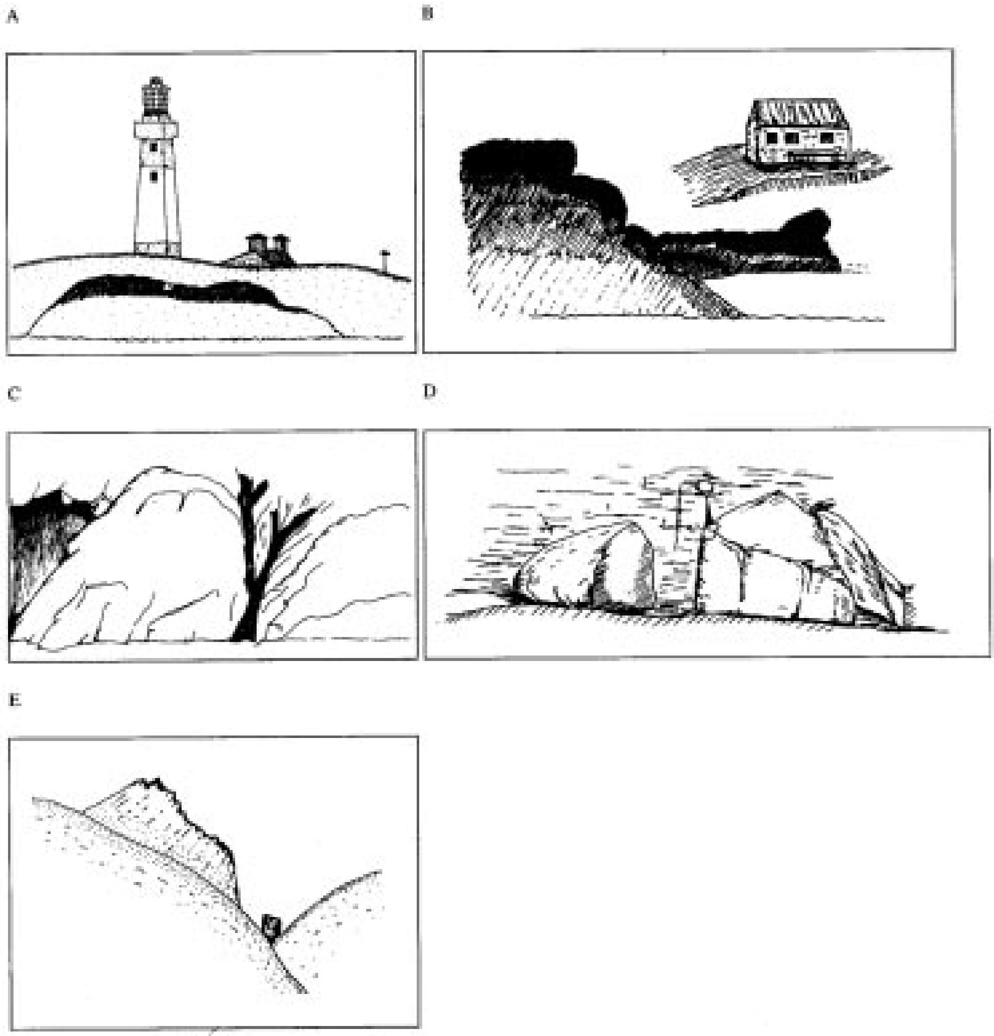

Figure 3-5 A example of the use of transits to relocate sampling stations.[c,3] Transits are straight sight-lines between land-based features (for example in B where the prominent rock aligns with the middle of the house) which intersect over the position of the sampling station. The best accuracy is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

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

3 See Procedural Guideline 6-2 on site marking

Box 3.7-1 Options for relocating a subtidal cave

Installation of a permanent marker buoy (surface or subsurface)

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

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

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

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

Transits or bearings

Detailed maps with locations marked

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

GPS (with datum)

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

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

Health and safety

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

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

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

4 See Procedural Guideline 6-1 on dGPS guidance.

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

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

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c Holt, R H F *et al*. (2000) Establishment of fixed stations on Ynys Enlli (Bardsey Island) – an evaluation of successful marking and relocation. 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. 187–190. CCW Contract Science Report No: 380, Countryside Council for Wales, Bangor.

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Lagoons

> **Definition**
>
> Lagoons are expanses of shallow coastal salt water, of varying salinity and water volume, wholly or partially separated from the sea by sandbanks or shingle, or, less frequently, by rocks. Salinity may vary from brackish water to hypersalinity depending on rainfall and evaporation, or the addition of fresh seawater from storms, temporary flooding of the sea in winter or tidal exchange. With or without vegetation from *Ruppietea maritimae, Potametea, Zosteretea or Charetea* (CORINE 91: 23.21 or 23.22).[1]
>
> Flads and gloes, considered a Baltic variety of lagoons, are small, usually shallow, more or less delimited water bodies still connected to the sea or have been cut off from the sea very recently by land upheaval. Characterised by well-developed reedbeds and luxuriant submerged vegetation and having several morphological and botanical development stages in the process whereby sea becomes land.

Introduction to the feature's interest

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

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

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

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

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

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

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

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

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

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

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

Typical attributes to define the feature's condition

Generic attributes

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

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

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

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

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

Suggested techniques for monitoring attributes of lagoons

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

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

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

Specific issues affecting the monitoring of lagoons

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

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

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

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

Seasonal effects

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

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

Meteorological changes

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

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

Access

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

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

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

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

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

Sampling issues

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

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

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

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

Site marking and relocation

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

Health and safety

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

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

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

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

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

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

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