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

Specific issues affecting the monitoring of estuaries

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

Seasonal effects

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

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

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

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

Meteorological changes

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

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

2 See Section 5 for an explanation.

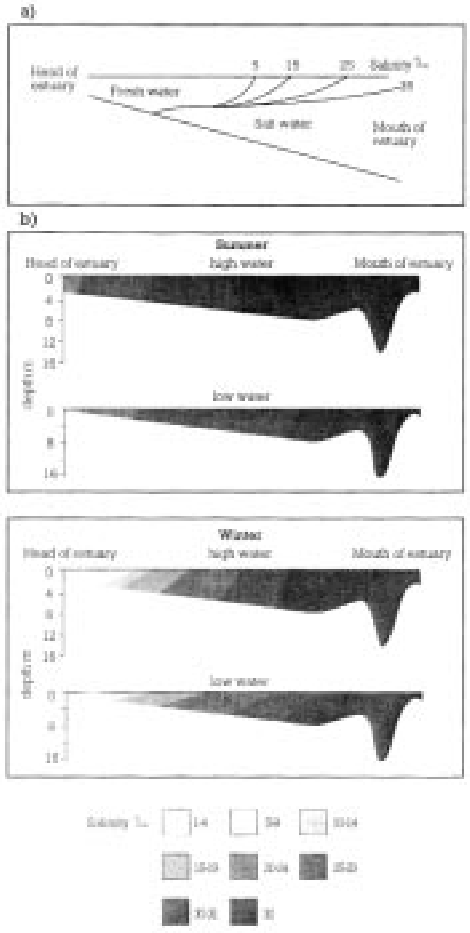

Figure 3-3 Seasonal changes in salinity in an estuary (from Davidson *et al.* 1991)

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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