ZOSTERA BIOTOPES

An overview of dynamics and sensitivity characteristics for conservation management of marine SACs

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August 1998

Prepared by Scottish Association for Marine Science (SAMS) for the

UK Marine SACs Project, Task Manager, A.M.W. Wilson, SAMS

Citation

D.M.Davison, D.J.Hughes, 1998. Zostera Biotopes (volume I). An overview of dynamics and sensitivity characteristics for conservation management of marine SACs. Scottish Association for Marine Science (UK Marine SACs Project). 95 Pages.

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PREFACE

The 1990s are witnessing a "call to action" for marine biodiversity conservation through wide ranging legislative fora, such as the global Convention on Biodiversity, the European Union's "Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora" (the Habitats Directive) and more recently in developments to the Oslo and Paris Convention (OSPAR). These landmark legal instruments have in turn provided sufficient scientific rationale, legal mandate and social synergy to rally governments, NGOs, private industry and local communities into a new era of unprecedented conservation action.

Each of these initiatives identifies marine protected areas as having a key role in sustaining marine biodiversity. To manage specific habitats and species effectively there needs to be a relatively clear understanding of their present known distribution, the underpinning biology and ecology and their sensitivity to natural and anthropogenic change. From such a foundation, realistic guidance on management and monitoring can be derived and applied.

The Habitats Directive requires the maintenance and/or restoration of natural habitats and species of European interest at favourable conservation status across their biogeographical range. The designation and management of a network of Special Areas of Conservation (SACs) have a key role to play in this. The specific 'marine' habitats defined in Annex I of the Habitats Directive include:

- Sandbanks which are slightly covered by sea water all the time,
- Estuaries
- Mudflats and sandflats not covered by seawater at low-tide,
- Large shallow inlets and bays
- Lagoons
- Reefs
- Submerged or partly submerged sea caves

These habitats are vast in scope and challenging to quantify in terms of favourable conservation status, so there has been increased attention to 'sub-features' of these habitats which are in effect constituent components and/or key elements of the habitats from a range of biodiversity perspectives.

One initiative now underway to help implement the Habitats Directive is the UK Marine SACs LIFE Project, involving a four year partnership (1996-2001) between English Nature (EN), Scottish Natural Heritage (SNH), the Countryside Council for Wales (CCW), Environment and Heritage Service of the Department of the Environment for Northern Ireland (DOENI), the Joint Nature Conservation Committee (JNCC), and the Scottish Association of Marine Science (SAMS). While the overall project goal is to facilitate the establishment of management schemes for 12 of the candidate SAC sites, a key component of the project assesses the sensitivity characteristics and related conservation requirements of selected sub-features of the Annex I habitats noted above. This understanding will contribute to more effective management of these habitats by guiding the detailed definition of the conservation objectives and monitoring programmes and by identifying those activities that may lead to deterioration or disturbance.

A diverse series of sub-features of the Annex I marine habitats were identified as requiring a scientific review, based on the following criteria:

- key constituent of several candidate SACs;

- important components of Annex I habitats in defining their quality and extent;
- extensive information exists requiring collating and targeting, or there is minimal knowledge needing verification and extended study.

This resulted in the compilation a nine-volume review series, each providing an "Overview of Dynamics and Sensitivity Characteristics for Conservation Management of Marine SACs" for the following sub-features:

Vol. I	Zostera Biotopes
Vol II	Intertidal Sand and Mudflats & Subtidal Mobile Sandbanks
Vol III	Sea Pens and Burrowing Megafauna
Vol. IV	Subtidal Brittlestar Beds
Vol. V	Maerl
Vol. VI	Intertidal Reef Biotopes
Vol. VII	Infralittoral Reef Biotopes with Kelp Species
Vol. VIII	Circalittoral Faunal Turfs
Vol. IX	Biogenic Reefs.

Each report was produced initially by appropriate specialists from the wider scientific community in the respective subject. These reports have been reviewed through an extensive process involving experts from academic and research institutions and the statutory nature conservation bodies.

The results of these reviews are aimed primarily at staff in the statutory nature conservation bodies who are engaged in providing conservation objectives and monitoring advice to the marine SAC management schemes. However these reports will be a valuable resource to other relevant authorities and those involved in the broader network of coastal-marine protected areas. In order to reach out to a wider audience in the UK and Europe, a succinct 'synthesis' document will be prepared as a complement to the detailed 9-volume series. This document will summarise the main points from the individual reviews and expand on linkages between biotopes, habitats and sites and related conservation initiatives.

These reports provide a sound basis on which to make management decisions on marine SACs and also on other related initiatives through the Biodiversity Action Plans and Oslo and Paris Convention and, as a result, they will make a substantial contribution to the conservation of our important marine wildlife. Marine conservation is still in its infancy but, through the practical application of this knowledge in the management and monitoring of features, this understanding will be refined and deepened.

We commend these reports to all concerned with the sustainable use and conservation of our marine and coastal heritage.

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EXECUTIVE SUMMARY

Project context and study aims

A number of sites around the UK of high scientific and conservation importance have been designated as marine Special Areas of Conservation (SACs) under the terms of the EU Habitats and Species Directive. As a contribution to the development of management plans for marine SACs, scientific reviews have been commissioned of the dynamics and sensitivity characteristics of selected biotope complexes found at some or all of the sites. These reviews are intended to summarize the available information relevant to conservation management, including the ecological characteristics of each biotope complex, its conservation importance, its sensitivity to natural and human-induced environmental changes, and the monitoring options suitable for use in marine SACs. Attention is focused on 12 candidate SACs selected as 'demonstration' sites. This report covers biotopes characterized by eelgrasses (*Zostera* spp.). *Zostera* beds can occur in five of the seven broad habitats defined in Annex I of the Habitats Directive, namely 'Lagoons', 'Estuaries', 'Large shallow inlets and bays', 'Intertidal mud and sand banks' and 'Sandbanks covered by sea water at all times'.

Nature and importance of the biotope complex

Seagrasses are marine flowering plants found in shallow coastal areas around the world, typically on sheltered sandy or muddy substrata to a maximum depth of about 10 m. Seagrasses often grow in dense, extensive beds or meadows, creating a productive and diverse habitat that provides shelter and food for a wide variety of other plant and animal species. Seagrass beds thus constitute an important reservoir of coastal biodiversity. In addition, the beds provide food for wildfowl and for the juveniles of some commercially-important fish species. The dense root networks of the plants stabilize the underlying substratum and so act to reduce coastal erosion. Seagrass beds are therefore of considerable economic and conservation importance. Increasing human pressures on the coastal zone have led to losses of seagrass beds in many parts of the world. The importance and vulnerability of these biotopes therefore make them a high priority for management and conservation efforts.

In the British Isles, three species of eelgrass of the genus *Zostera* occur, common eelgrass *Z. marina*, narrow-leaved eelgrass *Z. angustifolia*, and dwarf eelgrass *Z. noltii.* It is possible that *Z. angustifolia* is a variety of *Z. marina* rather than a distinct species (and it is usually so regarded by authorities outside the British Isles). However, most of the UK literature makes a specific distinction between *Z. marina* and *Z. angustifolia*, a convention followed in this report. All three eelgrasses were once abundant and widespread around the British coasts, but serious declines have occurred, in particular as a consequence of a severe outbreak of 'wasting disease' in the early 1930s. Recovery of eelgrass beds since the 1930s has been slow and patchy, and all three *Zostera* species are now considered nationally scarce in the UK.

Distribution in the UK and elsewhere

Zostera marina is the largest of the three British eelgrasses and typically occurs in the shallow sublittoral down to about 4 m depth, in fully marine conditions and on relatively coarse sediments. The species is still patchily distributed around most of the British coastline, with concentrations of recent records in south-west England and the west coast of Scotland. Elsewhere, the species occurs throughout the Atlantic and Pacific coastlines. *Zostera angustifolia* is an intertidal plant found from mid- to low-tide mark, usually in poorly-draining muddy sediments. The species is typically found in conditions of variable salinity, often in estuaries. In Britian, *Z. angustifolia* has a more easterly distribution than *Z. marina*, with concentrations in the Solent, Thames Estuary, and Moray and Cromarty Firths. Narrow-leaved, intertidal forms of *Zostera marina* are known in Europe and North America, and probably correspond to the form designated as *Z. angustifolia* in the UK. Dwarf eelgrass, *Z. noltii* occurs higher on the shore than the other two species, typically on mixtures of sand and mud. In the UK, recent records are clustered in the Thames Estuary area, Moray and Cromarty Firths, and in Argyll. Outside the UK, *Z. noltii* occurs in the eastern Atlantic from southern Norway to the tropic of Cancer.

Eelgrasses can be found in several candidate or possible SACs around the UK, with one or more species occurring in 10 of the 12 'demonstration' sites considered by the UK Marine SACs Project. Two biotopes within the MNCR classification system are defined by the occurrence of *Zostera* beds, and two within the 'BioMar' Life Form classification.

Environmental requirements

All three British eelgrass species are found on sedimentary substrata, sheltered or extremely sheltered from strong tides and currents. In more exposed sites, beds tend to be smaller, patchier and more vulnerable to erosion. The plants flourish best where the local sediments are closely balanced between the forces of erosion and accretion. Excessive sedimentation can be harmful as it tends to smother the plants. Highly turbid water also inhibits growth by reducing the amount of light available for photosynthesis. *Zostera marina* usually occurs down to about 4 m, but has been recorded as deep as 13 m in water of exceptional clarity.

The optimum temperature range for growth and germination appears to be approximately 10 - 15^{o}C, but plants can tolerate sea temperatures from 5 - 30^{o}C. The intertidal *Z. angustifolia* and *Z. noltii* may be damaged by exposure to frost in severe winters. *Zostera marina* is intolerant of dessication. *Zostera angustifolia* occurs intertidally, but generally in areas of waterlogged sediment. *Zostera noltii* is the best-adapted to resist aerial exposure and consequently occurs higher up the shore than the other two species. Mature *Zostera* plants have a high tolerance to salinity changes. Although *Z. marina* is not normally found in brackish water, exposure to reduced salinity appears to be necessary to stimulate flowering shoot production.

Nitrogen is usually the most significant limiting nutrient. Moderate nutrient enrichment may stimulate growth, but excessive inputs are usually harmful (see below). *Zostera* leaves provide a substratum for the growth of many species of epiphytic algae. These epiphytes may smother the *Zostera* plants unless kept in check by the grazing activities of gastropods and other invertebrates. Healthy populations of epiphyte grazers are therefore beneficial to the maintenance of *Zostera* beds. The grazing activities of wildfowl may also play an important role in preventing excessive build-up of sediment among the eelgrass plants.

Biology and ecological functioning

Leaf growth in *Zostera* takes place in spring and summer. Detached shoots or rhizome fragments may be dispersed by currents and re-establish themselves, so allowing beds to expand vegetatively. *Zostera marina* is generally a perennial plant, and maintains its populations largely by this vegetative process. Sexual reproduction by seed production does not appear to play a significant role in the life history in northern latitudes. *Zostera angustifolia* populations may be either annual or perennial. Reproduction may occur by a combination of vegetative growth and seed set, of which the latter appears to be the more important. In the UK, beds of *Z. noltii* persist mainly by vegetative growth, despite prolific seed production. The differing levels of emphasis on sexual and vegetative reproduction can result in a complex genetic structure in populations of *Zostera.*

Subtidal eelgrass beds are one of the most productive of shallow-water coastal ecosystems. Relatively few species possess the capacity to digest eelgrass leaves directly, but the detritus formed by the decomposition of *Zostera* tissue fuels food-chains both within the beds and outside them. Eelgrass detritus dispersed by currents may make an important contribution to the energy supply of biotopes far removed from the beds themselves.

Zostera beds are highly species-rich, particularly the subtidal beds of *Z. marina*. A large number of algal species occur as epiphytes on *Zostera* leaves (some species are found only in eelgrass beds). Other algae grow amongst the eelgrass or occur as mats on the sediment surface. Complex communities of fish and invertebrate species are supported by the algae and *Zostera* detritus. *Zostera* is a highly important food source for several species of ducks and geese, as shown by parallel declines in eelgrass and some wildfowl populations. *Zostera marina* was formerly the most important food source for species such as Brent geese, but has now been supplanted by *Z. noltii* in this role.

Sensitivity to natural events

Zostera beds are spatially dynamic, expanding or receding at their edges. They are subject to a number of naturally-occurring factors which can cause changes in bed extent and plant density at a range of scales. Extreme weather conditions such as violent storms or heavy floods can destroy or damage beds over wide areas. Plants may also be killed or defoliated by severe frosts.

‘Wasting disease’ is the single most important naturally-occurring cause of *Zostera* decline. The most serious recorded outbreak of this disease took place in the 1920s-30s, and led to widespread loss of eelgrass beds throughout Europe and North America. Recovery from this event has still been only partial. The pathogen responsible for wasting disease is a fungus, *Labyrinthula macrocystis*. This organism is probably naturally present at low levels but undergoes occasional large-scale outbreaks for reasons which are still not fully understood. It is possible that severe eelgrass losses occur only when the plants are under stress from some other factor. *Labyrinthula* does not appear to cause disease in conditions of low salinity, and so tends to affect *Z. marina* far more severely than *Z. angustifolia* or *Z. noltii*.

Grazing wildfowl can remove a high proportion of the available biomass of *Zostera* (consumption of > 90% of standing stock has been estimated in some cases). However, it is believed that eelgrass beds are normally able to tolerate wildfowl grazing pressure unless under stress from some other factor.

The consumption of epiphytic algae by gastropods or other invertebrates can be important in maintaining the health of *Zostera* plants, so that any factors leading to a reduction in algal grazer populations may indirectly also affect the eelgrass itself.

Sensitivity to human activities

Zostera beds are vulnerable to the effects of many of the major human activities in the coastal zone, including coastal development, water pollution and physical habitat disturbance. Large-scale land reclamation can completely destroy eelgrass beds over wide areas. Other forms of coastal development (eg. construction of harbours or marinas, pipeline laying, channel dredging) can also adversely affect eelgrass beds by altering the local hydrographic regime and sediment balance. Depending on circumstances, rates of sedimentation or erosion may increase, with adverse consequences for bed viability. Many forms of coastal development also cause increases in water turbidity, which will cut down the light available for photosynthesis and reduce the depth to which plants can grow.

Contamination of coastal water by heavy metals or antifoulants has not been shown to significantly affect *Zostera* plants, but agricultural herbicides are known to be harmful. Eelgrass beds do not appear to be highly sensitive to chronic oil pollution (eg. from refinery effluent). Major oil spills can inhibit growth of the plants, but in both cases, the associated fauna and flora seem to suffer more damage than the eelgrass itself. The chemical dispersants used to treat major oil spills facilitate penetration of oil into the sediment. Oil-dispersant mixtures appear to cause more damage to *Zostera* biotopes than the oil alone, and consequently the use of dispersants should be avoided in these habitats.

Excessive nutrient enrichment arising from sewage, agricultural fertilizers or aquaculture can have a variety of harmful consequences for eelgrass beds. High nitrate levels appear to cause metabolic imbalances in *Zostera.* Nutrient enrichment is also likely to cause eutrophication - the proliferation of epiphytic, benthic or planktonic algae - all of which are potentially harmful to *Zostera* plants. Stress caused by excessive nutrient enrichment (or other factors) may also render *Zostera* more vulnerable to infection with wasting disease.

Eelgrass beds are not physically robust, and the plants are easily destroyed or damaged by trampling, digging, dredging, bivalve harvesting or other forms of physical disturbance. Human disturbance may also affect the movements of wildfowl, causing them to spend longer on *Zostera* beds, with resulting increases in grazing pressure.

Two non-indigenous plants, the cord-grass *Spartina anglica* and the brown alga *Sargassum muticum* have colonized eelgrass beds in the UK, mainly in the south of England. To date, neither species appears to be a serious threat to healthy *Zostera* beds, but both can take advantage of space in eelgrass beds created by other forms of disturbance.

Human-induced climate change may ultimately have serious consequences for eelgrass beds if predictions of sea-level rise and increased frequency of severe storms prove to be accurate.

Monitoring and surveillance options

Eelgrass beds possess a range of attributes which are potentially of use to an SAC monitoring scheme. For the purpose of detecting changes in the *Zostera* biotope, the most important parameters to monitor are probably the distribution and extent of eelgrass coverage, the *Zostera* standing crop and shoot density, the condition of the *Zostera* plants (eg. leaf length, sexual status, presence of wasting disease), the occurrence of characteristic and representative species in the associated community, and the local water quality (turbidity, nutrient levels).

Of the various available monitoring techniques, airborne or sublittoral remote sensing (the latter including side-scan sonar and RoxAnn^{TM}) can rapidly map the distribution of beds over large areas, but must usually be ground-truthed by some other method. Underwater video and field observers (diving or shore survey) must be used to provide information on *Zostera* plant condition and the associated biological community.

A standardized system for mapping intertidal and shallow subtidal *Zostera* beds (for sue by field observers) has been developed following a workshop organized by English Nature in 1996.

Gaps and requirements for further research

Several aspects of *Zostera* biology are still relatively poorly-understood. Further information on these would make an important contribution to the conservation management of eelgrass biotopes.

Clarification of the taxonomic status of *Z. angustifolia* and more detailed information on the current UK distribution of all three *Zostera* types could be obtained by molecular genetic studies, and by re-examination of preserved specimens. Greater knowledge of the range of morphologic and life-history variability occurring within each form of *Zostera* would enhance the accuracy of field identifications and allow more detailed predictions of the responses of populations to environmental change.

In view of the potentially devastating effects of wasting disease on populations of *Z. marina*, it is essential to gain a more detailed understanding of the biology of the causative organism (*Labyrithula macrocystis*), the factors triggering large-scale epidemics and the role of other environmental stresses in determining rates of infection and recovery.

The success of attempts to preserve *Zostera* beds in the UK depends to a large extent on identifying the factors which limit or facilitate recovery following disturbance. Manipulation of these factors will be essential to the success of *Zostera* transplantation or re-introduction programmes. Considerable efforts have been made to artificially restore seagrass beds in several areas of the world, including some attempts in the UK, but long-term success has been very limited so far.

Synthesis and application to SAC management

The three key requirements for management of *Zostera* biotopes in an SAC are firstly, to ensure that the important environmental needs of *Zostera* are met (particularly with respect to sediment balance, water clarity and nutrient levels), secondly to review and manage human activities in and around the SAC to ensure that these are compatible with the maintenance of the biotope, and thirdly, to review and assess proposals for new activities to ensure that detrimental effects are avoided.

The human activities which are most likely to affect the integrity of *Zostera* biotopes are coastal development, nutrient input to coastal waters, and physical disturbance. These will be the most important factors to be considered in any SAC managment scheme. Management guidelines arising from the EU Habitats Directive and the UK Biodiversity Action Plan allow the compilation of a list of practical measures to be undertaken at National and SAC level.

I
INTRODUCTION

A. GENERAL INTRODUCTION AND STUDY AIMS

Seagrasses are marine flowering plants found in shallow coastal habitats around the world. They most commonly occupy sandy intertidal and subtidal areas to a maximum depth of about 10 m. Seagrasses typically grow in monospecific stands called ‘beds’ or ‘meadows’. These beds create a habitat of considerable importance from an ecological, economic and biodiversity perspective. The beds support a high density and diversity of associated flora and fauna, and provide valuable nursery and feeding grounds for fishes and birds. The binding of sediment by seagrass root networks also acts to stabilize the shoreline and reduce coastal erosion.

Before the early 1900s three species of *Zostera*, or ‘eelgrass’, were common in sandy coastal areas of the British Isles, but their abundance was severely reduced during the 1920s-1930s period by a ‘wasting disease’ that is still not fully understood today. Since this time there has only been limited and localized recovery of the *Zostera* beds. These plants flourish in accessible nearshore margins, and can therefore be adversely affected by many forms of coastal development, in particular dredging and excessive nutrient loading. Because of the value of seagrasses as a representative habitat for the UK, their high biodiversity and ecological importance, and their vulnerability to anthropogenic impacts, several parallel initiatives are now underway to better understand the role of these plants in coastal ecosystems and to facilitate effective conservation measures.

As described in the Preface to this report, this work is conducted through the auspices of the UK Marine SACs Project, as part of the implementation of the EU Habitats Directive. In this context, the three *Zostera* species occur in **eleven of the twelve UK Marine SAC Project demonstration sites**, and are key elements of **five of the seven Annex I habitats** for which marine SACs can be selected in the UK, namely:

- **Lagoons**
- **Estuaries**
- **Large shallow inlets and bays**
- **Intertidal mud and sand flats**
- **Shallow subtidal sandbanks**

The objective of this report is to summarize and review the available information on these species in their capacity as a functional ‘biotope’ or community, addressing both shared and distinct features of these three species. The review focuses on the fundamental environmental and biological attributes of the *Zostera* biotope, its sensitivity to natural and human-induced change, and options for monitoring such changes that are relevant to the management of marine SACs. This report serves as a complement to, and a synthesis and elaboration of, two recent reports, prepared as part of the UK Biodiversity Action Plan, Davison (1997a) and Holt et al. (1997). The current state of knowledge of *Zostera* in Wales is summarized by Kay (1998). These three sources should be consulted for more detailed infomation on the issues covered in this report.

B. NATURE AND IMPORTANCE OF THE *ZOSTERA* BIOTOPE COMPLEX

1. Status of Zostera species in the UK

'Seagrass' is a common name for a large group of higher flowering land plants that have spread into the marine environment in relatively recent geologic times. They are the only group of flowering plants that are truly marine and can function and reproduce under conditions of permanent or cyclic submergence in saline water. Den Hartog (1970) recognized a world total of 49 seagrass species. In temperate waters there are ten species of the genus *Zostera* and two species of *Ruppia*. Five seagrass species are found around the British Isles - two species of 'tassel weed' (*Ruppia maritima* and *R. cirrhosa*) and three species of 'eelgrass' (*Zostera* spp.). This report focuses on the three British *Zostera* species, which are as follows:

- **Common eelgrass, *Zostera marina***
  This is the largest of the three species, with leaves up to 1 m long (more usually 20 - 50 cm). It occurs from the shallow sublittoral to the lower littoral zone.

- **Narrow-leafed eelgrass, *Zostera angustifolia***
  This is a smaller plant than *Z. marina* (leaf length 15 - 30 cm) and is typically found on the mid to lower shore.

- **Dwarf eelgrass, *Zostera noltii***
  This is the smallest and hardiest species and occurs highest on the shore, often adjacent to saltmarsh communities. Maximum leaf length is about 22 cm.

Further details of the physical attributes of these three species are given in Appendix 1.

There is some disagreement concerning the taxonomic status of *Z. angustifolia.* This form was given specific status in 1942 based on differences (from the more common *Z. marina*) in morphology, reproductive strategy and habitat zonation. Populations conforming to the definition of *Z. angustifolia* used in Britain have been recorded in continental Europe and on the Atlantic coast of North America (den Hartog, 1970; Rae, 1979; Nienhuis, 1983; de Heij & Nienhuis, 1992; Cleator, 1993). However, outside the UK, most authors have regarded these narrow-leafed intertidal eelgrasses as a phenotypic variant of *Z. marina* rather than a distinct species (den Hartog, 1970). Many of the morphologic characters used to define *Z. angustifolia* are known to vary according to habitat and season. Initial results of DNA sequencing work undertaken at the Royal Botanic Garden, Kew, supports the hypothesis that *Z. marina* and *Z. angustifolia* are variants of a single species (J. Brenchley, pers. comm.).

For the purposes of this report, *Z. angustifolia* will be treated as a distinct entity, since it is so regarded in most of the UK-based literature. If this form is confirmed as a species separate from *Z. marina*, with a distribution largely confined to the British Isles, the need for appropriate monitoring and management in the UK increases due to its relative rarity within Europe. If, as appears more likely, *Z. angustifolia* is found to be a variety of *Z. marina*, then this apparent rarity could be considered to be less important (Cleator, 1993). Assessment of the distribution and status of eelgrass species in the UK is hindered by misidentification, which renders some historical records suspect (Kay, 1998). A clarification of the taxonomic status of *Zostera* species and a re-examination of specimens would contribute to an increased understanding of the distribution and habitat requirements of the three forms, with important implications for their future management.

2. Basic ecology of Zostera spp.

All three *Zostera* species can occur as dense swards on intertidal and shallow subtidal muds and sands in sheltered shallow inlets and bays, estuaries and saline lagoons. *Zostera* can also be found on more exposed areas of intertidal mud and sand flats, as well as shallow subtidal sandbanks. As a result of this habitat flexibility, *Zostera* species are widely but patchily distributed throughout the British Isles and extensive beds occur in some areas. Within Britain, mixed beds of *Z. angustifolia* and *Z. noltii* commonly occur together on the shore but exhibiting distinctive distribution patterns - *Z. noltii* typically occurs on hummocks that are free-draining at low tide, while *Z. angustifolia* occupies hollows that retain standing water at low tide (Wyer et al, 1977). In some lagoons, all three *Zostera* species may be found together, along with *Ruppia* species. The detailed habitat requirements of *Zostera* are summarized in Chapter II.

Zostera plants have an extensive network of branched, creeping underground roots that help bind the sand or mud substratum. These horizontal rhizomes bear leafy shoots with abundant green, grass-like leaves. The leaves are flat and linear, with maximum length and width varying according to species (see Appendix 1). Distinct veins run the length of the leaves. The leaves have large air spaces (lacunae) between the cells which act as buoyancy chambers and keep the leaves upright in the water (the name *Zostera* comes from the Greek *'zoster'*, meaning 'belt', referring to the ribbon-shaped leaves). *Zostera* plants have inconspicuous flowers which lack petals and are aggregated in inflorescences. Male and female flowers are separate but occur on the same plants. Despite these common features, all three *Zostera* species exhibit considerable morphological plasticity in response to environmental conditions. Growth and reproduction of *Zostera* are considered in greater detail in Chapter III.

3. Importance of Zostera biotopes

a. Economic importance

Zostera beds are an important source of food and shelter for the young stages of many fish and crustacean species, some of which are themselves food for commercially-valuable fishery species. They are also important feeding grounds for ducks and geese sought after by wildfowlers.

In addition to the value of the associated fauna, the eelgrass plants themselves play an important role in maintaining the stability of the shoreline. The dense network of rhizomes binds the sediment and reduces erosion in shallow waters. If beds are locally destroyed, their protective capacity can only be replaced by financially costly artificial shoreline reinforcements.

b. Biodiversity and conservation importance

The network of roots and leaves in an extensive *Zostera* bed provides ecological niches for a wide range of associated fauna and flora, so that these biotopes are important in maintaining coastal biodiversity. Eelgrass beds exhibit high rates of primary productivity and are an important source of organic matter, fuelling detritus-based food chains within the biotope. Organic matter transported out of *Zostera* beds can also be utilized in other biotopes, in some cases far removed from the point of origin. The role of *Zostera* beds in coastal and marine ecosystems will be discussed further in Chapter III.

c. Rarity and vulnerability to human impacts

Zostera biotopes were selected for the UK Marine SACs Project not only because of the values noted above, but also because they were in the past a widespread feature of Britain's nearshore margin, hence they are a significant element of Britain's natural marine heritage. Although all three *Zostera* species are still widespread today, they are now considered to be nationally scarce with a patchy distribution (see below). Although there has not been a comprehensive inventory, the existing data and previous records indicate that *Zostera* beds have made a poor or slow recovery from the impact of wasting disease in the 1920s -1930s. This same situation is generally true for other areas where *Zostera* was once common, such as along the Atlantic seacoast of North America.

Furthermore as human settlement along Britain's coast has increased (both in terms of population and scale of physical alteration to shorelines), especially in estuarine areas, the *Zostera* meadows in these areas have been subjected to increased direct (e.g. dredging, filling) and indirect (e.g. upstream channelization resulting in increased sedimentation) impacts. They are therefore a high priority for monitoring and conservation management.

C. DISTRIBUTION AND STATUS OF THE *ZOSTERA* BIOTOPE COMPLEX

1. European perspective

Species of the genus *Zostera* are common on many coastlines throughout the world, with a distribution range from the Arctic zone to the equatorial tropics. The genus has not been recorded from West Africa or South America to date, and it occurs only sparsely in the Mediterranean and Black Sea (Dawes, 1981). This may reflect true distribution patterns or a lack of documented observations from these areas. The three species discussed in this report are distributed as follows:

- *Zostera marina* is widespread throughout the Atlantic and Pacific. In the eastern Atlantic it extends from the Arctic Circle to Gibraltar, including the Mediterranean (Stace, 1997)

- *Zostera angustifolia* has only been recorded around the British Isles, Denmark and Sweden (Cleator, 1993; C. Stace, pers. comm.). This apparently limited distribution is a reflection of the disputed taxonomic status of this form (as discussed previously).

- *Zostera noltii* is more southerly than *Z. marina* and is restricted to the Atlantic, including the Mediterranean Sea. It extends from southern Norway to the tropic of Cancer (Cleator, 1993).

2. Overview of known UK distribution and extent

a. Historical context

Tubbs (1995) suggests that until the outbreak of wasting disease in the 1920s, the majority of intertidal and shallow subtidal mudflats in Britain and Europe were 'clothed' in eelgrass. The first *Zostera* distribution survey in England was undertaken by Butcher (1933a), reporting on the die-offs due to the wasting disease epidemic. He concluded that since 1917 *Z. marina* had become scarce and restricted to sheltered sites such as lagoons. *Zostera angustifolia* appeared to have become the most common *Zostera* species from this time. The distribution of *Z. noltii* remained stable, although this was still a relatively uncommon species (Butcher, 1933a,b, 1934). Two distinct periods of decline were identified, the first immediately after World War I, the second in the period 1931-32. Butcher (1941a, b) reported that recovery of the beds had begun by 1933 and was quite rapid, with some beds fully recovered within a few years of the 1930s epidemic.

However, Tubbs (1995) suggested that the disease continued to affect *Zostera* populations until the mid-1940s and that recovery did not really begin until the 1950s. The recovery has not been well documented but Tubbs considered that most *Zostera* beds have not yet fully recovered, and that only 20 of Britain's 155 estuaries have eelgrass meadows more than 1 ha in extent. He reported that *Z. marina* has not recolonized the estuaries in southern and eastern England where it was once abundant, but that there are numerous small beds on the Channel coast from the Isles of Scilly to the Isle of Wight. He also reported that *Z. marina* beds on the west coast of Britain are extensive, dense and vigorous, particularly on the west coast of Scotland and around the Outer Hebrides.

b. Current distribution and extent in targeted geographic areas

The current distribution and known extent of the *Zostera* biotope in the UK are summarized in Table 1. The table is organized around the Annex I habitat features, providing information on both marine sites that have been designated as SACs as well as others that are not formally SACs, but which support *Zostera*. The *Zostera* sites recorded range in extent from 6.5 km^2 to only 20-40 ha. Although brief descriptions of many of the sites with *Zostera* biotopes are provided in Davison (1997a), there is still a need for additional accurate estimates of extent. As discussed in Chapters VII-IX, obtaining this information is a high priority in the development of a conservation plan for *Zostera* biotopes in the UK.

Table 1.

<u>Overview of *Zostera* spp. records and extent within UK marine SAC & *non-SAC sites*</u>

Annex I Habitats with *Zostera* sp.					**Site Name**	***Zostera* sp. recorded**	**Estimates of total area of *Zostera* sp. cover**
S	E	M	L	I	**Bold** = UK Marine SAC Project Demonstration Site		
SCOTLAND							
*					**Sound of Arisaig cSAC**	*Zostera* sp.	
			*	*	**Loch Maddy cSAC**	*Z. marina* *Z. noltii*	
	*				Dornoch Firth pSAC	*Z. angustifolia* *Z. noltii*	
					Moray Firth cSAC - within which the <u>Cromarty Firth</u> is considered to have the largest *Zostera* population in Britain	*Z. angustifolia* *Z. noltii*	1, 200 ha (RSPB, 1995)
CROSS-BORDER SITES - SCOTLAND & ENGLAND							
*	*	*			**Solway Firth cSAC**	*Z. angustifolia* *Z. noltii*	At least 2 km^2 Hawker, 1993, 1994
		*			**Berwickshire & North Northumberland Coast cSAC**	*Z. angustifolia* *Z. noltii*	900 ha Percival et al., 1996
ENGLAND							
		*		*	**Morecambe Bay cSAC**	*Z. angustifolia* *Z. noltii*	
					Humber Estuary	*Z. angustifolia* *Z. noltii*	
*		*		*	**The Wash & North Norfolk Coast cSAC**	*Z. angustifolia* *Z. noltii*	
	*	*			Essex Estuaries cSAC	*Z. angustifolia* *Z. noltii*	844 ha Wyer et al., 1977
					Maplin Sands, North Thames Estuary is estimated to be the largest continuous population of *Z. noltii* in Europe	*Z. angustifolia* *Z. noltii*	325 ha (RSPB, 1995)
			*		Solent & Isle of Wight Lagoons cSAC - Langstone Harbour (280 ha) - Chichester Harbour (130 ha) - Portsmouth Harbour (20 - 40 ha) - Isle of Wight (?)	*Z. marina* *Z. angustifolia* *Z. noltii*	(see places for estimates) (Tubbs & Tubbs, 1983)
			*		**Chesil & the Fleet cSAC** The Fleet Lagoon is considered to have the most extensive population of all 3 *Zostera* sp. in Britain (cHAP, 1995)	*Z. marina* *Z. angustifolia* *Z. noltii*	

Table 1 continued:

Annex I Habitats with *Zostera* sp.					Site Name	*Zostera* sp. recorded	Estimates of area of *Zostera* sp. cover
S	E	M	L	I	**Bold** = UK Marine SAC Project Demonstration Site		
					Exe Estuary SPA	*Z. angustifolia* *Z. noltii*	
*	*			*	**Plymouth Sound & Estuaries cSAC**	*Z. marina*	
*		*		*	Fal & Helford cSAC	*Z. noltii* *Z. marina*	6.5 km^2 (Covey & Hocking, 1987)
*		*			Isles of Scilly Complex cSAC	*Z. marina*	
CROSS-BORDER SITE - ENGLAND & WALES							
*	*	*			Severn Estuary cSAC	*Z. marina* *Z. angustifolia* *Z. noltii*	Approx. 1 km^2 but very sparse (M. Hill, pers. comm.)
WALES							
	*			*	Pembrokeshire Islands pSAC - Skomer MNR - Milford Haven	*Z. marina* *Z. angustifolia* *Z. noltii*	
	*				**Lleyn Peninsula & the Sarnau cSAC**	*Z. marina* *Z. angustifolia* *Z. noltii*	
NORTHERN IRELAND							
				*	**Strangford Lough cSAC**	*Z. marina* *Z. angustifolia* *Z. noltii*	6.3 km^2 Portig et al., 1994
					Dundrum Bay	*Zostera* sp.	
					Carlingford Lough	*Zostera* sp.	
					Lough Foyle	*Zostera* sp.	

Key To Annex I Habitats (*)

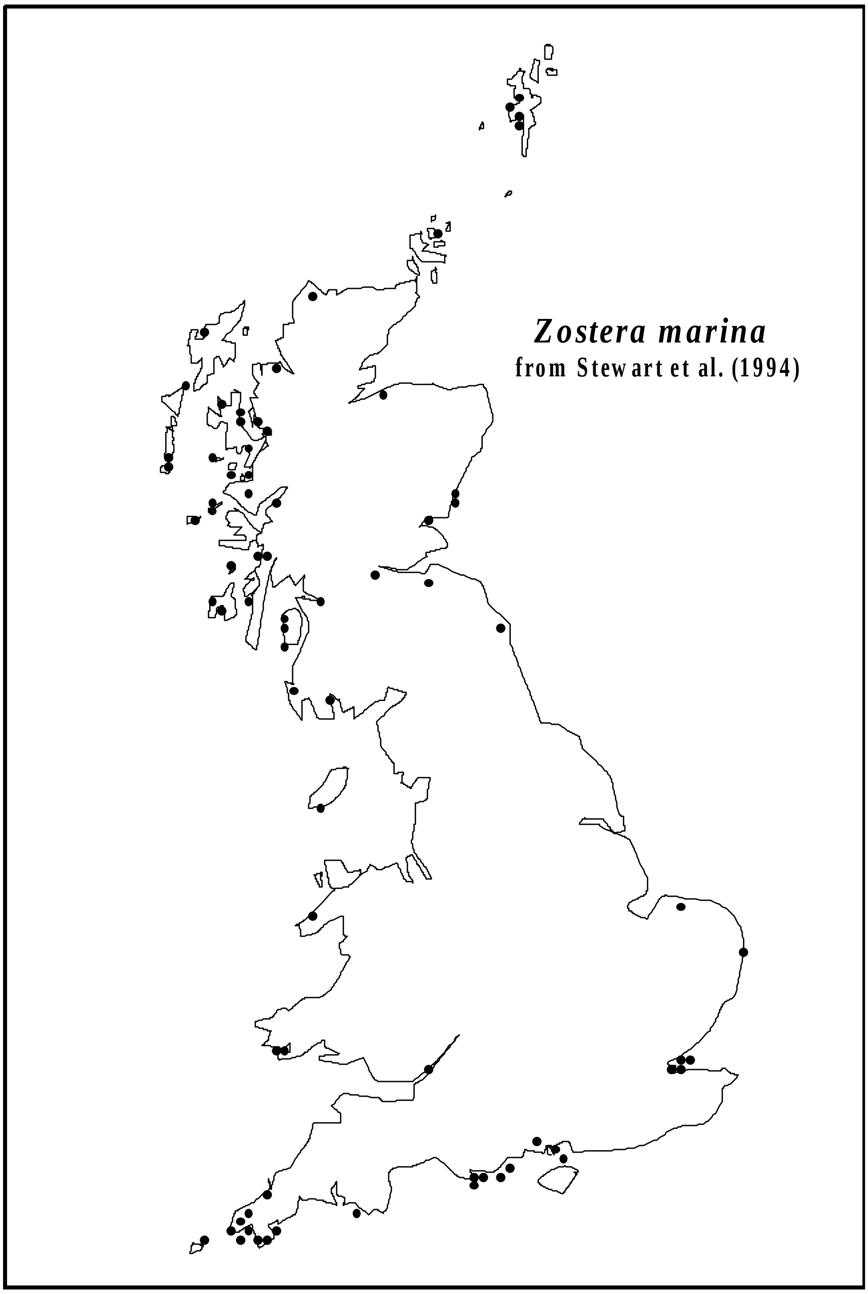
AI habitats with *Zostera sp.*

S Sandbanks slightly covered by seawater at all times
E Estuaries
M Mudflats and sandflats not covered by seawater at all times
L Lagoons
I Large, shallow inlets and bays

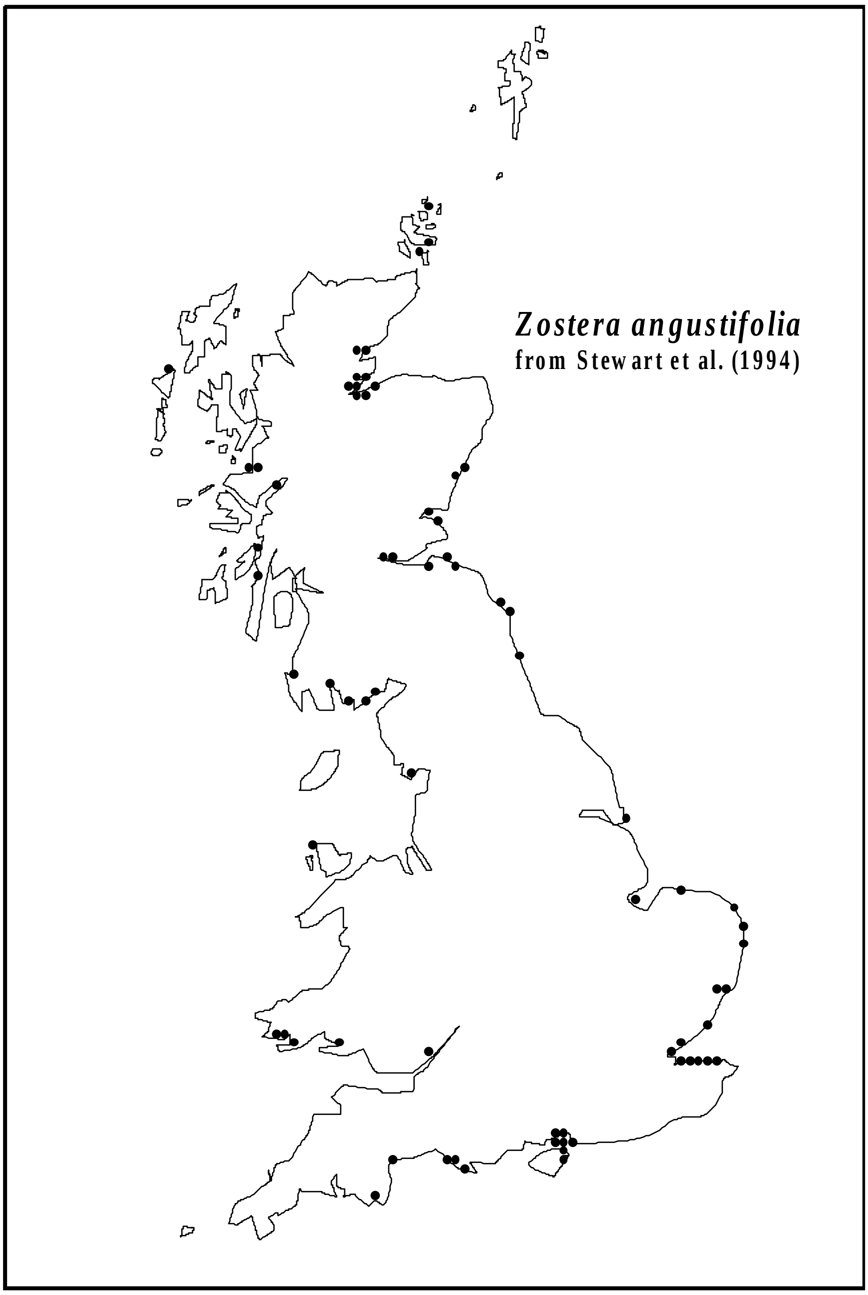
c. Summary of *Zostera* distribution in the UK

The overall distributions of the three *Zostera* species in mainland UK are summarized in the following maps, based on those given in Stewart et al. (1994). The maps show post-1970 records of the three species. Additional up-to-date information can be found in the MNCR database, while Kay (1998) gives a detailed review of *Zostera* distribution in Wales.

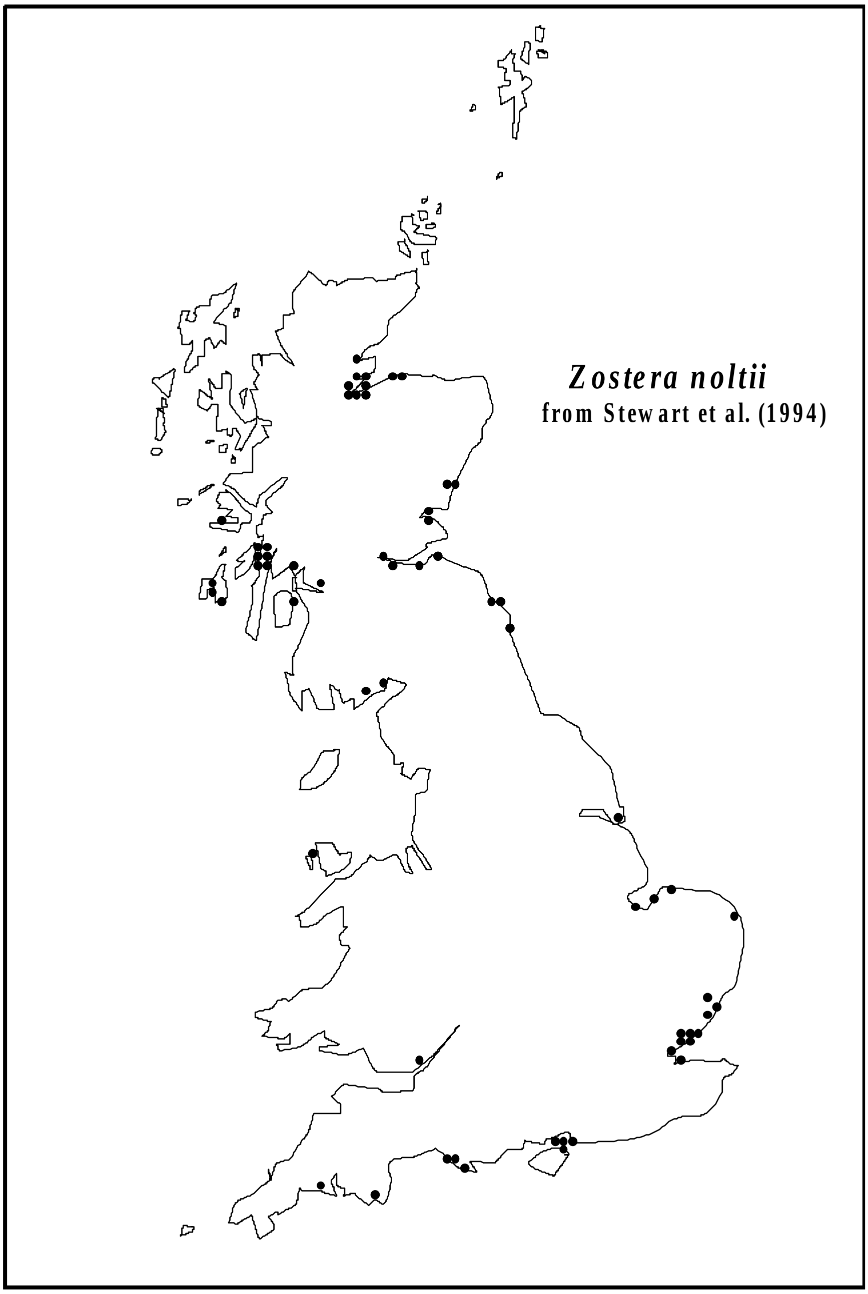
Zostera marina is still widely, but patchily distributed around England, Scotland and Wales, with concentrations of post-1970 records in south-west England and along the west coast of Scotland, including the Hebridean islands.



The post-1970 records of *Z. angustifolia* are located mainly on the southern and eastern coasts of the UK, with major concentrations near the Isle of Wight, the Thames Estuary and the Moray and Cromarty Firths in Scotland.



Zostera noltii also has a predominantly eastern post-1970 distribution, with concentrations in the Thames Estuary area and the Moray and Cromarty Firths. There are also a number of records in the Argyll/Clyde area of western Scotland.



D. *ZOSTERA* BIOTOPE CLASSIFICATION

1. The MNCR Biotope classification scheme

The Marine Nature Conservation Review (MNCR) biotope classification provides a hierarchical framework for differentiating and classifying the shallow-water benthic habitats and biological communities of the British Isles (Connor et al., 1997). The basic unit of classification is the **Biotope**, a recognizable **Community** of conspicuous species occurring in a **Habitat**, defined according to parameters of the physical environment such as substratum type or degree of wave exposure. Groups of biotopes with similar overall character, suitable for local mapping where biotopes consistently occur together and are relatively restricted in their extent, are termed **Biotope complexes**. The current version of the MNCR biotope classification (Connor et al., 1997) lists two main biotopes characterized by *Zostera* beds. The defining characteristics of these are summarized in Table 2 below:

Table 2: MNCR biotopes characterized by *Zostera* spp.

LMS.Znol : *Zostera noltii* beds in upper to mid shore muddy sand	
Salinity	Full - variable (8-30 ‰)
Wave exposure	Sheltered - very sheltered - extremely sheltered
Substratum	Muddy fine sand - sandy mud A black layer in sediments usually present below 5 cm depth
Zone	Eulittoral
Height band	Upper shore - mid shore
Characterizing species	Infaunal community: bristle worm (*Pygospio elegans*) & lugworm (*Arenicola marina*), sludge worms (*Tubificoides)*, amphipods *Corophium volutator* and bivalves - cockles (*Cerastoderma edule*), Baltic tellin (*Macoma baltica*) and peppery furrow shell (*Scrobicularia plana*) Epifaunal community: mud snail (*Hydrobia ulvae*), common periwinkle (*L. littorea*), shore crab (*Carcinus maenus*) and ribbon weed (*Enteromorpha*)
Frequency of occurrence	Scarce

IMS.Zmar: ***Zostera marina / Z. angustifolia* beds in lower shore or infralittoral clean or muddy sand**	
Salinity	Full
Wave exposure	Sheltered - very sheltered
Tidal streams	Very weak
Substratum	Clean sand - muddy fine sand - mud
Zone	Infralittoral
Height band	Lower shore
Depth band	0 - 5 m
Characterizing species	Infaunal community: burrowing urchin (*Echinocardium cordatum),* razor shells (*Ensis* sp.) and other bivalves, lugworm (*Arenicola marina*), sandmason worm (*Lanice conchilega*). Epifaunal community: snakelocks anemone (*Anemonia viridis*), hermit crab (*Pagarus bernhardus*), shore crab (*C. maenus*), grey topshell (G*ibbula cineraria*), netted dogwhelk (*Hinia reticulata*) as well the algae, *Laminaria saccharina, Chorda filum* and *Ulva.* In SW Britain, the community composition may be dominated by Lusitanian species such as the hydroid *Laomeda angulata,* seahorses *Hippocampus* sp. and stalked jellyfish (Stauromedusae)
Frequency of occurrence	Uncommon

The environmental parameters characteristic of these biotopes will be outlined in Chapter II, while the ecological relationships of *Zostera* and its associated flora and fauna are discussed in more detail in Chapter III.

2. 'Bio Mar' Biotope classification scheme:

The 'BioMar' classification system is closely related to the MNCR scheme, and is intended for basic mapping of intertidal and subtidal habitats and associated communities. It is based around a number of major physical categories of characterizing organisms, termed 'Life Forms', which can be further subdivided according to details of their composition. The treatment of *Zostera* biotopes within this scheme is outlined in Table 3 below:

Table 3: 'BioMar' biotopes within the overall Life Form SGB - Sea Grass Beds.
(Bunker & Foster-Smith, 1996.)

Life Form SGB - Sea Grass Beds	
SGB.Z Seagrass beds: *Zostera* sp.	<u>Community description:</u> • *Zostera* sp. (*Z. angustifolia* or *Z. noltii*) may form sparse to moderately dense stands. • Can colonize a wide variety of sediment shores so the underlying faunal communities will vary but usually contains *Hediste diversicolor*. • <u>Habitat description:</u> • Sandy mud to mud • Whole shore, mainly upper to middle • Sheltered to very sheltered Biotopes of enclosed tidal waterways and estuaries
SGB.ZOS Seagrass beds: *Zostera marina*	<u>Community description:</u> • *Zostera marina* may form dense stands • Can colonize a wide variety of sediment substrates so the underlying faunal communities will vary but will usually contain polychaetes such as *Nephtys hombergii* and *Scoloplos armiger* and bivalves such as *Ensis siliqua* and *Cerastoderma edule*. <u>Habitat description:</u> • Fine muddy sand • Lower shore and shallow sublittoral • Sheltered to very sheltered Biotopes of enclosed tidal waterways and estuaries

E. KEY POINTS FROM CHAPTER I

- Seagrasses are a group of flowering plants found on sheltered sedimentary coasts from the upper shore to about 10 m depth. They are especially characteristic of estuaries, shallow inlets and lagoons.

- In the UK, three species of the genus *Zostera* (commonly known as ‘eelgrasses’) are recognized, *Z. marina*, *Z. angustifolia* and *Z. noltii*. The specific status of *Z. angustifolia* is disputed, and it may prove to be a variant of *Z. marina*.

- *Zostera* plants often grow in dense ‘beds’ or ‘meadows’. Where they are extensive, these beds provide a habitat for a wide range of flora and fauna, including young stages of commercially-important fish and crustaceans. They also are important feeding grounds for wildfowl. Eelgrass beds are therefore an important reservoir of coastal biodiversity.

- In addition to their role as a habitat for other organisms, *Zostera* beds are highly productive and are a major source of organic matter in the coastal ecosystem. The root networks of the plants stabilize the sediment and act to reduce erosion of the shoreline.

- The three *Zostera* species are widely but patchily distributed around the UK. *Zostera* is found in five out of the seven Annex I habitats defined in the EU Habitats Directive, and in 10 of the ‘demonstration’ SACs considered by the UK Marine SACs Project.

- *Zostera* beds were formerly much more extensive and widespread around the UK, but were severely reduced by an outbreak of epidemic disease in the 1920s. Recovery since then has been slow and patchy. The coastal habitats favoured by *Zostera* are under increasing threat from coastal development, pollution and other forms of human disturbance. Seagrass biotopes are vulnerable to these impacts, and as a result of their economic and ecological importance, are considered as a high priority for conservation measures.

II
ENVIRONMENTAL REQUIREMENTS AND PHYSICAL ATTRIBUTES

This chapter summarizes the available information on the environmental factors which affect the distribution and extent of *Zostera* biotopes in the UK. Some of these important environmental parameters can be affected by human influences on the coastline, in ways which adversely affect the survival and growth of *Zostera.* These influences will be discussed in Chapter V.

A. PHYSICAL ENVIRONMENT

1. Habitat preferences of British Zostera species

The three British species of *Zostera* differ slightly in their typical depth, substratum and salinity preferences (Stewart et al., 1994) . These are summarized below and discussed in greater detail in the succeeding sections.

	Zostera marina	**Zostera angustifolia**	**Zostera noltii**
Substratum	Coarse sediments, sand - fine gravel	Mud or muddy sand	Typically on mixtures of sand and mud.
Depth	Subtidal, typically to 4 m.	Intertidal, mid- to low-tide mark. Rarely to 4 m.	Intertidal, never found below low-tide mark..
Dessication resistance	Intolerant of dessication	Occurs intertidally, but typically in poorly-draining sediments	Most resistant to dessication. Occurs higher on the shore than the other species
Salinity	Avoids brackish water	Typically in conditions of variable salinity	Can occur in variable salinities

2. Substratum type, water movement and stability of Zostera beds

Substratum type and water movement are considered together because of the close linkage between sediment grade and the degree of exposure to tides and currents. Finer sediments will generally occur in situations of lower water movement. As illustrated in the location maps, site descriptions and MNCR biotope classifications from Chapter I, all three *Zostera* species require sandy to muddy substrata and sheltered environments, such as enclosed bays or coastal areas with a gentle longshore current and tidal flux. Dense swards of *Zostera* are typically found on muds and sands in sheltered inlets and bays, estuaries and saline lagoons. In more unstable, higher energy (wave or current exposed) sites, the beds tend to be smaller, patchier and more vulnerable to storm damage.

Olesen & Sand-Jensen (1994a) reported that in Danish waters, new *Z. marina* beds took at least five years to become established and stable, and that the survival and viability of the bed was strongly influenced by its size. Small patches with less than 32 shoots showed high mortality, but as the sizes and ages of the patches increased, mortality declined. Once established, a dense bed of *Zostera* plants reduces current flow, leading to increased deposition of suspended sediment and organic detritus (much of the latter derived from the plants themselves). This enhanced deposition rate, together with the sediment-binding effect of the rhizome network, reduces erosion and acts to stabilize the substratum. Conversely, if an established, continuous bed becomes fragmented for any reason, the bed will tend to become less stable and more vulnerable to the normal forces of erosion. Channels may form, the cover may become patchier and if the trend continues, isolated patches will develop which are more likely to be washed away. It would appear that there is a threshold of loss, below which destabilization and further losses of beds can occur (Holt et al., 1997).

Ranwell et al. (1974) proposed that *Zostera* requires a sediment regime that closely balanced between the forces of erosion and accretion. They monitored sediment levels during transplant trials in Norfolk and found that during the summer growth period, the intertidal *Zostera* patches accumulated about 2 cm of silt, so that the patches became slightly raised. However, sediment accreted during the summer was lost when the leaves died back in the autumn and winter. Such a balance is potentially important for *Zostera* plants. For example, in subtidal beds of *Z. marina*, sedimentation can cause the level of the bed to rise, resulting in plants growing closer to the surface and increasing the likelihood of the plants being partially exposed at low tide and subject to higher temperatures and dessication in summer. At the other extreme, Portig et al. (1994) suggested that where sediment deposition exceeds sediment erosion, eelgrass beds could potentially become smothered.

Zostera beds tend to be reasonably stable once established, especially where the beds are formed by the perennial *Z. marina*. The more exposed intertidal beds of *Z. angustifolia* and *Z. noltii* are in general more susceptible to environmental fluctuations and episodic events such as severe storms or floods. The shallower-growing plants may also be more susceptible to the side-effects of human activities, such as increased sedimentation from large-scale dredging or other coastal engineering projects.

3. Light, depth and water clarity

These three interlinked factors will influence the depth to which *Zostera* is found. Like all plants, *Zostera* requires a particular light regime to photosynthize and grow. The amount of sunlight that filters through the water column (irradiance) is reduced as water depth increases, and is also affected by the clarity of the water. Turbidity affects *Zostera* growth by significantly reducing light penetration, thus restricting the amount of photosynthetically active radiation available to the submerged plants. Increases in turbidity are a commonly cited factor in the decline of eelgrass beds, particularly those of *Z. marina* (e.g. Giesen et al, 1990a, b).

Around the British Isles, *Z. marina* typically occurs down to 4 m but may extend deeper in some locations (Stace, 1997). In the very clear waters of Ventry Bay, south-west Ireland, *Z. marina* occurs in a continuous bed from 0.5 m to 10 m, and in patches to a maximum depth of 13 m (Whelan & Cullinane, 1985), probably the deepest-growing *Zostera* in north-west Europe. Off the north-west American coast, the maximum depth at which eelgrass has been recorded growing is 6.5 m. However, in the extremely clear water off the Californian coast, eelgrass has been found growing at depths of more than 30 m (Teal, 1980).

Jimenez et al. (1987) found that *Z. noltii* is better adapted to high light intensities than *Z. marina* (= *Z. angustifolia* ?) and this is probably one of several adaptations that allows *Z. noltii* to occur higher up the shore than *Z. angustifolia*.

4. Temperature and dessication

It appears that *Zostera* can tolerate sea surface temperatures ranging from about 5 - 30^o C, with an optimum growth and germination range of 10 - 15 ^{o}C (Yonge, 1949). Young concluded that the northern distribution of the genus was controlled by this breeding temperature 'window' and that the southern limit was set by the direct effect of heat upon the plant. Den Hartog (1970) stated that *Z. marina* generally tolerates temperatures up to 20^{o}C without showing signs of stress.

Although *Z angustifolia* and *Z. noltii* are more adapted to intertidal conditions and can tolerate a broader temperature range than *Z. marina*, their upper shore habitat renders them more exposed to extremes of cold or heat when exposed at low tide or in very shallow bays. Den Hartog (1987) suggested that cold winters can result in significant losses. In extreme winter conditions, the formation of ice amongst the sediments of exposed intertidal eelgrass beds can lead to the erosion of surface sediments and the uprooting of rhizomes, as well as direct frost damage to the plant. Critchley (1980) reported that intertidal *Zostera* beds at Bembridge, Isle of Wight were damaged by frost. Covey & Hocking (1987) observed that in the Helford River, during exceptionally cold weather in January 1987, ice formed in the upper reaches of the mudflats and led to the defoliation of *Z. noltii* (the rhizomes survived).

With regard to dessication, *Z. noltii* is typically found on areas of intertidal sediments that drain well while *Z. angustifolia* dominates areas where water is retained (Duncan, 1991; Fox et al., 1986). *Zostera marina* grows mainly in the shallow sublittoral, and is less resistant to desiccation. Tutin (1938) suggested that this may be due to the rigidity of the base of the plant, which results in a short length of stem being exposed to the air during very low tides. Thirty minutes exposure on a warm, sunny day can kill the base of the leaves. *Zostera angustifolia* is less susceptible to desiccation because its flexible shoots lie flat at low tide when unsupported by water and it tends to grow in waterlogged sites. *Zostera noltii* occurs higher up the shore than the other two *Zostera* species and is the best adapted to coping with aerial exposure and desiccation. In well-drained sites *Z. noltii* may dry out completely twice a day.

5. Salinity

Mature *Zostera* plants have a wide tolerance to salinity changes. McRoy (1966) reported optimum salinities of 10 - 39 parts per thousand, while den Hartog (1970) reported tolerance of 5 parts per thousand. in the Baltic. Subtidal populations of *Z. marina* that are not subjected to lowered salinity produce few or no reproductive shoots (Giesen et al., 1990b). Laboratory studies indicate that maximum germination in *Z. marina* occurs at 1 part per thousand salinity (Hootsmans et al., 1987). This low salinity figure is surprising as *Z. marina* occurs almost exclusively in fully saline conditions. However, field studies indicate that germination in *Z. marina* occurs over a range of salinities and temperatures (Churchill, 1983; Hootsmans et al., 1987).

6. Nutrients

Nutrient uptake by *Zostera* from the water column occurs through the leaves and from the interstitial water via the rhizomes. Nitrogen is usually the limiting element and is most easily absorbed as ammonium. In sandy sediments, phosphate may become a limiting factor due to its adsorption onto sediment particles (Short, 1987).

In the laboratory, Roberts et al. (1984) found that moderate nutrient enrichment of the sediments stimulated the growth of *Z. marina* shoots. Tubbs & Tubbs (1982) observed that an increase in Z*ostera* beds paralleled an increase in the nutrient input to the Solent. However, excessive nutrient enrichment has been cited as a factor in the decline of *Zostera* beds in many parts of the world. This issue is considered in further detail in Chapter V.

B. BIOTIC ENVIRONMENT

In addition to the physical parameters of the environment, the growth and survival of *Zostera* plants will be affected by the activities of other organisms which co-occur with them in these biotopes. In this respect, two factors that have been cited are the grazing of epiphytes growing on *Zostera* leaves, and the removal of excess sediment by the activities of wildfowl.

1. Epiphyte grazing

Zostera leaves provide a substratum for the growth of epiphytic algae. Excessive algal growth can smother the *Zostera* plants, but this is counteracted by the grazing activities of animals such as gastropods. Epiphyte grazing may be important in maintaining the health of *Zostera* plants. Phillipart (1995) demonstrated experimentally that increased numbers of the gastropod *Hydrobia ulvae* reduced the density of epiphytes on *Zostera noltii* and led to enhanced growth of the eelgrass. He noted that populations of *H. ulvae* decreased on the tidal flats of the Dutch Wadden Sea in the early 1970s. This coincided with the appearance of very heavy epiphyte fouling in some areas and may have contributed to the later decline of *Z. noltii.* Similar results were obtained by Nelson (1997), studying *Z. marina* in Puget Sound. The gastropod *Lacuna variegata* was shown to be capable of reducing the epiphyte biomass to levels well below those sometimes found in the field. The *Zostera* plants had a healthier appearance in the presence of the snails and it was demonstrated that heavy epiphyte growth could permanently damage leaves.

2. Sediment removal by wildfowl

As described previously, *Zostera* beds encourage sedimentation. The consequent accumulation of material can increase aerial exposure and the likelihood of desiccation. However, Jacobs et al. (1981) suggested that the feeding activities of overwintering wildfowl cause some of this sediment to be resuspended, and that this may play an important part in preventing excessive build-up of sediment around the *Zostera* plants.

C. KEY POINTS FROM CHAPTER II

- All three British *Zostera* species occur on sheltered sediments where there is a close balance between the rates of sediment erosion and accretion.

- The three species have slightly differing habitat preferences. *Zostera marina* occurs subtidally on relatively coarse sediments and is not found in brackish water. *Zostera angustifolia* and *Z. noltii* are found intertidally on finer substrata and can tolerate variable salinities. *Zostera noltii* is the most tolerant of dessication and occurs highest on the shore.

- Survival and growth of subtidal *Z. marina* will be affected by water turbidity, with plants growing deeper where the water is clearest (and light penetrates further). Lower depth limit is typically about 4 m, but may exceed 10 m in exceptional circumstances.

- Intertidal *Z. angustifolia* and *Z. noltii* will be more exposed to extremes of temperature than *Z. marina*. Freezing conditions can cause defoliation or death of the plants.

- *Zostera* growth can be stimulated by modest nutrient enrichment, but excessive input of nutrients can have deleterious effects.

- The removal of epiphytic algae by grazing invertebrates such as gastropods may be important in maintaining the health of *Zostera* plants.

- Excessive build-up of sediment in *Zostera* beds may also be harmful to the plants. The feeding activities of wildfowl may remove accumulated sediment and help counteract this accretion.

III
BIOLOGY AND ECOLOGICAL FUNCTIONING

This chapter will review what is known of the biology and ecology of the three *Zostera* species found around the UK, focusing on growth and reproduction of the *Zostera* plants themselves, primary productivity, associated fauna and flora, and ecological relationships within the biotope.

A. BIOLOGY OF *ZOSTERA*

1. Vegetative growth

Eelgrass growth is seasonal and closely related to environmental temperature. In Britain, growth generally occurs during the spring and summer, from April to September. In Danish waters, leaf biomass has been found to quadruple and rhizome mass to double during this period (Sand-Jensen & Borum, 1983).

Zostera invests a large proportion of its resources in the maintenance of rhizomes and roots. The underground mat of horizontal rhizomes branches during growth, producing vertical leaf shoots, which are responsible for the lateral expansion of patches. Short pieces of rhizome that break off the parent plant and are carried away by currents may generate new plants if deposited on a suitable substratum (Olesen & Sand-Jensen, 1994b). Eelgrass populations can therefore expand either by the vegetative growth of shooting rhizomes that have survived the winter, or sexually, by production of seed. Subtidal *Z. marina* beds in the UK are perennial and are believed to persist almost completely as a result of vegetative growth rather than by seed production.

In intertidal populations of *Z. noltii* and *Z angustifolia*, new leaves appear in spring and the eelgrass meadows develop over the intertidal flats during the summer. Leaf growth ceases around September or October (Brown, 1990), and leaf cover begins to decline during the autumn and over the winter. Intertidal plants may experience a complete loss of foliage, dying back to the buried rhizomes. Natural leaf-fall, grazing by wildfowl and a few specialized invertebrates and removal by wave action are the major factors contributing to this seasonal disappearance of the leaves. In perennial populations, the rhizomes survive the winter to produce new leaves the following spring, while in annual populations, both the leaves and rhizomes die. In contrast to the two intertidal species, sublittoral *Z. marina* beds can remain green throughout the year, as summer leaves that are shed in the autumn are generally replaced with smaller winter leaves.

2. Sexual reproduction: flowers and seeds

In all three species, flowers and seeds are generally produced between early/late summer (May/July) and early autumn (September) (Brown, 1990; Tubbs & Tubbs, 1983). *Zostera* flowers are highly adapted to optimize pollination efficiency in an aquatic environment (Ackerman, 1983, 1986). The male flowers release long filamentous strands of pollen into the water. The density of these pollen filaments enables them to remain at the depth at which they were released for periods of up to several days, so increasing the likelihood of the pollen filaments encountering receptive stigmas. After fertilization, the seed develops within a green membranous wall which photosynthesises, producing a small bubble of oxygen that is trapped inside the seed capsule. Eventually this forces the capsule wall to rupture, releasing the mature seed. The seeds generally sink and are dispersed by currents, waves and, possibly over short distances, on the feet of birds. However, Churchill et al. (1985) found that the bubble can adhere to the seed's coat, increasing its buoyancy and consequently its likelihood of dispersal.

Relatively high temperatures (above 15 oC) appear to be required for flowering and seed germination, suggesting that sexual reproduction does not play a major role in the life history of *Z. marina* in northern latitudes. In comparison, the *Z. angustifolia* and *Z. noltii* intertidal beds in the UK rely on a combination of vegetative growth and seed set. *Zostera angustifolia* appears to rely more on seed set while *Z. noltii* appears to rely more on vegetative growth (Cleator, 1993; Rae, 1979; van Lent & Vershuure, 1994a,b).

3. Population structure

Zostera patches resulting from vegetative growth will be composed of plants with an identical genetic composition. Beds formed largely by this process will as a result be less genetically diverse than those arising from sexual reproduction. This may have a major impact upon the resilience of a bed to anthropogenic impacts. In intertidal eelgrass beds, the genetic composition can be complex as both *Z. angustifolia* and *Z. noltii* rely on a combination of vegetative growth and seed set. The situation can be made more complex still as often both species often co-occur in mixed beds (Cleator, 1993).

Molecular-genetic techniques can be used to assess the relative importance of vegetative growth and sexual reproduction in determining population structure. Alberte et al. (1994) used DNA fingerprinting to assess the genetic similarity of three geographically and morphologically distinct populations of *Z. marina* from central California. They found that the within- and between-population genetic diversity were both higher than expected for largely vegetatively-reproducing populations, indicating that some sexual reproduction was occurring. In addition, they found that the genetic diversity of an intertidal population in a disturbed habitat was lower than that of one occurring in a more pristine habitat 30 km away. This research suggests that there may be significant differences between populations of *Zostera* in the relative importance of sexual and vegetative reproduction.

B. ECOLOGICAL FUNCTIONING OF *ZOSTERA* BIOTOPES

The extensive rhizome networks and above-ground leaf meadows of eelgrass create a complex biotope that significantly affects the functioning of the local coastal ecosystem and also provides a habitat for a diverse range of organisms. Significant ecosystem-level effects include the stabilization of coastal sediments and the production of organic detritus.

1. Sediment stabilization

As previously mentioned, dense meadows of eelgrass leaves increase rates of sedimentation, and the rhizome and root networks bind the substratum together, thereby reducing sediment erosion. The roots also allow oxygen to penetrate into otherwise impermeable sdiments. The penetration of *Zostera* roots into the sediment aerates the upper layers and provides a more favourable habitat for burrowing animals.

2. Primary productivity

Seagrass meadows are considered to be the most productive of shallow, sedimentary environments. Seagrass primary production supports a rich, resident fauna and as a result, the beds are used as refuge and nursery areas by many species, including commercial fish species (discussed further below). The decomposition of dead seagrass tissue by bacteria drives detritus-based food chains within the *Zostera* bed. High numbers of heterotrophic protists are found in the water column over seagrass meadows and take up both the dissolved organics leaching from the seagrasses and the rapidly multiplying bacteria. Seagrass detritus is also very rich in micro-organisms. 1 g (dry weight) has been calculated to support, on average: 109 - 1010 bacteria, 5 x 107 - 108 heterotrophic flagellates and 104 - 105 ciliates, yielding a total biomass of some 9 mg of bacteria and protists.

In addition to supporting detritus-based food chains within the seagrass bed, dead seagrass leaves can be transported by currents into other coastal biotopes. They can be deposited on the shore as dense drifts and enrich the upper littoral zone (den Hartog, 1987). Exported seagrass material can also enter the food webs of areas distant from the coastal zone. Seagrass leaves have been recorded at depths of nearly 8000 m, and after hurricanes mats of leaves up to 50 m across have been reported from the Florida Current.

3. Associated fauna and flora

The community composition of an eelgrass bed will depend upon a combination of factors, including the species of seagrass, the stability of the bed, the substratum type, salinity, tidal exposure and location. The richness of the community will reflect the variety and density of microhabitats and the local ecological conditions. The three *Zostera* species are found on similar substrata but in different tidal zones. Species diversity tends to be highest in the subtidal, fully marine, perennial populations of *Z. marina* and tends to be lowest in the intertidal, estuarine, annual beds of *Z. angustifolia* and *Z. noltii* (Jacobs & Huisman, 1982).

Detailed species lists for a number of the major British eelgrass beds have been compiled, including those in the Salcombe Estuary (Gardener, 1934), Helford Passage (Turk, 1990), Isles of Scilly (S. Hiscock, 1986) and Skomer (K. Hiscock, 1980, 1987). The characteristic and representative plant and animal species found in UK *Zostera* beds are listed in Appendix 2. Three major components of the eelgrass bed community are discussed below: epiphytes and non-epiphytic alage, invertebrates and fish living amongst the eelgrass, and wildfowl.

a. Epiphytes and other algae

Living *Zostera* leaves provide a suitable substratum for numerous epiphytic algae, while other algae live between the seagrass shoots and within the surface layers of the underlying sediment. Whelan & Cullinane (1985) identified 60 algal species in a *Z. marina* bed in Ventry Bay, Ireland. A number of species (eg. the brown algae *Halothrix lumbricalis* and *Leblondiella densa*) are found only on *Zostera* leaves, while the large brown alga *Cladosiphon contortus* occurs principally on *Zostera* rhizomes.

Zostera beds are generally rich in epiphytes but poor in associated macroalgae owing to the shading effect of the dense eelgrass swards. In sandy habitats *Chorda filum* is often found with *Z. marina.* On mixed substrata, a layering of flora can be observed, with *Zostera* plants protruding up through stones colonized by macroalgae such as *Halidrys siliquosa* and *Laminaria saccharina,* often with *Cystoseira* sp. at the margins of the eelgrass bed (Whelan & Cullinane, 1985).

The algae found within *Zostera* beds are more digestible than the eelgrass itself and support the majority of the abundant grazers found within seagrass communities. In relatively open stands, the benthic algae may account for 70% of the total primary production of the bed. However, in dense beds, the thick carpets of *Zostera* leaves can reduce light availability for the algal understorey and as a result productivity is lower. Estimates of epiphytic productivity are relatively scarce but biomasses of the same order as those of the leaves to which they are attached are known.

b. Invertebrates and fish

A wide variety of invertebrate species occur on and among the plants of an eelgrass bed. Small gastropods grazing the algal epiphytes on the *Zostera* leaves include *Hydrobia* spp., *Rissoa membranacea* and *Littorina littorea.* The sediments underlying the beds support large numbers of polychaete worms (eg. *Arenicola marina, Lanice conchilega*) , bivalve molluscs (eg. *Cerastoderma edule, C.* glaucum) and burrowing anemones (eg. *Cereus pedunculatus*). Amphipod and mysid crustaceans are among the most abundant and important of the mobile fauna living amongst the eelgrass leaves.

Eelgrass beds are widely recognized to be important spawning and nursery areas for many species of fish, including commercial species. Smaller fish species include two-spot gobies *Gobiusculus flavescens,* and 15-spined stickelbacks *Spinachia spinachia.* Larger, commercially-important species using eelgrass beds as feeding grounds include bass *Dicentrarchus labrax.* Seahorses, *Hippocampus* spp., reach their northern limits in eelgrass beds along the south coast of England.

Eelgrass beds may act as corridor habitats for species migrating north from warmer water. The first (as yet unconfirmed) British record of the green wrasse, *Labrus turdus*, comes from eelgrass beds in the Isles of Scilly. The species is normally associated with seagrass beds in the Mediterranean (Fowler, 1992).

c. Wildfowl

Wildfowl (ducks and geese) are among the few animals which graze directly upon *Zostera* and are able to digest its leaves. In Britain, *Zostera* is an important constituent of the diet of two sub-species of Brent geese *Branta bernicla*, wigeon *Anas penelope*, mute swans *Cygnus olor*, and whooper swans *C. cygnus*. Teal *Anas crecca* are reported to consume eelgrass seeds (Tubbs & Tubbs, 1983).

Since the occurrence of wasting disease and the consequent decline of *Z. marina* beds, the relative importance of the different *Zostera* species in Brent geese diet has shifted. *Zostera noltii* has replaced *Z. marina* as the preferred food and currently provides the main source of energy for Brent geese overwintering in Britain.

Ogilvie & Matthews (1969) reported that in Europe, the decline of the population of dark-bellied Brent geese (to approximately 25% of its pre-1930s level) strongly paralleled the decline in *Zostera* following the wasting disease epidemic. Since it appears that the intertidal *Zostera* species were not as severely affected by the wasting disease as *Z. marina*, it can be assumed that *Z. marina* must have been the preferred food species prior to the epidemic (Charman, 1977). As a result of the decline of *Z. marina* and its slow recovery, Brent geese were forced to migrate to other feeding areas and to switch their feeding to intertidal beds of

Z. angustifolia and *Z. noltii*. Burton (1961) studied dark-bellied Brent geese on the Essex coast in the late 1950s and early 1960s and found that they fed almost entirely on *Z. noltii* and the alga *Enteromorpha*. Both he and Ranwell & Downing (1959) suggested that *Z. angustifolia* was not the preferred species because it had shed most of its leaves before the migrant geese arrived in Britain. Charman (1975) found that when Brent geese had exhausted the *Zostera* stock along the Essex coast, they had to move onto less preferred food sources, including *Enteromorpha* and saltmarsh plants, and then onto less traditional food sources such as inland pastures and winter cereals.

This shift in eelgrass abundance from *Z. marina* to *Z. noltii* has also affected wigeon. Wigeon numbers have declined dramatically in recent years and the availability of eelgrass is considered to be one of the contributory factors. Grazing wigeon are very vulnerable to human disturbance. Where wildfowling is popular, wigeon appear to avoid the *Z. noltii* beds near the top of the shore and only begin to feed there when the *Z. angustifolia* and *Z. marina* lower down the shore are exhausted (Percival & Evans, 1997).

C. KEY POINTS FROM CHAPTER III

- Leaf growth in *Zostera* takes place over the spring and summer. Beds may spread vegetatively - by growth from dispersed fragments of rhizome, or by dispersal of sexually-produced seeds.

- *Zostera marina* is considered to be a perennial plant and sexual reproduction does not play a major role in its life history of in northern latitudes. Populations are maintained largely by vegetative growth and dispersal.

- *Zostera angustifolia* populations can be either perennial or annual, relying on a combination of vegetative growth and seed set, though seed set appears to be the more important process. British *Z. noltii* beds appear to persist mainly by vegetative growth, despite prolific seed production.

- The differing emphasis on vegetative growth and sexual reproduction can result in a complex genetic structure in *Zostera* populations, with consequences for their resilience in the face of environmental change.

- Subtidal eelgrass beds are one of the most productive of shallow-water sedimentary environments. The transfer of energy through the ecosystem is via direct grazing of *Zostera* (by the few species that possess cellulose-digesting cultures of gut bacteria and can utilize seagrass production directly), and via detrital pathways. The majority of consumers are dependent upon the decomposition of eelgrasses.

- *Zostera* detritus transported by currents can make an important contribution to ecosystems at considerable distances from the eelgrass beds.

- *Zostera* beds, particularly those of *Z. marina*, are species-rich habitats. Species diversity tends to be highest in the subtidal, fully marine, perennial populations of *Z. marina* and lower in the intertidal, estuarine, annual beds of *Z. angustifolia* and *Z. noltii*. Some algal species are obligate associates of *Zostera*.

- *Zostera* is an important food resource for several wildfowl species. Declines in populations of wigeon and dark-bellied Brent geese parallel the decline of *Z. marina*. *Zostera noltii* has replaced *Z. marina* as the main food source for Brent geese.

IV
SENSITIVITY TO NATURAL EVENTS

Like all marine biotopes, eelgrass beds are subject to natural change. *Zostera* beds are known to be spatially dynamic, with advancing and receding leading edges, causing changes in coverage. Naturally-occurring changes can take place at a range of scales, with effects ranging from small alterations to *Zostera* coverage or density, to destruction of entire beds over large geographic areas. This chapter considers the main naturally-occurring processes known to affect eelgrass beds. Changes induced by human activities are considered in Chapter V.

Naturally-occurring agents of change can be conveniently divided into those relating to the physical and biotic environments of *Zostera* beds.

A. PHYSICAL ENVIRONMENT

Zostera beds typically occur in physically-sheltered environments such as shallow inlets and lagoons. The plants stabilize the sediment within the beds and the canopy of leaves reduces current flow (Fonseca and Fisher, 1986). However, increased wave action and current flow, particularly during storms or floods, can remove sediments and cause damage to the eelgrass beds.

Storms and hurricanes have been observed to remove large areas of *Z. marina* (Wyer et al., 1977; Orth & Moore, 1983; den Hartog, 1987, Aio & Komatsu, 1996). After storms, large amounts of *Zostera* material can be deposited on the strandline of the shore. Fowler (1992) reported the degradation of *Z. marina* beds around the Isles of Scilly following winter storms in 1989 and 1990. Floods can also damage seagrass beds (Preen et al., 1995).

In extremely cold winters, the formation of ice amongst the sediments of eelgrass beds can lead to the erosion of surface sediments as well as uprooting of rhizomes and frost damage to foliage (Den Hartog, 1987). Critchley (1980) observed frost damage to *Zostera* on the Isle of Wight.

B. BIOTIC ENVIRONMENT

1. Wasting disease

Potentially the greatest natural threat to eelgrass beds is the periodic outbreak of wasting disease, which appears to principally affect sublittoral beds of *Z. marina*. Between the 1920s and mid-1930s, formerly extensive eelgrass beds on both sides of the Atlantic experienced significant declines in the first recorded major outbreak of the disease. By the end of this outbreak, wasting disease had been reported throughout western Europe. The narrow-leaved form of *Zostera* (presumably *Z. angustifolia*) was less affected by the disease, while *Z. noltii* did not appear to be affected at all (Rasmussen, 1977).

The symptoms of wasting disease are the appearance of rounded, dark brown spots on the leaves, which coalesce until the leaf is completely blackened. The leaves die and detach from the main plant, the regenerative shoots decay and after two or three seasons of this defoliation,

the rhizomes discolour and die. The final stages of this disease can be devastating, with up to 90% of the plants being lost and the bed being laid bare.
The indirect effects of the disease were also severe. A variety of characteristic and representative species declined or disappeared, some fisheries declined and a number of beaches and sandbanks, previously protected by eelgrass, experienced increased erosion. The food supplies for overwintering wildfowl (wigeon, Brent geese and swans) were reduced, forcing the birds to migrate to different feeding grounds

Recovery did not begin until the mid-1930s and has generally been slow. A further decline in the Dutch Wadden Sea was reported in the 1970s (Den Hartog & Polderman, 1975; Polderman & den Hartog, 1975; van den Hoek et al., 1983). In the early 1980s, wasting disease reappeared on the east coast of North America (Tubbs, 1995; Short et al., 1986; Short et al., 1988). Between 1987 and 1992, symptoms of wasting disease appeared in several populations in north-west Europe, including estuaries on the southern coast of England and the Isles of Scilly (Fowler, 1992).

The causes of wasting disease have been debated since the 1920s - 1930s epidemic and several causative factors were suggested, including a number of fungal, bacterial or protozoan pathogens. After the 1980s outbreak, research in America identified the pathogen as the fungus *Labyrinthula macrocystis*. Muehlstein et al. (1988, 1991) showed that *Labyrinthula* does not generally cause disease in low salinities, explaining why UK populations of the intertidal *Z. angustifolia* and *Z. noltii* appear to have been relatively unaffected by wasting disease.

It is likely that the causative factor, presumed to be *L. macrocystis*, persists at low, harmless levels within *Zostera marina* populations between epidemics. The reasons for the disease outbreaks are not fully understood (Giesen et al., 1990a, b), but it is possible that *Zostera* plants only succumb when stressed by other environmental factors such as low levels of insolation, increases in water temperature, or pollution (Short et al., 1988). The disease may occur periodically, in an unredictable long-term cycle whose triggering factors remain to be identified.

2. Wildfowl grazing

Several studies in Britain have monitored changes in eelgrass populations in relation to grazing by overwintering wildfowl, particularly wigeon and Brent geese. *Zostera* is an important food source for wildfowl, providing a concentrated and nutritious food supply that quickly replenishes energy reserves expended during migration. As overwintering wildfowl numbers can fluctuate from year to year, often related to weather patterns, the grazing pressure on *Zostera* can be highly variable. When migrant birds arrive at their overwintering site, they generally preferentially feed on eelgrass and only switch to algae when the *Zostera* resource becomes exhausted. Wyer et al. (1977) suggested that Z. *noltii* is the most important of the three species. It retains its leaves well into the winter, unlike the other two species which begin shedding their leaves in the late autumn. As *Z. noltii* is found highest up the shore, the low water grazing period is longer.

Wigeon nip off the eelgrass, blade by blade, without much waste. Brent geese tear up parts of the plant and the material they do not consume floats away on the surface. However, when they stop feeding directly on the eelgrass beds due to the rising tide, they may later locate and feed on this floating ‘reserve’ material (Butcher, 1941a). Swans tear up large quantities, with the rhizomes attached, but do not consume all the plant material disturbed. Madsen (1988) found that geese feed preferentially on above-ground material and only shift to the below-ground material at lower *Zostera* densities. However, in Strangford Lough, Portig *et al* (1994) found that the impact on the below-ground biomass occurred as soon as birds arrived, as the *Zostera* occurs on thixotropic mud which liquefies on disturbance, making it easier for the birds to paddle and dig for rhizomes.

Grazing wildfowl can consume a high proportion of the available standing stock of *Zostera*. Portig et al. (1994) found that in Strangford Lough, 65% of the estimated biomass (~1100 tonnes fresh weight) of *Zostera* was consumed by grazing wildfowl but that up to 80% was disturbed by their feeding activity. The above-ground biomass (~330 tonnes fresh weight) was reduced by 93% while the below-ground biomass (~770 tonnes fresh weight) was reduced by 74%. Tubbs and Tubbs (1983) reported that Brent geese grazing resulted in the cover of *Z. marina* and *Z. noltii* being reduced from 60-100% in September to 5-10% between mid-October and mid-January. Jacobs et al. (1981) estimated that grazing wildfowl consumed 50% of the total standing stock of *Z. noltii* at Terschelling in the Dutch Wadden Sea. Madsen (1988) reported that in the Danish Wadden Sea, dark-bellied Brent geese consumed 91% of the *Zostera* biomass in consecutive years.

At Lindisfarne, Northumberland, Percival (1991) reported that grazing pressure did not affect the percentage cover of *Zostera* until late winter and that most of the loss appeared to be due to other factors, particularly wave action during storms. It appears that *Zostera* can recover from ‘normal’ levels of wildfowl grazing (Charman, 1979; Madsen, 1984; O’Brian, 1991; Ranwell, 1959; Tubbs & Tubbs, 1982), but if a bed is stressed by other factors it may be less able to withstand grazing pressure. An example of this was reported by den Hartog (1994b) who found that Brent geese may have removed the few remaining healthy plants that survived after beds of *Z. marina / Z. angustifolia* in Langstone Harbour had been overwhelmed by growth of the alga *Enteromorpha.*

3. Epiphyte grazing

It was noted in Chapter II that epiphyte grazers such as *Hydrobia ulvae* can contribute to the health of *Zostera* plants by removing the algae which foul the eelgrass leaves. Any factors (natural or anthropogenic) which reduce grazer populations or cause increased proliferation of algae may therefore have an indirect adverse impact on the *Zostera* bed. The factors most likely to cause such changes are pollution incidents (causing grazer mortality) or excessive nutrient enrichment (causing eutrophication). These processes are most likely to occur as a result of human activities and will therefore be discussed more fully in Chapter V.

C. KEY POINTS FROM CHAPTER IV.

- *Zostera* beds are spatially dynamic, and subject to a number of naturally-occurring factors which can cause changes in coverage at a range of scales.

- Extreme weather conditions such as violent storms or heavy floods can denude eelgrass beds over wide areas. Plants can also be killed or damaged by severe frosts.

- Wasting disease is the most important factor observed to cause long-lasting declines in the number and extent of *Zostera* beds. The most severe outbreak of this disease took place in the early 1930s, and recovery from this is still incomplete.

- The disease-causing agent is the fungus *Labyrinthula macrocystis*. This is probably continually present at low levels, but undergoes occasional epidemic outbreaks for reasons which are not fully understood.

- *Labyrinthula* does not appear to cause disease in conditions if low salinity, so that the intertidal/estuarine *Zostera* species (*Z. angustifolia* and Z. *noltii*) are much less susceptible than *Z. marina*, which prefers subtidal marine conditions.

- Widlfowl grazing can remove a high proportion of the available *Zostera* biomass (over 90% in some cases), but beds can normally withstand this grazing pressure unless under stress from some other factor.

- Declines in populations of epiphyte grazers can indirectly affect the health of *Zostera* beds by allowing increased growth of fouling algae. Nutrient enrichment or other forms of anthropogenic pollution are the factors most likely to bring about such changes.

V
SENSITIVITY TO HUMAN ACTIVITIES

A large proportion of the UK's population lives on or adjacent to the coast. As a result, pollution, development and recreation pressures are increasingly affecting the coastal environment, and their impacts can be especially acute in the shallow bays, estuaries and lagoons where *Zostera* biotopes most commonly occur. Holt et al. (1995, 1997) concluded that *Z. marina* is extremely sensitive to human-induced changes in the coastal environment, particularly in relation to eutrophication, sedimentation and turbidity. In addition to the direct impacts on *Zostera* plants, many human activities will affect the other species associated with the eelgrass biotope. In some cases, the eelgrass fauna may be more susceptible than the *Zostera* itself.

This chapter considers the range of human activities that have been shown to affect the extent and viability of *Zostera* beds and their associated flora and fauna. Human impacts can be conveniently grouped into the following broad categories:

- Coastal development
- Water pollution
- Physical disturbance
- Introduction of non-native species
- Effects on wildfowl distribution and behaviour

In addition, human-induced climate change may ultimately prove to have significant consequences for the distribution and health of coastal biotopes, including eelgrass beds, although its likely effects are difficult to predict.

A. COASTAL DEVELOPMENT

As noted in Chapter II, the long-term survival of *Zostera* beds requires an equilibrium between the processes of sediment accretion and erosion. Water clarity is also very important, as this affects the amount of light available for photosynthesis and so determines the depth to which the plants can grow. Many forms of coastal development can strongly influence the local hydrographic regime, causing profound changes in rates of sedimentation and erosion, and increasing the quantities of suspended sediment in the water column. The most common activities of this kind include:

- Construction of docks, piers, coastal defences and marinas
- Pipeline laying
- Channel dredging
- Land reclamation
- Seabed or water extraction

Increased sediment erosion has been strongly implicated in the loss of seagrass (*Posidonia* sp.) beds in the Mediterranean (Boudouresque & Meinesz, 1982) and *Posidonia* and *Heterozostera* beds in Australia (Shepherd et al., 1989). In both the Mediterranean and Australia, it has been shown that such seagrass losses can be self-perpetuating. Sediments that are no longer stabilized by seagrasses erode more quickly and the turbidity resulting from the increased sediment load in the water can lead to further degradation of beds (Shepherd, et al., 1989).

Increased sediment accretion has caused losses of seagrass beds in several parts of Australia (Shepherd et al., 1989). Reduction in light penetration is a major contributory factor in these declines but it has been suggested that other factors such as changes in the redox potential of surface sediments may have additional impacts (Thayer et al., 1975). Sediment accretion around the cofferdam for the Second Severn Crossing appears to have caused a decrease in the extent of the *Zostera* bed in the Severn Estuary pSAC (M. Hill, pers. comm.).

Butcher (1941a) suggested that the decline of *Zostera* beds in the Solent prior to the 1950s, may have been related to dock construction and channel dredging. Tubbs (1995) suggested that in the estuaries of southern and eastern England, where *Zostera* was formerly widespread and abundant, an adverse silt budget arising from a steepening shore profile, associated with a rise in sea level, may have limited recolonization.

Giesen et al. (1990a, b) suggested that in the Wadden Sea, increased turbidity caused by deposit extraction and dredging activities (and exacerbated by eutrophication) was a major factor in the decline of *Zostera* in the 1970s and 1980s and that fluctuations in salinity and temperature were of minor importance.

B. WATER POLLUTION

Several forms of anthropogenic water pollution can cause loss of, or damage to *Zostera* beds. This can occur rapidly, for example where plants are killed by water-borne toxins or smothered by oil, or over a longer time-scale, as when nutrient input causes eutrophication, with associated increases in turbidity and proliferation of epiphytic algae.

1. Toxic contaminants

There has been relatively little research on the effects of chemicals, other than oil or dispersants, on the growth and survival of seagrasses, but heavy metals, antifoulants and herbicides are all thought to have the potential to cause harmful effects.

a. Heavy metals

A review by Williams et al. (1994) summarized current knowledge on heavy metal uptake and toxicity in saltmarsh plants, including *Z. marina*. They suggested that since *Z. marina* readily takes up heavy metals, mainly through the leaves, this species could be used as an indicator species for heavy metal levels in the surrounding water and sediments. However, they found that heavy metals had not caused any observable damage to *Zostera* plants in the field and concluded that the concentration of heavy metals in most estuaries was not sufficiently high to cause ill effects.

However, Brackup et al. (1985) investigated the effects of a number of pollutants on the nitrogenase activity of *Z. marina* roots. They found that several heavy metals (mercury, nickel and lead) along with a number of organic substances (naphthalene, pentachlorophenol, Aldicarb and Kepone) reduced nitrogen fixation, which may affect *Zostera* viability.

b. Antifoulants

Zostera marina is known to accumulate tributyltin (TBT), found in antifouling paints (Francois et al., 1989), but Williams et al. (1994) found that TBT had not caused any observable damage to *Zostera* plants in the field.

Research on the effects of the triazine herbicide Irgarol, used in antifouling paints, on *Z. marina* has shown that this herbicide is present in the roots and shoots. Triazine herbicides are specific inhibitors of photosynthesis and sublethal effects have been detected (P. Donkin, pers. comm.).

c. Terrestrial herbicides

Terrestrial herbicides entering the coastal zone via streams and rivers may damage eelgrass. The herbicide Atrazine has been implicated in declines of *Z. marina* in Chesapeake Bay (Hershner et al., 1983). Delistraty & Hershner (1984) studied the effects of Atrazine on *Z. marina* and found exposure to 100 ppb over 21 days resulted in growth inhibition and 50% mortality.

2. Oil

In the modern coastal environment, marine biotopes may be exposed to oil pollution from a number of different sources. Continuous, long-term exposure to small concentrations of hydrocarbons may result from proximity to coastal oil refineries, industrial installations or harbours. Conversely, massive, effectively instantaneous exposure will occur in association with major pollution incidents such as oil spills or tanker wrecks. These contrasting degrees of exposure may have quite different consequences for eelgrass beds.

a. Long-term exposure to refinery effluent

Sensitivity to chronic exposure to oil refinery effluent may not be very high. K. Hiscock (1987) reported that there were no long term effects attributable to the presence of an oil refinery on *Zostera* in Littlewick Bay, Milford Haven, Wales, but suggested that this may be due to the effluent not penetrating into this area. Cambridge et al. (1986) and Shepherd et al. (1989) reported that *Posidonia sinuosa* in Western Australia was rather insensitive to oil refinery effluent based field observations and experiments in aquaria. However, they did attribute some local, small-scale, declines to this cause.

b. Major oil spills

In the event of an oil spillage, the likely impact depends upon a number of factors including the type of oil, the degree of weathering and the nature of the habitat. A number of studies have suggested that, in general, it is the associated faunal communities that are more sensitive to oil pollution than the *Zostera* plants themselves (Jacobs 1980, Zieman et al., 1984, Fonseca, 1992). Rocky shore gastropods such as limpets, have been found to be very sensitive to dispersants or oil dispersant mixtures, and it is possible that gastropod grazers on *Zostera* epiphytes may be equally sensitive, which could potentially result in epiphyte overgrowth.

As *Z. noltii* occurs highest up the shore, this species is likely to be the most vulnerable to covering by oil while *Z. angustifolia* and *Z. marina* may be partially protected by seawater from direct contact with the oil. Since *Zostera* generally occurs in sheltered, low-energy sites, natural weathering of oil will be slow.

Jacobs (1980) reported little damage to *Z. marina* in Roscoff after the Amoco Cadiz spill, other than a blackening of the leaves for 1 - 2 weeks. He observed that the growth, production and reproduction of the plants were not affected, despite the leaves being covered for a period of six hours. The fauna of these eelgrass beds was slower to recover than the eelgrass itself.

c. Treatment of oil spills

Major oil spills are often treated with chemical dispersants to encourage break-up of the oil layer. In some cases, these dispersants have been found to be cause greater damage to biological communities than the oil itself.

Holden & Baker's (1980) 11- 16 month studies in Milford Haven found that a single application of either (i) Forties crude oil, (ii) BP 1100 WD dispersant, (iii) oil followed by dispersant or (iv) pre-mixed oil and dispersant, could reduce growth of intertidal *Zostera*. Howard (1986) repeated these earlier experiments and found that that three of the treatments; Nigerian crude oil, Dispolen 34 dispersant and oil followed by dispersant, arrested growth but appeared to cause little change in the *Zostera* cover. In comparison, the plots treated with the pre-mixed oil and dispersant showed rapid death of the leaves and a significant decline in cover one week after application. By the end of the eight week experimental period, cover had been reduced from 55% to 15%.

Howard (1986) also found that pre-mixing the oil and dispersant promoted penetration of oil into the sediment, resulting in a hydrocarbon concentration of more than 7000 ppm 24 hours after application, compared with 1000 ppm in the other treatment plots. The high oil concentrations were not retained within the sediment, and within a week of application, all oiled plots had hydrocarbon concentrations of 500 - 1000 ppm. The main findings of the Milford Haven research are generally similar to the conclusions reached by other researchers, namely that pre-mixed oil and dispersants have the greatest potential for killing seagrasses, whereas contact with oil alone may reduce or halt growth.

Howard et al. (1989) concluded that if oil cannot be prevented from covering eelgrass beds, then dispersant treatments must be avoided in order to minimize the risk of a partly dispersed oil mixture affecting the eelgrass. It was advised that oil coverage on eelgrass beds should be left untreated, and the oil layer allowed to disperse by tidal action.

3. Nutrient enrichment and eutrophication

Eutrophication (excessive proliferation of planktonic or benthic algae) can be caused by increased nutrient inputs, originating from sewage, agricultural runoff or aquaculture. In some cases, local increases in nutrient levels appear to have favourable consequences for eelgrass beds. This is likely to occur in situations where *Zostera* growth is limited by available nitrate (Fonseca et al., 1987, Kenworthy & Fonseca, 1992, Fonseca et al., 1992). Tubbs & Tubbs (1983) reported that rapid increases in the extent of *Zostera* beds paralleled increased volumes of treated and untreated sewage entering three areas of the Solent. However, it was concluded that despite the spatial and temporal associations, there was no direct evidence of a causal relationship.

Eutrophication is more often cited as a major cause of the decline, or the lack of recovery of, *Zostera* beds (Borum, 1985; Wetzel & Neckles, 1986; den Hartog & Polderman, 1975; Orth *et al* 1983; Shepherd et al., 1989; Kikuchi, 1974). A variety of different harmful effects have been identified. These are not mutually exclusive, and several or all of them may apply in any given situation.

a. High nitrate concentrations and metabolic imbalance

High nitrate concentrations have been implicated in the decline of mature *Z. marina* (Burkholder et al., 1992). The meristems of the plants were found to deteriorate and it was suggested that high internal nitrogen concentrations caused a metabolic imbalance. Burkholder et al. (1992) found that nitrate enrichment could cause death or decline in seagrasses, including *Z. marina* in poorly-flushed areas. They found that *Z. marina* was more sensitive than *Halodule wrightii* and *Ruppia maritima* and that the effect was exacerbated by heavy epiphyte growth. In the Dutch Wadden Sea, declines in *Zostera* since 1965 may have been associated with increased nutrient levels (Den Hartog & Polderman, 1975; Polderman & den Hartog, 1975). Kikuchi (1974) made a similar suggestion about the decline of *Zostera* beds in Japan.

b. Increased growth of epiphytic algae

Many studies have correlated seagrass loss with increased growth of epiphytic, blanketing or floating algae, often as a result of eutrophication (e.g. Borum, 1985; Burkholder *et al*, 1992; Orth et al., 1983; Shepherd et al., 1989; Wetzel & Neckles, 1986).

Increased growth of epiphytic algae can result in increased numbers of epiphyte grazers. However, populations of grazers may not be able to respond rapidly enough to utilize and control the epiphytes and the *Zostera* plants may still become smothered.

c. Blanketing algae

Nutrient enrichment can also encourage rapid growth of blanketing algae. Some opportunistic species such as *Enteromorpha* sp., *Ectocarpus confervoides* and *Ceramium rubrum* may cause severe shading of *Zostera* (Den Hartog, 1987). Den Hartog (1994) reported that at Langstone Harbour, the growth of a dense blanket of *Enteromorpha radiata* in 1991 resulted in the loss of 10 ha of *Z. marina* and *Z. noltii,* and that by the summer of 1992, *Zostera* was entirely absent.

d. Phytoplankton blooms

Phytoplankton blooms, resulting from nutrient enrichment, can increase turbidity and have been shown to reduce the biomass production and the depths to which *Z. marina* can grow (Dennison, 1987). Increased turbidity caused by phytoplankton blooms has also been implicated in the loss of seagrass beds in Australia (Shepherd et al., 1989).

e. Increased vulnerability to wasting disease

Buchsbaum et al. (1990) found that the levels of phenolic compounds were lowered under conditions of nutrient enrichment, possibly due to a reduction in available carbon within the plant. Phenolic compounds play an important role in providing *Zostera* with defence against infection, including wasting disease. Burkholder et al. (1992) found that plants from enriched mesocosms succumbed to infection by *Labyrinthula macrocystis*, while plants in the control mesocosm remained healthy.

C. PHYSICAL DISTURBANCE

Seagrasses are generally not physically robust. Their root systems are typically located within the top 20 cm of the sediment and so can be dislodged easily by a range of activities, including trampling, anchoring, digging, dredging and powerboat wash (Fonseca, 1992).

Physical disturbance can reduce the stability of *Zostera* beds. The removal of plants typically results in increased patchiness. This may destabilize the bed and increase the likelihood of additional losses. Disturbance can lead to reduced sedimentation rates or increased removal of sediments. Sediment removal can also increase turbidity, which may affect the success of *Zostera* reestablishment (Holt et al., 1997).

Trampling may be caused by recreational activities such as walking, horse-riding and off-road driving. Some watersports (eg. swimming, windsurfing) may result in damage to subtidal beds. Trampling damage may also be caused by environmental mitigation work. Thom (1993) reported that *Z. marina* beds in Washington State were damaged by trampling when mitigation work was being carried out in response to crab mortalities. Trampling damage resulting from oil clean-up attempts has also been reported. After the Sea Empress oil spill, near Milford Haven in Wales, damage to *Zostera* appeared to be limited to those plants living on areas of shore traversed by clean-up vehicles (SEEEC, 1996).

Zostera beds are particularly vulnerable to physical disturbance of the sediment caused by activities such as anchoring, hand-gathering of cockles, bait-digging, dredging or suction dredging. The wash from powerboats and jet skis can also cause physical disturbance to the sediment. Rhizomes are damaged or broken-up and seeds are removed or buried too deeply for successful germination. The frequency and season of such activities are important in determining the level of impact.

Cockle collection can be particularly damaging, as cockle beds and *Zostera* beds are frequently associated. Perkins (1988) discussed cockle harvesting by suction dredges in the Solway Firth. Harvesting of cockles by hand is a traditional practice here, but with the introduction of mechanical dredgers, the fishing effort rose dramatically between 1987 and 1992. In undredged areas, the substratum was characteristically hummocky and covered with abundant *Zostera*. In dredged areas, the substratum surface was smoothed and no *Zostera* were present. Perkins observed that the removal of *Zostera* was accompanied by a loss of silt from the substratum and suggested that this fishery could cause widespread damage or even completely eradicate *Zostera* from the bay. Due to concerns over the sustainability of this fishing activity, the impacts on cockle and *Zostera* stocks, and the effects on overwintering wildfowl, this fishery was closed to all forms of mechanical harvesting in 1994 (Solway Firth Partnership, 1996).

In Strangford Lough, a practice known as ‘sand ploughing’ where farmers drive onto the mudflats and pull ploughs through the sand to remove rust, is a notifiable operation under the ASSI regulations, due to the damage it causes to intertidal *Zostera* beds and invertebrate communities.

However, physical disturbance can have positive consequences in certain circumstances. Rae (1979) found that small-scale disturbance encouraged new growth of intertidal *Zostera* in the Moray Firth. She suggested that this could be due to the opportunistic colonization of newly-disturbed sediment when seeds or viable rhizome fragments were deposited in newly created hollows on the shore or when viable but deeply- buried seeds were brought closer to the surface where they could germinate successfully.

D. INTRODUCTION OF NON-NATIVE SPECIES

There is increasing concern about the effects on marine ecosystems arising from the introduction of non-native species, this process often occurring accidentally as a result of human activities (Carlton, 1996). To date, the British Isles have been colonized by two plant species which may potentially affect the native *Zostera* beds.

1. Spartina sp. *(Cord-grass)*

The smooth cord-grass *Spartina alterniflora* was introduced to Southampton Water, probably via ship's ballast water, from the east coast of North America prior to 1870 and was first found on mudflats near Hythe, Southampton. It subsequently interbred with the native small cord-grass, *S. maritima* to produce the sterile hybrid *S. townsendii*, and later the fertile hybrid *S. anglica*. *Spartina anglica* has rapidly colonized mudflats in England and Wales due to its fast growth rate and high fecundity. Deliberate planting to stabilize sediments accelerated its spread throughout Britain. *Spartina anglica* forms dense monospecific swards and is now the most common cord-grass species in Britain.

The spread of *S. anglica* has had a number of ecological consequences. It is an aggressive pioneer species and may have contributed to the demise of the native *S. maritima*. Butcher (1941a) raised concerns that its pioneering consolidation, raising mudbanks and affecting currents, may result in the removal of sediments from *Zostera* beds. Percival et al. (1997) reported a reduction in *Zostera* coverage at Lindisfarne, Northumberland, due a combination of change in sedimentation pattern and encroachment by *S. anglica*.

2. Sargassum muticum (Wire weed, strangle weed, Japanese weed)

Fears have been expressed that the introduced brown alga *Sargassum muticum* may compete with and displace eelgrass (Druehl 1973). The species was first recorded in Europe in 1971 as drift material on Southsea Beach and by 1983 it occupied suitable habitats along approximately 360 km of the southern coast of Britain (Critchley 1983a, b). Within the British Isles, populations of *S. muticum* are currently found along the entire Channel coast from Kent to Cornwall, with one site in north Cornwall. There are also populations in the Isles of Scilly and Channel Isles. Currently the most northerly population is the most recently established, in Strangford Lough in Northern Ireland (Davison & Davison, 1995; Davison, 1996, 1997b).

The colonization of the UK by *S. muticum* has generated an intensive research and monitoring programme, creating one of the best documented case-histories of the spread of a non-indigenous marine organism in European waters. As a colonizer, *S. muticum* requires the availability of clear substratum. The presence of any existing canopy or algal turf can restrict or totally inhibit colonization (Deysher & Norton, 1982). Consequently, its spread is favoured where competition for space is reduced. A clean, hard, textured surface such as shell, rock or metal is preferred. Mature *S. muticum* plants can be also be dispersed when attched to small stones or shells carried by the current (Critchley, 1983a, b; Jephson & Gray, 1977; Nicholson et al., 1981).

The evidence that *Sargassum* competes significantly with *Zostera* is conflicting. In the San Juan Islands, Washington State, *S. muticum* and *Z. marina* were found to co-exist in different habitats with no evidence of competition or displacement (Norton, 1977). Fowler (1995) observed that despite the shading caused by the extensive *S. muticum* canopies in the Solent and Isle of Wight area, there did not appear to be any associated declines in *Zostera*. Covey and Hocking (1987) found no evidence of *S. muticum* replacing *Zostera* in the Helford, Cornwall.

At the Bembridge lagoons, Isle of Wight, *S. muticum* sporelings colonized newly exposed substratum only after the frost-induced die-back of *Z. marina* (Fletcher & Fletcher, 1975). However, the establishment of *Sargassum* may have prevented subsequent recolonization by the eelgrass (Critchley, 1980**;** Farnham *et al*, 1981). Tubbs (1995) reported that in the Solent, *S. muticum* and *Z. angustifolia* compete for space in lower shore lagoons. Replacement of *Laminaria saccharina* and *Z. marina* by *S. muticum* has been documented at Grandcamp on the French Atlantic coast. However, Givernaud et al., (1991) reported that *S. muticum* had replaced *Z. marina* mainly in parts of seagrass beds that had been damaged by human activity.

E. EFFECTS ON WILDFOWL DISTRIBUTION AND BEHAVIOUR

The potential of wildfowl to consume a large proportion of the available *Zostera* biomass has been noted in Chapter IV. The feeding patterns of wildfowl can be heavily modified by shooting disturbance (Madsen, 1988), and this may therefore have an indirect effect on the exposure of *Zostera* beds to grazing pressure. Recent experiments in Denmark (Madsen, 1988, 1995) showed that reducing shooting disturbance could significantly increase the numbers of wildfowl using a site and grazing on the *Zostera* resources.

F. HUMAN-INDUCED CLIMATE CHANGE

The effects of long-term climatic changes on *Zostera* beds are not easy to predict. Hot summers can stress *Zostera* and may increase its vulnerability to infection by wasting disease, so this is one possible consequence of climatic warming. It has been predicted that as a result of global warming, sea levels will rise and the frequency and severity of storms may increase (Houghton et al., 1990). If so, this could also cause significant degradation of *Zostera* beds.

G. KEY POINTS FROM CHAPTER V

- Coastal development can have adverse effects on *Zostera* beds by causing increased sediment erosion or accretion (depending on the nature of development), and by causing increases in water turbidity.

- There is little evidence of harm caused by heavy metals or antifoulants, but runoff of terrestrial herbicides has been shown to affect growth and survival of *Zostera* plants.

- Eelgrass beds are not highly sensitive to chronic oil pollution (eg. refinery effluent). When exposed to major oil spillages, the associated fauna appear to be more susceptible to damage than the *Zostera* itself.

- The chemical dispersants used to control oil spills are more harmful to *Zostera* than the oil alone, and should not be used in these biotopes.

- Excessive nutrient enrichment can cause damage to eelgrass beds by a variety of mechanisms, the most important of which are metabolic imbalance, proliferation of phytoplankton, epiphtyic or blanketing algae, and increased susceptibility to wasting disease.

- Eelgrass beds are not physically robust biotopes, and can be degraded by trampling, mechanical bivalve harvesting, dredging and other forms of disturbance.

- Two non-indigenous plants, the cord-grass *Spartina anglica* and the brown alga *Sargassum muticum* have colonized eelgrass beds in the UK, mainly in the south of England. To date, there is no firm evidence of either species competing significantly with *Zostera* or displacing it in the absence of other adverse environmental factors.

- Disturbance by wildfowlers may cause local increases in numbers of ducks and geese on *Zostera* beds, and hence higher grazing pressure on the eelgrass.

- Human-induced climate change may have significant long-term effects on the distribution and extent of *Zostera* beds. Possible significant effects include higher temperatures and increased frequency and severity of storms.

VI
MONITORING AND SURVEILLANCE OPTIONS

There is a requirement within the Habitats Directive (Article 17) for Member State governments to report to the EC on the *favourable conservation status* of the habitats and species which SACs (and SPAs) will assist in conserving. In addition to this reporting role, it is likely that a monitoring programme will be developed for each SAC to assess the effectiveness of the management scheme in achieving the conservation objectives. It should allow the management scheme to be reviewed, and where necessary, revised.

This chapter will review the methods that are available for monitoring the distribution and status of eelgrass beds within an SAC, and briefly describe how some of these techniques have been applied to particular sites. A number of techniques also exist for determining the physiological state of *Zostera* plants, with particular respect to the degree of sublethal stess to which the plants are exposed. These are briefly outlined in Section C.

A. MONITORING REQUIREMENTS

Zostera plants, and the communities associated with them, possess a number of attributes that can provide information on the condition of these biotopes. These attributes are listed in the table below, and assigned a numerical priority ranking. A priority ranking of 1 indicates those attributes whose monitoring is considered essential to effective SAC management and accurate reporting of conservation status. A priority ranking of 2 indicates those attributes whose monitoring is considered desirable for some SACs. A priority ranking of 3 indicates those attributes that may require targeted research or monitoring in response to specific events. Appropriate monitoring methods are listed in the table, and discussed more fully in Section B.

Measurable attributes of *Zostera* biotopes, monitoring priorities and appropriate methods

Measurable attributes	Priority ranking	Appropriate methods
Biotope-level attributes		
• Distribution and spatial extent of *Zostera* beds	1	• Aerial remote sensing • Acoustic surveys • Underwater video • Field observers
• Biomass and productivity	1	• Remote sensing • Underwater video • Remote sampling (eg. grabs) • Field observers
Attributes of *Zostera* plants		
• Plant condition (eg. leaf length) • Sexual status (presence/number of flowers) • Reproductive success (eg. seed production, seedling germination and survival) • Presence of wasting disease	1 1 2 1	• Underwater video • Remote sampling (eg. Grabs) • Direct sampling by field observers
Attributes of associated community		
• Presence of characteristic & representative species • Total number of associated species • Density of epiphyte grazers • Density of wildfowl • Presence & abundance of non-native species (eg. *Spartina anglica*, *Sargassum muticum*)	1 2 3 3 3	• Underwater video • Remote sampling • Field observers • Existing MNCR Phase II data • Targeted research as required
Environmental attributes		
• Water clarity • Water quality (eg. nutrient & contaminant levels) • Water temperature • Sediment erosion/accretion	1 1 3 2	• May be monitored by public environmental agencies, or in cooperation with these
• Climatic change/extreme weather conditions (eg. sea level change, storms, extreme temperatures)	3	• These are the focus of specific national & international research initiatives. The use of marine SACs for such research should be encouraged

B. BIOTOPE MONITORING TECHNIQUES

To undertake surveys, surveillance and monitoring of *Zostera* biotope attributes, site managers will need to identify the most appropriate and cost-effective field and analytical methods, as well as determining the quality assurance requirements. Analytical methods include Geographical Information Systems (GIS) and Remote Sensing Information Systems. A major advantage in using a mixed monitoring strategy, employing a combination of the methods outlined below, is the production of more accurate maps allied with the increased flexibility of interpretation and query within GIS.

Techniques that can be used to monitor *Zostera* biotope attributes are listed below. In the following sections, each technique is briefly described, and its advantages and disadvantages summarized. Examples of the use of particular methods are given.

1. Aerial remote sensing techniques	• Aerial photography (colour or infra-red) • Satellite sensor images • Compact Airborne Spectrographic Imager (CASI)
2. Sublittoral remote sensing techniques	• Acoustic Ground Discrimination Systems e.g. RoxAnn™ , side-scan sonar
3. Underwater video	• Remotely-operated vehicles (ROV) • Towed video • Drop-down video
4. Remote sampling	• Grabs • Cores
5. Field observers	• Divers • Intertidal field biologists

1. Aerial remote sensing techniques
Aerial remote sensing techniques include aerial and infrared photography, satellite sensor images and multi-spectral scanning imagery (CASI).

a. Aerial photography

A vertically mounted camera on a light aircraft takes high resolution, large format, digital natural colour transparencies, in transects across the site. Using infra-red, the methodology is the same, but this format allows better differentiation between intertidal algae and *Zostera*. The advantages and disadvantages are summarized below:

Advantages	Disadvantages
• Cost-effective (despite high cost) • Allows large areas to be mapped relatively accurately	• Requires ground-truthing, as there may be problems distinguishing between Zostera and algal cover, and in detecting seasonal variations in leaf cover • Sparse Zostera cover is not detected • Interpretation is difficult (cannot rely upon classification of spectral images) • Poor penetration below sea level. Applicability is limited to very shallow, clear water • Can be limited by weather conditions

BKS Surveys Ltd. tested the usefulness of aerial photography for mapping *Zostera* beds in the Isles of Scilly SAC and at Lindisfarne and Budle Bay (within the Berwickshire/ North Northumberland SAC) in 1996. Infra-red photography was found to be more effective than natural colour, but difficulties were experienced in distinguishing between living and dead material, and in distinguishing *Zostera* from the alga *Enteromorpha* (P. Gilliland, pers. comm.). The Isles of Scilly aerial survey was ground-truthed by the Coral Cay Conservation Sub-Aqua Club in 1997. The technique was found to be valid but the density classes were found to be optimistically high (Irving et al., 1998).

b. Satellite sensor images

Images from satellite sensors (Landsat Thematic Mapper & SPOT XS) can be used for a number of mapping applications. However, the habitat classification accuracy is highly dependent upon the methods used and different habitats may not be accurately distinguished (Mumby et al., 1997).

c. Compact Airborne Spectrographic Imager (CASI)

The Compact Airborne Spectrographic Imager is a digital airborne sensor providing high spectral and spatial resolution. It has been used for a number of mapping applications, principally on tropical reefs and seagrass beds. This sensor is mounted on a light aircraft and can be flown for example, at 3000 m giving 4 million pixels in 15 bands, and at 750 m for 1 million pixels in 8 bands. This provides considerable mapping accuracy and its application for mapping *Zostera* biotopes is under review. Initial trials suggest that predictions of standing crop using CASI give results to a similar order of magnitude to quadrat sampling *in situ* (Mumby et al., 1997). CASI is now being tested and used by the Environment Agency, SEPA and water companies.

Advantages	Disadvantages
• Can be very accurate • Allows large areas to be mapped in great detail • Provides an indication of standing crop biomass • Data is easily geo-referenced	• High cost • Likely to require some ground-truthing to confirm the Zostera biotope • Can be limited by weather conditions

2. Sublittoral remote sensing techniques

Acoustic Ground Discrimination Systems (AGDS) are a comparatively recent development in through-water remote sensing and are becoming increasingly important in the large-scale mapping of benthic habitats and communities. The two principal techniques relevant to the mapping of subtidal *Zostera* biotopes are RoxAnn^{TM} and side-scan sonar.

RoxAnn^{TM} is an electronic system using a sonar signal. The first and second echoes returned from the seabed are re-analyzed. This analysis derives values for the roughness and hardness of the seabed. By integrating these data with other information on water depth and position, a map of the physical characteristics and distribution of substratum types can be produced. The biotic characteristics of many marine communities will predictably affect the values recorded and consequently, it is possible to map the distribution and the extent of these characteristic benthic communities. An essential part of any AGDS survey is to adequately ground-truth the data to confirm the habitats and communities mapped. Differential GPS can be used for position fixing.

Advantages	Disadvantages
• **Low cost** • **Allows large areas to be mapped relatively quickly** • **The broad scale maps will display habitats, lifeforms and some biotopes** • **Data are easily geo-referenced**	• There can be misidentification of communities that have similar physical characteristics but very different biological characteristics. • Many biotopes are differentiated or defined by features to which RoxAnn™ is completely insensitive • Requires considerable ground truthing to confirm Zostera biotopes • The equipment requires an 8-10 m boat and consequently, access to shallow areas may be limited. • Rough seas may affect the accuracy of the data

When using RoxAnn™ around the Isles of Scilly, it was possible to clearly differentiate between dense *Zostera* beds and sand, but the beds could not be distinguished from alga-covered rock or gravel areas. Side-scan sonar clearly demarcated dense *Zostera* beds with eroding margins but was insensitive to sparse *Zostera* beds (Munro & Nunny, 1998).

3. Underwater video

The use of video for underwater survey is becoming increasingly important as it allows a permanent record of many aspects of benthic biotopes to be kept. Three remote video surveying techniques can be employed in the study of *Zostera* beds, Remotely-operated vehicles (ROVs), towed video and drop-down video.

The ROV is the most versatile system, as it is a mobile vehicle that has complete three-dimensional movement in the water and is highly manoeuvrable. A high quality camera and lighting system allows good quality video to be obtained. An ROV can be operated at a height above a *Zostera* bed, and flown along a transect to obtain data on the distribution, extent and boundary dynamics of the bed. It can also be flown into the bed to obtain data on plant condition, bed density and associated species diversity.

A towed video camera is mounted on a light-weight, metal sledge that is towed at a known speed over the seabed by a boat. This method can provide information on the extent of a *Zostera* bed, and may be able to gather additional information on the bed's boundary dynamics. However, one disadvantage of the technique is that repeated passes of a towed sledge through a *Zostera* bed may cause some physical damage.

The drop-down video is the simplest and cheapest of all three remote video surveying techniques. It consists of a video camera in a waterproof casing, mounted in a simple metal frame. The camera is held off the seabed and points down and forwards. When deployed, the camera will obtain spot information over a small field of view, allowing identification of the *Zostera* biotope in that location, and providing an indication of the plant density and associated community. The system is quick to deploy and recover.

Technique	Advantages	Disadvantages
ROV	• No time or depth limits • Can survey large areas of seabed • Highly manoeuvrable • Versatile, providing both overview and close-up (detailed) data • Can provide continuous data transects • Easy deployment • Can ground-truth remote sensing surveys	• High cost • Requires hard boat to operate, restricted access to shallow areas • Difficult to fly in straight transects • Relatively slow flight speed
Towed video	• No time depth limits • Can survey large areas of seabed, faster than an ROV • Provides continuous data transects and is easy to use in a grid pattern • Can ground-truth remote sensing surveys	• Requires hard boat to operate, restricted access to shallow areas • May cause physical damage to Zostera biotopes • Provides generally poor data on biotope quality, associated communities and plant condition • Deployment may be constrained by obstacles on the seabed
Drop-down video	• Low cost • Easily deployed • Many drops can be completed in a day • Can ground-truth remote sensing surveys	• Requires hard boat to operate, restricted access to shallow areas • Generally poor image quality • Provides generally poor data on biotope quality, associated communities and plant condition • Deployment may be constrained by obstacles on the seabed

4. Remote sampling

Grabs and cores can be used to sample *Zostera* beds. However, as a destructive sampling technique, with the potential to cause damage to the beds, their widespread application as a monitoring tool is likely to be restricted to targeted studies, relating to plant status and aspects of infaunal community structure.

A variety of grabs and cores can be employed on the shore and from boats. Those commonly employed by biologists in the intertidal and shallow sublittoral zones are tube-corers, Van

Veen grabs and Day grabs. The data obtained from these samples can provide useful information on the substratum type, plant condition, plant and rhizome density, sexual status and infaunal community composition. It is possible to determine the location of a sublittoral *Z. marina* bed and to establish its approximate extent using a series of grab transects. However, this is likely to be both time-consuming and destructive.

Advantages	Disadvantages
• Simple to deploy • Provides physical samples for subsequent analysis • The sampling and analysis techniques are well-established • Can measure a number of Zostera attributes in each sample	• Destructive sampling, a form of physical damage to which Zostera beds are particularly vulnerable

5. Field observers

An experienced and skilled field biologist, with sufficient time and resources, will often provide the best quality data when monitoring complex communities such as *Zostera* biotopes. The remote sensing and sampling techniques outlined above will provide quick and cost-effective data over a large area, for many *Zostera* attributes, particularly distribution and extent. However, many aspects of detailed ecological monitoring of *Zostera* biotopes require hands-on fieldwork, both intertidally and subtidally.

a. Divers

An indication of the quality of a subtidal *Z. marina* biotope and its associated community can be provided by the remote video techniques outlined above, most successfully using an ROV. However, to obtain more comprehensive information on the species diversity, including the presence of characteristic and representative species, surveying by experienced diving biologists will be required.

There are many techniques that divers can employ, including MNCR Phase II and III surveys, which involve taking core and grab samples for later analysis. In addition, targeted studies and monitoring of key attributes can be undertaken.

b. Intertidal field biologists

Intertidal field biologists can collect monitoring data for the majority of intertidal *Zostera* attributes, often in the same site visit. MNCR Phase II and III survey methodologies can be employed. Samples can be collected, and remote sensing can be accurately ground-truthed.

Field observers	Advantages	Disadvantages
Divers	• The most flexible survey / sampling technique for monitoring Z. marina • Allows first hand observation of Z. marina attributes • Several Z. marina attributes can be monitored in one dive • Allows repeatable fixed point monitoring	• High cost • Time limited • Can only cover small areas during each dive
Intertidal field biologists	• The most flexible survey / sampling technique for monitoring intertidal Zostera species • Allows first hand observation of intertidal Zostera species attributes • Several intertidal Zostera species attributes can be monitored on one visit • Allows repeatable fixed point monitoring	• High cost • Time limited (Tides) • Can only cover small areas during each site visit

C. MEASURABLE INDICATORS OF ENVIRONMENTAL STRESS IN *ZOSTERA*

1. The use of adenylates as an indicator of metabolic state in Z. marina

The adenylate energy charge (AEC) regulates metabolic processes in plants by controlling rates of enzymic reactions, and has been widely applied as an index of sub-lethal stress. Delistraty and Hershner (1984) studied adenine nucleotide levels (adenylates) and the adenylate energy charge in *Z. marina* to evaluate whether they could be used as an indicator of the metabolic state of the plant in response to environmental stress. It was found that adenylate and AEC responses to environmental variation appeared to provide useful measures of the metabolic state of *Z. marina* under certain conditions, but it was concluded that they posed difficulties when attempting to evaluate the effects of a single variable.

2. Photosynthetic ability (Fv/Fm fluorescence kinetics parameter)

Changes in the photosynthetic ability of *Zostera* are a good indicator of environmental stress. With the appropriate equipment, sublethal effects can be measured easily and quickly in the field, using the Fv/Fm fluorescence kinetics parameter, which measures the efficiency of the light harvesting aspect of photosynthesis. Recently, this has successfully been used to investigate the effects of the triazine antifouling herbicide Irgarol, on *Zostera* species. The technique may have applications for investigating the effects of other herbicides, TBT, heavy metals, as well as light stress and nutrient effects (P. Donkin, pers. comm.).

D. *ZOSTERA* BIOTOPE MONITORING IN THE UK: SOME EXAMPLES

The purpose of this section is to provide a very brief overview of the kinds of research, survey and monitoring that have been undertaken in some of the marine SACs with respect to *Zostera* biotopes. Much of the data gathered by this work is incorporated in the previous chapters of this report.

Davison (1997a) provides detailed information describing the occurrence of *Zostera* biotopes in sixteen marine sites around the UK, fifteen of which are cSACs.

1. Morecambe Bay cSAC - a UK Marine SACs Project demonstration site

Between 1992 and 1997, work has been undertaken on the intertidal *Zostera* beds in the Barrow and Walney Island areas of Morecambe Bay, relating to the construction and laying of two gas pipelines. During this work, areas of *Z. angustifolia* and *Z. noltii* were destroyed by the clearance of a 150 m wide swathe and the excavation of a trench. To assist recovery, the surface sediments of the *Zostera* bed were removed, stored and consequently replaced. The recovery has been monitored. Populations to the north of the pipelines have been recovering, albeit slowly and patchily. However, populations to the south of the pipeline have decreased or disappeared (I. Tittley, pers. comm.).

2. Changes in the Zostera bed at Leigh, Outer Thames: 1946 -1974

Aerial photographs of the *Zostera* bed at Leigh were available for a number of years, and allowed Wyer et al. (1977) to map the changes in distribution. At this site, *Z. noltii* and *Z. angustifolia* grew together, with *Z. noltii* predominant on free-draining hummocks and *Z. angustifolia* predominant in the wetter depressions between the hummocks. Flood damage in 1953 severely affected the bed, which had previously been decimated by the wasting disease between 1930-1935, but Wyer et al., (1977) reported that the bed appeared to have successfully recovered and expanded. However, no further information on this site has been published since 1977.

3. Chesil and the Fleet cSAC - a UK Marine SACs Project demonstration site

Whittaker (1989, 1981) assessed the seasonal distribution of seagrass meadows within the Fleet, and Holmes (1983, 1985, 1993) undertook detailed monitoring work. Within the seagrass meadows two eelgrasses, *Z. angustifolia* and *Z. noltii*, occur together with two tassel weeds, *Ruppia cirrhosa* and *R. maritima*. Holmes' (1983) baseline assessment found *Z. angustifolia* to be the most abundant seagrass species, although monospecific stands *Zostera* were uncommon. In some areas, all four species occurred together forming mixed stands. West of Rodden Point *R. cirrhosa* was dominant. From this point east, the dominance changed gradually with the *Zostera* species becoming dominant within the main body of the lagoon, from Herbury Point to Lynch Cove. In addition to this west-east transition, there was a north-south transition, with *Z. angustifolia* dominant along the southern shore and in the main body of the Fleet, while *Z. noltii* was dominant or co-dominant in the coves of the northern shore.

Dyrynda and Cleator (1995) completed a series of cross-lagoonal transects, mapping benthic communities and providing information on variations in vegetation cover, sediment composition and invertebrate population structure. The distributions of the seagrass meadows across the lagoon were found to be generally consistent with the Holmes surveys, with *Z.*

angustifolia predominant within the Littlesea and Moonfleet sites and more mixed seagrass populations at the Langton Herring and Cloud's Hill sites. High levels of competition were observed between the seagrasses and green algal mats.

In the spring of 1995, a one year, integrated seasonal monitoring study, funded by WWF-UK, was undertaken at a cross-channel transect, situated at Langton Hive Point (Dyrynda, in prep.). Monitoring involved 1-2 monthly observations of percentage vegetation cover, recording the presence of conspicuous invertebrates and fish and the quantitative sampling of invertebrates. Trial monitoring work included the use of video transects to assess vegetation cover and a specific fish survey.

4. Plymouth Sound and Estuaries cSAC - a UK Marine SACs Project demonstration site

The Department of Biological Sciences, University of Plymouth is currently instigating a varied programme of research, in the form of honours research projects and field courses, in the Yealm Estuary (part of the SAC), and Salcombe-Kingsbridge Estuary (not within the SAC) (A. Rowden, pers. comm.).

As a result of the English Nature *Zostera* mapping workshop (November 1996), University of Plymouth students that had carried out *Zostera* research were to be employed by the District Council to map the extent and relative density of these beds in the early summer of 1997. A research project has also been advertised within the English Nature College - English Nature Links Scheme titled 'Comparative biodiversity study of two eelgrass beds of the Salcombe - Kingsbridge Estuary'. It is likely that Plymouth University will undertake this research and instigate other projects in the future.

5. The Fal and Helford cSAC

A number of surveys have been undertaken in the Helford (Gardener, 1934; Bishop, 1983; Turk, 1986; Rostron, 1987). As a result of concerns being expressed that the diversity and abundance of species in the Helford had declined, a Steering Group was formed in 1985, to undertake a twelve month survey of the area. The baseline Helford River Survey report was produced by Covey & Hocking in 1987. Intertidal *Zostera* were noted to have disappeared from many areas and the faunal diversity of these sites was found to have declined. However, four new records for subtidal beds were obtained. Giesen (1988) investigated seven sites but *Z. marina* was not found, either subtidally or intertidally. To date, monitoring reports to the Helford VMCA have been published for the surveys undertaken in 1988, 1989, 1990 and 1993 (Hocking, 1989; Turk, 1990; Tompsett 1991; Tompsett, 1994a, b). Local divers are undertaking subtidal mapping of the extent and relative density of these beds (R. Covey, pers. comm.).

6. The Isles of Scilly complex cSAC

Fowler & Pilley (1992) reviewed the monitoring techniques that had been applied to subtidal *Z. marina* beds in the Isles of Scilly, initially undertaken by the NCC and continued by English Nature. In the baseline survey in 1984, the shoots emerging from the substratum within a quadrat were counted and then destructively sampled to allow the number of leaves, leaf length, the number of flowering shoots and number of flower heads per shoot to be counted. Conspicuous species present on the leaves, bases of the shoots and on and within the surrounding sediment were also recorded. Observations on the general structure of the bed were made and photographs of the community and individual species were taken. In 1985, quadrat (0.1 m^2) data was gathered at 0.5 m intervals along 10 m transect lines that radiated out, on the eight primary magnetic compass bearings, from a central marker. Between 1986 and 1988, the same methods were used but the level of data gathering varied. No annual surveys were undertaken in 1989 and 1990. In 1988 and 1991, plants were examined for symptoms of wasting disease. No symptoms were observed in 1988, but the disease was found to be present in 1991. In 1991 *Sargassum muticum* was recorded at all the survey sites.

During the summer of 1996, an aerial photo-mapping exercise was undertaken to map the distribution of *Zostera* and estimate densities of the beds. The preliminary results were ground-truthed by Coral Cay Conservation Sub Aqua Club (Irving et al., 1998).

7. Wales

The *Zostera* beds of North Haven, Skomer (part of the Pembrokeshire Islands cSAC) have been well-studied and are monitored on a regular basis as part of the Skomer Marine Nature Reserve work programme. Trigg (1998) undertook undergraduate research on temporal changes in the distribution and abundance of *Z. marina* in North Haven and the possible effects on the benthic community structure.

The three *Zostera* beds of Milford Haven (also part of the Pembrokeshire Islands cSAC) were surveyed in 1978, 1979, 1981 and 1986 (K. Hiscock, 1987). In 1994 and 1995, Pembrokeshire National Park undertook a survey of Milford Haven, to re-map the location, extent and density of *Z. angustifolia* as part of an ongoing programme of research and monitoring administered by the Milford Haven Waterway Environment Monitoring Steering Group. It is likely that repeat surveys will be undertaken in the future (Howe, 1994; RSPB, 1995). O'Brien (1996) investigated the effects of disturbance on *Zostera* populations in Milford Haven, while Hodges & Howe (1997) monitored three populations of *Z. angustifolia* following the Sea Empress oil spill.

The *Zostera* bed in the Severn Estuary pSAC is found near the turbidity maximum of the Severn, probably the most turbid estuary in the UK. This bed has been monitored in recent years in relation to the impacts of the Second Severn Crossing. Sediment accretion around the cofferdam for the Second Severn Crossing appears to have caused a decrease in the area of the *Zostera* bed in the Severn Estuary pSAC (M. Hill, pers. comm.).

8. Strangford Lough MNR and cSAC - a UK Marine SACs Project demonstration site

The *Zostera* beds of Strangford Lough have been mapped by Lynn (1936), Bleakley (1971) and Corbett (1980). Considerable research has been undertaken investigating wigeon and Brent geese interactions and their dependence upon the Lough's *Zostera* beds. Portig (1997) surveyed the *Zostera* resources of the Lough for his Ph.D. research thesis on the utilisation of *Zostera* by wildfowl. The relevant information from this study is outlined in Chapters IV and V.

E. KEY POINTS FROM CHAPTER VI

- *Zostera* beds possess a range of attributes which can potentially be used in an SAC monitoring scheme. From the perspective of detecting changes in the extent or health of the eelgrass biotope, the following attributes should be given the highest priority:

  Distribution and extent of *Zostera* beds
  Zostera standing crop and shoot density
  Zostera plant condition (leaf length, sexual status, presence of wasting disease)
  Presence of characteristic and representative species
  Water quality (turbidity, nutrient levels)

- Of the available monitoring techniques, airborne or sublittoral remote sensing allows bed distribution to be mapped rapidly over large areas, but usually requires ground-truthing by video or field observers.

- Underwater video or field observers (either diving or intertidal biologists) must be used if details of plant condition or community composition are sought.

- Several physiological parameters can be used as indices of environmental stress in *Zostera*.

- A standardized system for mapping intertidal and shallow subtidal *Zostera* beds was developed at a workshop organized by English Nature in 1996. Notes from this workshop are included in Appendix 3.

VII
GAPS AND REQUIREMENTS FOR FURTHER RESEARCH

A considerable volume of research has been undertaken on *Zostera* ecology. Because of the volume of material identified and gathered during the course of producing this report, it was not possible to review every publication on the *Zostera* species found in the UK. A fundamental problem in collating information on these species relates to the continued confusion over the taxonomic status of *Z. angustifolia*. This can affect the direct applicability of some international eelgrass research.

Site managers will need to possess a good understanding of the environmental requirements, biology and ecology of the *Zostera* species and their sensitivities to natural events and human activities. In order to contribute to SAC management, and to help fill some of the remaining gaps in our knowledge, research institutions should be encouraged to use marine SACs as research sites. Site managers approached by research groups may find the following table of assistance in identifying those issues for which research would be valuable and relevant to their site.

The issues of concern and suggestions for appropriate research are listed below and are assigned a numerical priority ranking on a 3-point scale. A rank of 1 indicates the highest priority, a rank of 3 the lowest.

Major gaps and requirements for further research

Gaps and issues of concern	**Priority**	**Suggestions for research topics** (Nation-wide studies or site-specific research)
The taxonomic status of *Z. angustifolia,* and consequently the distribution status of all three *Zostera* species in the UK.	1	• Genetic research, eg. DNA fingerprinting • Re-examination of biological record specimens
The degree of variability in, and taxonomic usefulness of, the characteristics currently used to distinguish between *Zostera* species	2 or 3	• Identification of diagnostic features of *Zostera* plants useful in species identification - leaf length, leaf width, shape of the leaf tip, number and position of leaf veins and stigma : style ratios • To determine the reproductive strategy or strategies employed by the three *Zostera* species • To determine the longevity of the three *Zostera* species
The causes of outbreaks of wasting disease	2 or 3	• To confirm whether *Labyrinthula macrocystis* is the cause of wasting disease in the UK • To identify any outbreak triggers • To investigate the role of environmental stress in increasing vulnerability to infection • To investigate the reasons for the apparent poor recovery of *Zostera* beds from wasting disease
The recoverability of *Zostera* beds	1 or 2	• To identify the factors that limit or facilitate recovery
The feasibility of *Zostera* mitigation in the UK	2 or 3	• To establish the viability of transplantation or re-introduction programmes

VIII
SYNTHESIS AND APPLICATION OF INFORMATION FOR CONSERVATION MANAGEMENT RELEVANT TO MARINE SACS

The management of a marine SAC site for which *Zostera* is a conservation feature presents a number of challenges and opportunities. As discused in the earlier chapters, to thrive, *Zostera* species require sheltered conditions, stable sediments, low turbidity, an absence of eutrophication (and other forms of pollution) and destructive physical disturbance, and healthy populations of epiphyte grazers. Where these requirements are not fulfilled, the *Zostera* species may experience environmental stress and become more susceptible to wasting disease.

These requirements are similar to those of many other species and biotopes selected as conservation features within UK marine SACs and are also logical objectives to which the management of SACs can aspire. Using these requirements as a guide, the challenge is for site managers and all others involved in SAC management to consider the current human activities, likely future development pressures and socio-economic and cultural requirements of the local communities, and to integrate these with the conservation requirements of the SAC. This can only be achieved through the establishment of an inclusive, co-operative and agreed management scheme that is based on a suite of realistic and achievable conservation objectives.

This chapter tries to bring together the major conclusions from the report and to present them in a way that is solution-oriented. The chapter first provides a general discussion of the cross-cutting management issues or themes that are relevant to most sites, and to our understanding of *Zostera* in general. The question of *Zostera* bed recovery is then addressed. This is put into a more specific context with a technical synopsis of the main findings from the preceding chapters with regard to the priority issues for *Zostera* in the UK. Finally, the chapter focuses on various management interventions at strategic and site levels that are relevant to the conservation of *Zostera* biotopes.

A. SENSITIVITY PERSPECTIVES AND KEY TRENDS:

In general, the requirements for managing *Zostera* biotopes in the UK can be summarized as follows:

- Ensuring that the environmental and ecological requirements of the *Zostera* species are met so that the favourable conservation status of the biotopes are maintained or enhanced.
- Reviewing and managing human activities appropriately within SACs in order to ensure that current activities are compatible with the maintenance of the *Zostera* biotopes.
- Reviewing and assessing proposals for new activities, or changes to current activities, in order to ensure that detrimental impacts can be avoided.

A site manager responsible for the conservation of *Zostera* biotopes within an SAC will need to consider consider the following perspectives when attempting to develop a feasible management plan:

1. Difficulty of active intervention in the marine environment

The management of plant biotopes in marine SACs contrasts sharply with management in terrestrial SACs in that direct action, such as planting, cutting, clearing, grazing control and *ex situ* propagation, cannot be easily employed. In addition, in the marine environment, actions are less likely to be so directly focused on individual species. Instead, they are more likely to concentrate on attempting to maintain or restore the ambient environment. With respect to *Zostera*, this is likely to include attempting to control sediment movement and deposition, reducing levels of pollution, and minimizing disturbance by physically damaging activities such as bait digging. However, despite these problems, *Zostera* biotopes are unique amongst marine plant biotopes in that *ex situ* activities such as seed banks, propagation and transplants can potentially contribute significantly to management initiatives (discussed further below).

2. Natural vs. anthropogenic change

One of the greatest challenges facing any site manager will be to distinguish between natural and anthropogenic change. Hiscock (1984) stated that the management of marine species and communities requires an understanding, not only of the designated site, but also of the dynamics of the communities and the ecology and life history of the species present. Without information on a species' longevity, potential for recruitment, vulnerability to environmental change and to the impacts of human activities, combined with a good knowledge of natural fluctuations, management objectives cannot be easily defined or justified, and their achievements cannot be assessed. To obtain this kind of information, surveillance and monitoring work on a variety of levels is required (Fowler and Pilley, 1992).

From the preceding chapters of this report, it should be apparent that large-scale, natural stochastic events can occur in eelgrass beds. For example, storms can remove large areas of *Zostera* .Such events are inherently unpredictable and are clearly beyond the control of any management scheme. In contrast, when considering potential anthropogenic agents of change, the nature of the marine environment is such that coastal developments, often remote from the SAC, may have long-term, slow acting, but significant impacts on the *Zostera* biotopes within the SAC. The site manager must carefully consider all possible short- and long-term human impacts and identify those for which mitigation measures are possible.

3. Application of relevant legislation

Site managers will be aware that there is a requirement under Regulation 48 to review all new plans and projects, which may affect the conservation features of an SAC. The likely impacts of these plans and projects should be assessed against the activities that are known to have detrimental effects upon *Zostera* biotopes ,and against the conservation objectives for the SAC.

With respect to plans and projects that relate to coastal development, particular care should be taken to consider their possible impacts on the processes which may affect *Zostera* biotopes (eg. sediment deposition or erosion). Other plans and projects may include discharge consents and consents under other legislation, such as the Food and Environmental Protection Act and the Control of Pollution Act. Applications for new discharges, which may affect the water quality and clarity in the vicinity of the *Zostera* biotope, also need to be considered with respect to the conservation objectives of the SAC. Where eutrophication occurs, high nutrient levels could be controlled through the designation of 'Nitrate Vulnerable Zones', as defined in the EC Nitrates Directive. Similarly, new fisheries or significant changes to existing fisheries should be subject to review and assessment, regarding likely impacts on the features of the SAC.

Changes in the pattern of some human activities are largely outside planning control, including many recreational activities such as yacht anchoring, bait digging and horse riding on the shore, which may all affect *Zostera* beds within SACs. The approach to the management of such activities should be tempered with the knowledge that in many cases, suitable compromises can be reached through information, education and communication, rather than by applying unwieldy statutory routes.

These examples illustrate that any new coastal developments or activities within an SAC must be considered against the conservation objectives of the SAC. These are new responsibilities for the relevant authorities and Statutory Conservation Agencies, and are likely to require careful negotiation and good working relationships between all the parties within the SAC Management Group. The site manager will have a crucial role in facilitating the consideration and assessment of new plans and projects.

4. Public involvement and awareness

In the management of marine SACs, public information and education must be given priority and a proactive policy of communication should be implemented, to keep the relevant authorities and local people informed and aware of the importance and practical implications of the local management scheme. Positive steps should be taken to raise awareness of critical issues and damaging activities so that these can be resolved or avoided. For example, the Salcombe-Kingsbridge Estuary Environmental Management Plan has produced a Code of Conduct leaflet on sand eel collection to discourage collection over the local *Zostera* beds.

5. Multiplicity of Initiatives

At many of the marine SACs where *Zostera* occurs, a variety of other management initiatives may already exist which recognise *Zostera* as an important conservation feature. The challenge for the future of the marine SACs is to work in co-operation with all the interested parties to develop successful management schemes for each marine SAC, integrating and co-ordinating the management of the site so that the protection of the conservation features of the site is ensured.

B. THE RECOVERABILITY OF *ZOSTERA* SPECIES

Although *Zostera* species are fast-growing and relatively short-lived, they can take a considerable time to recover from damaging impacts - if recovery is possible at all. Holt et al. (1997) estimated that *Zostera* species recoverability is within the range of five to ten years but, in many cases, recovery may take longer. This is borne out by the slow or apparent lack of recovery from the 1920s to mid-1930s wasting disease epidemic, previously discussed in Chapter IV.

In the management of a marine SAC with *Zostera* biotopes, it is important to consider the factors required to facilitate the recovery, maintenance and expansion of the *Zostera* beds.

1. Factors that may limit or facilitate recovery

The factors and processes that control the successful development and consolidation of eelgrass beds are not yet fully understood and further research is required.

When *Zostera* plants reproduce sexually, seed production can be high. Despite reports of generally high germination success in the field (Churchill, 1983), Olesen & Sand-Jensen (1994a, b) maintained that colonization of new areas is probably restricted by the limited dispersal and the subsequent successful development of seedlings into patches. They reported that seedling development into patches is often unsuccessful or slow.

Within European waters, an improvement in light penetration and an increase in photosynthetically active radiation (PAR), usually resulting from a reduction in turbidity, are considered to be the main pre-conditions for successful recovery (Giesen e*t al*, 1990a; Jonge & Jonge, 1990). Reductions in nutrient inputs, which contribute to reductions in eutrophication and turbidity, are also considered to be beneficial (Olesen & Sand-Jensen, 1994b).

The table below summarizes the major factors believed to influence the capacity of *Zostera* beds to recover after disturbance or destruction.

Factors that may affect *Zostera* bed recovery

Factors that may limit bed recovery	Factors that may facilitate bed recovery
• Removal of habitat	• Artificial transplantation
• Unstable substrata	• Stable substrata
• Fragmenting and destabilized *Zostera* beds, caused by factors such as changes to coastal processes, physical damage or stochastic weather events	• Stable *Zostera* beds
• Reduced rhizome growth, seed production, germling success and seedling development into patches	• Increased rhizome growth, seed production, germling success and seedling development into patches
• Reduced light penetration, caused by increased turbidity, eutrophication, some forms of pollution, or epiphyte smothering	• Improvements in light penetration, caused by reductions in turbidity, eutrophication, pollution, epiphyte and algal smothering
• Nutrient enrichment	• Reductions of, or limited increases to, nutrient inputs
• Declines in epiphyte grazer populations	• Healthy and stable epiphyte grazer populations
• Unusual increases in wildfowl grazing pressure	• Wildfowl grazing activities may prevent excessive sediment build up in *Zostera* beds
• Competition with non-native species, *Spartina* sp. and *Sargassum muticum*	• Absence of non-native species, *Spartina* sp. and *Sargassum muticum*
• Environmental stress, (e.g. extreme temperatures or pollutants), which may increase the susceptibility to wasting disease infection	• Absence of environmental stresses and low populations of *L. macrocystis*, the causative fungal pathogen for wasting disease

C. *ZOSTERA* MITIGATION PROJECTS

Owing to the general lack of natural recovery of seagrass beds from wasting disease, numerous workers in North America and Australia, and to a lesser extent in Europe, have put a great deal of effort into seagrass restoration projects, concentrating on researching methods for transplanting seagrasses into suitable areas.

The UK Biodiversity Action Plan for seagrasses recognises that there is a need to restore areas of *Zostera* beds. Ranwell et al. (1974) outlined three reasons for attempting to transplant eelgrasses.

1) To replenish stocks in areas damaged by natural events or human activities

2) To create new eelgrass beds to compensate for those lost to land claim and development

3) To study variations in growth patterns between *Zostera* species and to detect distinct varieties

In the UK, large-scale transplantation trials have taken place in a number of locations around the south coast of England. All trials had limited early success but in the longer term, the plants either disappeared altogether or the transplanted areas did not expand. Transplantation techniques in the UK are still developing and there is potential for future, long-term success. The transplantation of *Zostera* and other seagrasses in the USA has been more successful, particularly in warmer latitudes. A number of transplanting techniques are employed, using plugs, turfs, individual mature plants (turions) and seeds. Transplantation is reviewed in detail in Davison (1997a).

D. SUMMARY OF THE MANAGEMENT ISSUES RELATING TO *ZOSTERA* BIOTOPES

The following table draws together the main conclusions from the preceding chapters (particularly Chapter V) to summarize the important processes and activities which must be taken into account in the development of an SAC management scheme for *Zostera* biotopes.

Process	Possible consequences	Impacts on Zostera beds
Coastal development (eg. Dredging, flood defences, marina construction)	• Complete removal of habitat	• Biotope destruction
	• Changes in balance of sediment accretion/erosion	• Smothering or erosion of beds
	• Increased water turbidity	• Shading of plants, reduced depth limits to growth
Increased nutrient input (eg. From sewage, fertilizers, fish farms)	• Increased nitrate concentrations	• Metabolic imbalance
	• Eutrophication: Proliferation of planktonic, benthic or epiphytic algae	• Smothering of plants by epiphytes or benthic algae • Shading of plants by increased turbidity • Increased susceptibility to wasting disease

Water pollution (dissolved contaminants)	• Heavy metals	• May affect nitrogen fixation
	• Antifoulants (triazine herbicides)	• Inhibition of photosynthesis
	• Terrestrial herbicides	• Growth inhibition
	• Other pollutants (eg. industrial effluents)	• May be toxic to Zostera or to epiphyte grazers
	• Loss of epiphyte grazers due to pollutants	• Smothering by epiphytic algae
Oil pollution	• Chronic exposure to refinery effluent	• No evidence of significant effects
	• Major oil spills	• Smothering effect: may halt or reduce growth
	• Chemical dispersants	• Highly toxic to Zostera and associated community
Physical disturbance (eg. Trampling, bait digging, Dredging)	• Removal of sediment	• Increased erosion and shading (turbidity)
	• Crushing, physical damage	• Damage to leaves and rhizomes
Spread of non-native species (Spartina, Sargassum)	• Potential competitive displacement of Zostera	• Little evidence of serious competition so far
	•	• Herbicides used to control Spartina may be harmful
Wasting disease	• Large-scale loss of Zostera beds	• Environmental stress may increase susceptibility to infection
Wildfowl grazing	• Can result in consumption of high percentage of Zostera biomass	• Beds can normally tolerate grazing pressure, but may be more seriously affected if stressed by other factors
Climatic change	• Possible effects: • Warmer temperatures • Sea level rise • Increased storm frequency and severity	• Increased flooding and erosion of beds • Increased stress, resulting in greater susceptibility to wasting disease

E. EXISTING MANAGEMENT INITIATIVES

Recent initiatives arising from the EU Habitats Directive and the Convention on Biological Diversity have led to eelgrass habitats being specifically targeted for conservation and restoration (Wynne et al., 1995). The key provisions and requirements of these two initiatives, as they relate to marine SAC management, are summarized below

1. EU Habitats Directive:

The Habitats Directive has five major requirements :

- European marine sites should be managed in order to maintain or restore the favourable conservation status of their natural habitats and species.

- In European marine sites, steps should be taken to avoid deterioration of the habitats, or disturbance to the species for which the site has been designated.

- Activities, whether inside or outside the site, that are likely to have significant effects upon the conservation status of the site's features shall be subject to assessment. Generally, such plans and projects may proceed only if it is considered that they will not affect the integrity of the site.

- At each site, the condition of the conservation features of the site and the effectiveness of any management measures undertaken will be monitored.

- Any management of the site should take into account the economic, cultural, social and recreational needs of the local population (SNH et al., 1997).

Under the Regulations, the conservation agencies have a statutory responsibility for developing ***conservation objectives***, defined as *a statement of the nature conservation aspirations for a site*. They will be expressed in terms of the favourable condition of the conservation features for which the SAC has been selected. The set of conservation objectives that are developed for each site should be specific, attainable, measurable and regularly reviewed. They should help to identify the management needs of the site, and to determine whether the existing management measures are appropriate or whether new measures should be introduced to maintain or restore the conservation features of the site (SNH et al., 1997).

The Regulations make provision for the development and implementation of ***management schemes*** for European marine sites, to achieve the set of conservation objectives for each site. The Regulations suggest that *Relevant Authorities* (such as Local Authorities and Harbour Authorities that have statutory powers over the area) should work together within a *Management Group / Forum*. They will have a responsibility to undertake their duties to ensure the maintenance of the conservation features of the site, that the conservation objectives of the site are achieved and that the management scheme is reasonable, workable and appropriate to the site (SNH et al., 1997).

2. UK Biodiversity Action Plan

A costed Habitat Action Plan for seagrass beds has been prepared by the UK Biodiversity Steering Group. A South West Regional Biodiversity Habitat Action Plan for seagrass beds has also been developed. These provide a summary of conservation issues and management approaches being considered. Copies of both documents are included in the Appendices. The UK Biodiversity Steering Group has also prepared Habitat Statements for 'Inlets and enclosed bays' and Estuaries which both refer to Zostera species as key elements of these habitat types Estuary Management Plans are being prepared by the statutory conservation agencies and a number of these also refer to Zostera.

County Biodiversity Action Plans (BAPs) are also being developed and some are likely to refer to *Zostera* species. For example, the Kent BAP refers to *Z. marina* as a key element of the marine communities even though this species has not occurred there for some time (I. Tittley, pers. comm.).

As biotopes of high conservation importance, *Zostera* beds are recognized within a number of recent national and international nature conservation designations and international conservation agreements. Under these complimentary designations, a combination of commitments and management responsibilities can be used by site managers to reinforce the protection given to *Zostera* beds. For example, some of the UK Marine SACs Project demonstration sites are also designated SPAs and in the Birds Directive, *Zostera* beds are an important conservation feature. Some SACs are also RAMSAR sites, which gives international recognition of the site's importance as a habitat for birds and requires the UK government to protect the site.

Each of the UK countries have their own national conservation designations, both statutory and non-statutory (National Nature Reserves, SSSIs) which can assist in the conservation management of *Zostera* beds. National management initiatives, such as 'Focus on Firths' in Scotland and Estuary Initiatives in England, will also assist in the conservation management of these biotopes.

Some practical management actions, developed from the costed and regional seagrass Action Plans are listed below (UK Biodiversity Steering Group, 1995 and RSPB, 1996).

National / strategic / policy level

- Compile and publish an inventory of the distribution, extent and quality (e.g. species diversity) of *Zostera* beds in the UK.

- Identify *Zostera* beds in the UK that are of particular significance (e.g. in extent and species diversity) and ensure that they are covered by the protected area network.
  Ensure that the full range of variation within *Zostera* biotopes is adequately represented within the network of European Marine Sites.
  Consider listing *Zostera* sp. under Annex I of the Habitats Directive, if the opportunity for amendment arises.

- Identify suitable sites, such as within the marine SAC network, where attempts could most successfully be made to restore *Zostera* beds, and draw up a targeted national strategy.

- Identify/confirm the important natural and anthropogenic activities that affect the *Zostera* biotope in the UK.

- Consider the conservation requirements of *Zostera* in the development of national or regional coastal zone management initiatives, to ensure that *Zostera* biotopes are not managed in isolation from other habitats and communities.

- Provide appropriately targeted information and advice to the Relevant Authorities, local people and the general public on the importance of *Zostera* biotopes, the need for conservation management, the range of damaging activities and the action they can take to prevent or minimize such damage.

- Consider the establishment of a national programme of *Zostera* biotope monitoring, to provide information on issues such as the incidence of wasting disease.

SAC site level

- Confirm the distribution, extent and quality (e.g. species diversity) of *Zostera* beds in the SAC.

- Identify/confirm the important natural and anthropogenic activities that affect the *Zostera* biotope in the SAC.

- Identify particular local factors that may affect *Zostera* biotopes in the SAC.

- Record natural stochastic events and, if required, monitor impacts and recovery.

- Monitor changes in the types and intensity of human activities occurring within and adjacent to the site, particularly relating to fishing and recreation.

- Be aware of other activities and coastal developments remote from the SAC that may have impacts on the *Zostera* biotopes.

- Ensure that under Regulation 48 of the Habitats Directive, all new plans and projects, particularly coastal developments are reviewed and assessed so that the impacts on *Zostera* biotopes of the SAC are prevented or minimized.

- Utilize other existing legislation, relating to pollution, water quality and fishing to prevent or minimize damage to the *Zostera* biotopes of the SAC.

- Record major anthropogenic incidents and if required monitor impacts and recovery.

- Link SAC management with any other management initiatives that may already apply to or include the SAC.
- Increase awareness amongst the Relevant Authorities and local people of the importance of *Zostera* biotopes, the need for conservation management, the range of damaging activities and the action they can take to prevent or minimize such damage.

- Seek to halt any declines in the *Zostera* biotope in the SAC.

- Maintain and /or restore the *Zostera* biotope in the SAC.

F. KEY POINTS FROM CHAPTER VIII

- There are three key requirements for management of *Zostera* biotopes in SACs:
- To ensure that the environmental requirements of *Zostera* are met, so that favorable conservation status can be maintained or enhanced.
- To review and manage human activities in the SAC to ensure that these are compatible with maintenance of the biotope.
- To review and assess proposals for new activities (or changes to current activities) to ensure that detrimental effects are avoided.
- A site manager must be aware of the various factors that complicate the conservation management of marine biotopes in general.
- The natural rate of recovery of *Zostera* beds following disturbance or disease outbreaks is often slow.
- Considerable efforts have made around the world to artificially restore seagrass beds. The need for such restoration is recognized in the UK Biodiversity Action Plan.
- Large-scale *Zostera* transplantation trials have been undertaken at sites in southern England. Long-term success has been very limited, but restoration techniques are still developing and further attempts are likely.
- Management guidelines arising from the EU Habitats Directive and the UK Biodiversity Action Plan make possible the compilation of a list of practical measures to be undertaken at National and SAC level.

IX
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APPENDIX 1

Description and physical attributes of UK *Zostera* species

a. *Zostera marina*

Named by:	• Linnaeus, 1758.
Synonyms:	• None.
Varieties:	• Zostera marina var. angustifolia (Hornem). • Zostera marina var. stenophyila (Ascherson & Graebner). The only difference from var. angustifolia is related to leaf vein number and location. (Butcher, 1941b).
Common names:	• Common eelgrass, wigeon grass, broad-leaved grass wrack, marlee, sedge, slitch
Zone:	• In the British Isles, it is considered to be fully marine and subtidal. • Occurs in the shallow sublittoral, typically from below the mean low water mark to 5m. • Elsewhere, in northern Europe and North America, Z. marina is recorded growing intertidally (mid-shore) as well as subtidally but these records may refer to Z. marina var. angustifolia = Z. angustifolia.
Habitat:	• Primarily muddy-sand or mud habitats.
Colour:	• Dark green, with leathery texture.
Abundance:	• This species appears to have been the most seriously affected by wasting disease • Prior to these outbreaks, it was probably the most common species in Britain and populations do not appear to have returned to their original levels.
Sterile shoots:	• The leaves are alternately arranged and flattened. • The sheaths at the base are fused into a tube around the stem.
-Leaf length:	• Maximum - 1 m, but typically between 20 - 50 cm.
-Leaf width:	• 4 - 10 mm wide.
-Leaf tip:	• Narrow, rounded tips, tips may have a sharp point (mucronate).
-Leaf veins:	• Approximately 5 – 11 parallel veins, that may be regularly spaced.
Flowering shoots	• Branched.
-Length:	• Are generally shorter than the sterile shoots, with a maximum length of 60 cm.
-Width:	• Are narrower than the sterile shoots.
-Stigma : style ratio:	• 2:1 - the stigma is twice as long as the style.
Flowering period:	• Mid to late summer.
Seeds:	• Ribbed, brown seeds, up to 3.5 mm long, excluding the style.
Rhizomes:	• High root/rhizome biomass. • In transverse section, clumps of strengthening fibres are present in the outer cortex (Butcher, 1941b).
Main method of reproduction:	• Generally perennial, beds expand by vegetative growth. • Annual populations of Z. marina have been recorded in northern Europe and North America (van Lent & Vershuure, 1994a, b). However, these may be populations of what is considered to be Z. angustifolia within the British Isles.
Seasonal leaf cover	• Can remain green throughout the year. Summer leaves shed in the autumn, are generally replaced by smaller winter leaves.
Longevity:	• Unknown.

b. *Zostera angustifolia*

There continues to be some doubt over the taxonomic status of Z. angustifolia. Outside the UK, workers generally regard it as a smaller, narrow-leaved, intertidal variety or form of Z. marina.

Named by:	• (Hornem) Reichenb.
Synonyms:	• Z. hornemanniana (Tutin). • Z. marina var. angustifolia (Hornem).
Common names:	• Narrow-leaved eelgrass.
Zone:	• It is commonly intertidal, ranging from the mid-shore down to Low Water Springs. • It is considered to be just as susceptible to desiccation as Z. marina but survives intertidally where mudflats provide damp conditions. • It may occasionally be found in deeper water, to a maximum depth of 4 m. However, these may be populations of what is considered to be Z. marina.
Habitat:	• It is common in estuarine conditions. • It often occurs in mixed beds with Z. noltii, where it predominates in waterlogged depressions between the free-draining hummocks dominated by Z. noltii.
Colour:	• Light, yellow-green.
Abundance:	• In Britain, it may have replaced Z. marina as the most common Zostera species.
Sterile shoots:	• The leaves are alternately arranged and flattened. • The sheaths at the base are fused into a tube around the stem.
- Leaf length:	• Between 15 - 30 cm.
- Leaf width:	• Typically around 2 (1.5 - 3) mm
- Leaf tip:	• Are initially rounded but as the plant matures, they become notched (emarginate).
- Leaf veins:	• Approximately 3 -5 veins.
Flowering shoots:	• Branched.
- Length:	• Are generally shorter than the sterile shoots, between 10 - 30 cm.
- Width:	• Are slightly narrower than the sterile shoots, around 1 mm.
- Stigma : style ratio:	• 1:1- the stigma is as long as the style
Flowering period:	• From early to late summer.
Seeds:	• Ribbed, brown seeds, 2.5 - 3.0 mm long, excluding the style.
Rhizomes:	• 1.0 - 2.0 mm thick and have slightly swollen nodes (Wyer et al, 1977); • In transverse section, the fibre bundles occur in the outer layer of the cortex (Butcher, 1941b; Wyer et al, 1977).
Main method of reproduction:	• It appears to rely more upon annual seed set than Z. marina.
Seasonal leaf cover	• Begin loosing leaves from late September and beds may be bare of leaves by mid-winter (Wyer et al, 1977).
Longevity:	• Unknown, but some populations may be annual.

c. Zostera noltii

Named by:	• Hornemann.
Synonyms:	• Z. nana (Roth).
Common names:	• Dwarf eelgrass.
Zone:	• It is intertidal, forming a definite belt between Mean High Water and Mean Low Water Neap. • It is the most tolerant of desiccation and is found highest up the shore. • It is rarely found below the low water mark (Stace, 1997).
Habitat:	• Like Z. angustifolia, it is common in estuarine conditions. • It often occurs with Z. angustifolia, with Z. noltii predominating on free-draining hummocks whilst Z. angustifolia predominates in the water-logged depressions.
Colour:	• Grass-green.
Abundance:	• In Britain, it the least common of the three Zostera species.
Sterile shoots:	• The leaves are alternately arranged and flattened. • The sheath at the base clasps the stem but is not fused into a tube.
- Leaf length:	• Maximum length - 22 cm.
- Leaf width:	• 0.5 - 1.5 mm.
- Leaf tip:	• The leaves of Z. noltii are initially rounded but as the plant matures, they become notched (emarginate).
- Leaf veins:	• Approximately 3 irregularly spaced veins.
Flowering shoots:	• Un-branched or with a few branches near the base.
- Length:	• Are generally shorter than the sterile shoots.
- Width:	• Are generally narrower than the sterile shoots.
- Stigma : style ratio:	•
Flowering period:	• From mid to late summer.
Seeds:	• Smooth, white seeds, 1.5 - 2.0 mm long, excluding the style.
Rhizomes:	• In transverse section, the strengthening fibre bundles occur in the in the inner part of the cortical layer. (Butcher, 1941b; Wyer et al, 1977).
Main method of reproduction:	• Seed production is high. • However, vegetative growth appears to be of equal or greater importance.
Seasonal leaf cover	• Retains its leaves well into the winter (Wyer et al, 1977).
Longevity:	• Unknown.

APPENDIX 2

a. Some examples of characteristic species of *Zostera* beds in Britain

Characteristic species **are those that are considered to be special to (rare or at the limits of their distribution) or are especially abundant in a particular biotope. They are generally immediately conspicuous and easily identified (K. Hiscock 1996).**		
COMMON NAME	SPECIES	• DETAILS
Stalked jellyfish	*Haliclystus auricula* *Lucernariopsis campanulata*	• Widespread • South-west distribution
Common cuttlefish	*Sepia officinalis*	• Southern distribution
Little cuttlefish	*Sepiola atlantica*	•
Seahorse	*Hippocampus ramulosis*	• Reaches its northern limit along the south-west coast
Seahorse	*H. hippocampus*	• Possibly occurs on the south-west coast
Broad-nosed pipefish **Snake pipefish**	*Entelurus aequoraeus* *Syngathus typhie*	• Both are almost totally restricted to eelgrass beds, south and east coasts
Hydroid	*Laomedea angulata*	• A distinctive shallow water hydroid whose substrate appears to be totally restricted to *Z. marina*. Few hydroids are so substrate specific. • Was thought to have disappeared from Britain after the eelgrass wasting disease epidemic of the 1930s. • In 1981, it was found on *Z. marina* leaves in Studland Bay, Dorset and in a small bed, just north of Misery Point in the River Yealm, Plymouth Sound. • Cornelius (1982) suggested that it may be dispersed on detached, floating *Zostera* sp. leaves and that perhaps these populations had re-colonised previous habitats from European populations.
Red algae	*Polysiphonia harveyii* *Rhodophysema georgii*	• Was unintentionally introduced to the British Isles before 1908 with oysters • This diminutive crustose red algal epiphyte is host specific to *Z. marina*.
Green algae	*Cladophora etroflex* *C. battersii* *Entocladia perforans*	• Both are very rare and have only been recorded in a few locations on the south coast of England and the west coast of Ireland. • This microscopic green alga is an endophyte and host specific to *Zostera* species.
Brown algae	*Halothrix lumbricalis* *Leblondiella densa* *Myrionema magnusii* *Cladosiphon zosterae* *Punctaria crispata* *Cladosiphon contortus*	- These 3 small brown algal epiphytes are host-restricted to *Zostera* leaves. - These 2 larger brown algae are also host-restricted to *Zostera* sp. leaves. This large brown alga occurs principally on *Zostera* rhizomes.

b. Representative species of *Zostera* beds in Britain

***Representative species* are those considered to be typical of a feature, habitat or community (K. Hiscock 1996)**

The other British seagrass species, *Ruppia maritima* and *R. cirrhosa*, may be found amongst *Zostera* beds.

MICROHABITAT: Surface of leaves and stems		
GROUP	**SPECIES**	**COMMON NAME**
Algae	Films of ciliates and diatoms etc. *Enteromorpha* sp. *Ectocarpus* sp. *Cladophora rectangularis* *Rhodophysema geogii* *Ceramium nodulosum* *Gracilaria gracilis* *Gracilariopsis longissima* *Polysiphonia* sp. *Brongniartella byssoides* *Dumontia contorta* *Stypocaulon scoparia* *Ulva lactuca* *Fucus serratus*	
Crustaceans	*Gammarus insensibilis* *Idotea baltica* *I. linearis* *Praunus* sp.	Amphipods Chameleon shrimps (mysids)
Molluscs	*Rissoa membranacea* *Hydrobia ventrosa* *Bittium reticulatum* *Littorina littorea* *Calliostoma striatum* *C. montacuti* *Cantharidus striatus* *Jujubinus striatus* *Hinia reticulata* *Haminoea navicula* *Akera bullata* *Aplysia punctata* *Oscanius membranaceus* *Archidoris pseudoargus* *Cadlina obveolata* *Aeolis papillosa* *Alderia modesta*	 Spire shell Common or edible periwinkle Topshell Grooved topshell Netted dogwhelk All seaslugs
MICROHABITAT: On or in the sediment		
GROUP	**SPECIES**	**COMMON NAME**

Bivalve molluscs	*Cerastoderma edule* *C. glaucum* *C. exiguum* *Lucina/Lucinoma borealis* *Lepton* sp. *Mytilus edulis*	Common or edible cockles Lagoonal cockle Little cockle Northern Lucina This and other commensal molluscs may be found in other species' burrows Mussels, attached to old rhizomes
Worms	*Arenicola marina* *Lanice conchilega* *Marphysa bellii* *Oerstedia dorsalis* *Myxicola infundibulum*	Lugworm Sandmason worm Annelid worm, local & probably rare Ribbon worm Slime tubeworm
Echinoderms	*Synapta digitata* *Paracentrotus lividus*	Sea cucumber Sea Urchin, normally bores holes in rocks but often found amongst *Zostera*
Sipunculans	*Phascolosoma pellucidum*	
Crustaceans	*Upogebia* sp.	Burrowing shrimps
Sea Anemones	*Cereus pedunculatus* *Peachia hastata* *Nematostella vectensis*	Daisy anemones Burrowing anemones Starlet anemone, typical of lagoon eelgrass beds
Fish	*Gobiusculus flavescens* *Spinachia spinachia* *Ballanas* sp. *Anguilla anguilla* *Liza* sp. *Dicentrarchus labrax*	2-spot goby 15-spined stickleback Small wrasse Eels Grey mullet Bass