Natural England Commissioned Report NECR111

A guide to assessing and managing anthropogenic impact on marine angiosperm habitat

Part 1: Literature review

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NATURAL ENGLAND

Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

This series of reports provides Natural Englands commitment to the MAIA Interreg project (Marine Protected Areas in the Atlantic Arc), and advice to the Marine Management Organisation (MMO) on the impact of anthropogenic activity at Studland Bay.

The MAIA Interreg project stems from part of the EU Atlantic Area Programme which is a transnational cooperation programme in the framework of the "European Territorial Cooperation" objective, which is one of the instruments of EU cohesion policy for the programming period 2007-2013. It is financed by the European Commission through the European Regional Development Fund (ERDF). MAIA gathers 9 partners from 4 European countries (United Kingdom, France, Spain and Portugal), which are involved in MPA designation and management. The purpose of MAIA is to create a network of MPA managers, which will take initiatives on an international level in terms of designation, governance and management, and be involved in the development of a representative, consistent, efficient and accepted network of Marine Protected Areas in the Atlantic arc. MAIA sets up four technical Work packages, and Natural England is inputting directly into WP2 (Developing common monitoring strategies), with the aim of sharing best practise, in order to develop joint methodologies to effectively monitor MPAs in the Atlantic Arc.

This work delivers Natural Englands statutory advice to the MMO on the impact of anthropogenic activity in Studland Bay, Dorset. The bay, which has become a controversial focus due to the presence of protected seahorse species which rely on the *Zostera marina* bed habitat, was also recommended by the Finding Sanctuary Project in 2011 as a potential Marine Conservation Zone for inclusion by Defra in the Marine Protected Area network. Due to this recommendation, and existing legislation, evidence is required on the amount and level of impact from anthropogenic activity on the seagrass beds, to inform appropriate management.

The broad range of work has been split into two reports. However, the work which was done jointly, aimed to:

- Understand the natural processes and pressures which play a considerable role in shaping seagrass beds and influence their individual vulnerability to anthropogenic pressures.
- Develop techniques to accurately distinguish the impacts from a variety of anthropogenic activity from natural pressures.
- Identify and guide on appropriate methods to monitor both the natural and anthropogencially induced changes in seagrass.
- Identify good practice in managing both commercial and recreational activities to reduce pressures on seagrass beds.
- Undertake a technical analysis using Studland Bay as a case study, to learn from and demonstrate the variety of techniques in the guidance.

Part 1 of the work presented in this report, provides a synthesis of information and guidance in monitoring and management requirements and techniques. This provides an indepth understanding of the natural environmental pressures which shape the unique characters of seagrass beds, and changes likely to be induced from additional anthropogenc pressures. Drawing from this, guidance is provided on how to monitor, and manage these impacts. Understanding the ecosystem services of seagrass is also an important aspect to consider when deciding management options, so this is also included.

Part 2 provided in a separate report, delivers a technical analysis of the character and vulnerability of seagrass beds in Studland Bay, Dorset, using techniques which draw on the guidance developed in Part 1. A critical analysis of approaches to assess the impact of anthropogenic impact is undertaken for Studland Bay. A review of existing information was undertaken to identify limitiations in each, and to identify new analytical approaches to fill gaps in knowledge. A significant amount of existing useful information as well as new survey and analytical work provides aerial photography analysis, wind and wave modelling, Landscape character assessments, and resultant vulnerability assessments to identify how the various natural and anthropogenic pressures have played a role in shaping the seagrass bed over time. This provides information on the current and likely future resilience of the seagrass bed and allows for a number of informed management options to be suggested.

The results and guidance from this work will inform managers across Europe through the MAIA Interreg project.

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Photos credits: Fiona Crouch (meadow and seahorse), Lin Baldock (anchor), Paul Naylor (young cuttlefish in seagrass)

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Further information
This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**.

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MAIA
Marine protected areas in the Atlantic arc

A guide to assessing and managing anthropogenic impact on marine angiosperm habitat - Part 1: Literature review.

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Field Study Report

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Executive summary

Globally, seagrasses have been disappearing at a rate of 110 km^2 yr^{-1} since 1980 and the rate of loss is increasing. Seagrass beds are in decline in OSPAR Region II (Greater North Sea - The North-East Atlantic) and under threat in all areas where they occur. In the UK, seagrass habitat is identified as a Feature of Conservation Importance (FOCI) for the proposed English Marine Conservation Zones (MCZs) and Welsh Highly Protected MCZs under the Marine and Coastal Access Act; a Scottish MPA search feature under the Marine Scottish Act; a Biodiversity Action Plan Habitat; a threatened and declining habitat under OSPAR and a sub-feature of subtidal sandbanks for the designation of Special Areas of Conservation under the European Habitats Directive.

There are multiple justifications for protecting these habitats from their association pressures. Seagrass beds provide a number of ecosystem services. They function as important nursery and foraging habitat for fish, shellfish and wildfowl. They are also thought to oxygenate and stabilise sediments, provide shoreline stabilisation and protection from erosion, and are natural hotspots for carbon sequestration and nutrient cycling. Finally, they are considered a foundation species, i.e. a species that provides habitat and enhances ecosystem biodiversity, home to intrinsically valuable species such as the seahorse and are an important bio-indicator of system health. Seagrass meadows are ranked amongst the three most valuable marine ecosystems on earth on a per hectare basis.

Recent reports on the status of seagrass habitats in the UK suggest that improvements to sewerage treatment and national regulations resulting from Urban Waste Water Treatment Directive and Water Framework Directive have started to negate pressures associated with decreased water clarity or quality, e.g eutrophication, aquaculture, coastal development, dredging and spoil disposal. However, continued direct physical pressures such as anchoring, propeller scarring, dredging and destructive fishing methods are increasingly resulting in further losses and fragmentation of many beds.

Understanding the environmental and natural factors which influence seagrass health and distribution at a specific location will not only help managers to differentiate between natural and human pressures on the habitat, but also to recognise the unique sensitivities of the habitat and how changes to the habitat may influence its role in the wider ecosystem (ecosystem services).

Ecology and biology of seagrass

Seagrasses are the only truly marine flowering plants and are fully adapted to submerged marine conditions and can form large intertidal and subtidal meadows. In the UK there are three recognized species of seagrass; eelgrass (*Zostera marina*), dwarf eelgrass (*Zostera noltii*) and narrow-leaved eelgrass (*Zostera angustifolia*). The main factors regulating the colonisation, growth and health of seagrasses are light, substratum and wave exposure, but the presence and distribution of seagrasses at different localities are also regulated by a number of site specific physical, chemical and biological factors. Table i summarises the main influencing environmental factors.

Table i The main environmental factors regulating the growth, distribution and condition of seagrass

Factor	Processes influenced	Limits	Controls*
Light	For photosynthesis	*Z. marina* range from 11 to 37% of SI, but for *Z. noltii* it is only 2% SI	Lower depth limits; growth rates; shoot density.
Hydrology (i.e. currents, wave action and tide)	Complex interaction as the seagrass also mediates water movement. Epiphytic biomass Sediment grain size and associated nutrient and oxygen conditions. Turbidity (see light) Desiccation (tidal exposure) Diffusion of nutrients/ gases across leaf boundary layers Sediment erosion	Minimum current velocity for *Z. marina* was 5 $cm.s^{-1}$ and the maximum that this species could tolerate in the field was 180 $cm.s^{-1}$	Upper depth limit; vegetative (rhizome) spreading; seedling colonisation; accumulation of fine sediments and organic matter; shoot density; direct influence on associated biota; meadow configuration (pattern, shape and juxtaposition of patches)
Geology	Erosional/depositional processes as well as the availability of nutrients and phytotoxins	*Zostera* can colonise a wide variety of sediments, from sheltered gravel to sand or mud	Growth, morphology and landscape configuration of seagrasses.
Temperature	All enzymatic processes relating to plant metabolism Flowering, germination Dessication	*Z. marina* is a temperate species and optimum conditions for growth are thought to be between 10 and 15°C. *Zostera noltii* can endure slightly higher temperatures.	Can influence the growth, biogeographical distribution
Oxygen	Aerobic metabolism	Data not found	If oxygen supply to meristems and roots of the seagrass is inhibited for long periods of time the plant risks reduced growth rates or even mortality
Salinity	Osmoregulation	*Z. marina* is euryhaline, sustaining growth in a wide range of salinities, 10 to 31. Salinities as low as 1 for optimum seedling development in *Z. marina var. angustifolia* and *Zostera noltii*, and optimum seed germination in *Z. marina.*	Biogeographical distribution
Nutrients (C, N, P)	Photosynthesis, Growth, Light availability	It is estimated that seagrasses requires about four times less nitrogen (N) and phosphorous (P) in the water column per weight than phytoplankton cells Seagrass C:N:P (Redfield ratio) is about 400:20:1, suggesting they are phosphorous limited	Epiphyte cover, seagrass growth density. Eutrophic conditions can result in light limitations (see light).

*This is not a comprehensive list as there are many indirect influences of each factor.

Competition between different species of seagrass, disease and grazing by wildfowl can also set limits to growth and distribution. In the 1930s abnormal climatic conditions are thought to have contributed to outbreaks of a wasting disease across the North Atlantic. Recent discoveries of diseased plants have led scientists to believe that the wasting disease outbreak of the 1930's was not a unique event. Curtailing stresses such as pollution and physical damage improves the resilience of the habitat to natural factors which may not be under human control.

To manage seagrass beds it is important to understand not only the variability of the environment in which they occur, but also the population dynamics of both the seagrass and the species associated with them.

Recruitment and growth in seagrasses, which are important for recovery and maintenance of a seagrass bed, can occur by both sexual (flowering and seed dispersal) and asexual (vegetative growth along roots and rhizomes) processes.

Pressures on seagrass beds

A number of human activities cause physical, chemical and biological environmental change which impact the factors that limit seagrass growth and health (as summarised in Table i) and result in a specific state change to the seagrass bed.

Nutrient enrichment from sewage, agricultural runoff and more localised inputs such as boating and aquaculture have all been correlated with increased growth of epiphytic algae (in particular filamentous), drift algae and phytoplankton. Each of these plant groups has the potential to compete with the seagrass for nutrients and reduce the amount of light reaching the plant. Loss of seagrass exposes the seabed to wave action causing resuspension, which further increases turbidity, creating a feedback loop impeding recovery. Any disturbance that lowers light availability to the plant will likely reduce photosynthesis thus limiting the amount of oxygen transported to the root system.

Zostera root systems are typically located within the top 20 cm of the sediment and can be easily uprooted. Physical disturbance can be caused by trampling, dredging, mobile fishing gear, land claim and adjacent coastal development. Intensive boat activity may result in direct physical damage to the seagrass beds by propeller, anchor or mooring scarring, or hull grounding during shore landings.

Management of seagrass habitats

Advice, policy and management for the protection of seagrass habitats is tiered from international to local scales (see summary in Table ii), and involves statutory bodies, non-governmental organisations, land owners and the wider public. Some management actions specifically target seagrass andothers aim to protect the wider ecosystem and biodiversity.

Table ii A summary of the political framework for seagrass protection in the UK

Protective statute	Requirements	Relevance to seagrass protection
International		
Convention on the Conservation of European Wildlife and Natural Habitats 1979, (The Bern Convention)	Control of exploitation and other factors causing loss and disturbance of endangered and vulnerable species of fauna and flora.	*Zostera marina* (but not *Zostera noltii*) listed in Appendix I but only for the Mediterranean and the convention provides no legal basis for its protection in the UK
Convention on Wetlands, 1976 (known as the Ramsar convention)	Management plan with conservation objectives. New developments require an Environmental Impact Assessment (EIA) under the Town and Country Planning Regulations 1988 (see below). Significant changes in character of the site may result in it being placed on the Montreux Record flagging it to the Ramsar Advisory Mission.	The definition of wetlands in the convention specifically covers seagrass beds, both intertidal and subtidal. Six Ramsar sites include seagrass in the UK, all coincidental with other other types of protection for example, European marine sites
European		
EU Habitats Directive (Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora)	Designation of Special Areas of Protection (SACs) for listed features. All new or planned activities within a site must be assessed to ascertain whether they would compromise the features of the site.	*Posidonia oceanica* is a named habitat on Annex I of the directive. Other seagrasses, including *Zostera marina* gain protection as named components of 'Lagoons and Shallow Sandbanks', 'Large shallow inlets and bays', 'Intertidal mud and sand flats', 'Estuaries' and 'Sandbanks covered by sea water at all times'
EU Water Framework Directive (WFD, 2000/60/EC)	Member States must aim to reach good chemical and ecological status in inland and coastal waters by 2015.	Seagrass status is one of the indicators of Good Ecological Status.
Marine Strategy Framework Directive	Monitoring and protection requirements currently being consulted on.	Protection to Benthic habitats
European Nitrates Directive (91/676/EEC)		Indirect protection of seagrass by controlling nitrate enrichment which may lead to eutrophication
Urban Wastewater treatment Directive (91/271/EEC)		Indirect protection of seagrass by controlling waste water inputs which may lead to eutrophication, increased turbidity and sedimentation
Birds Directives (79/409/EEC)	Designation of Special Protection Areas (SPAs). All new or planned activities within a site must be assessed to ascertain whether they would compromise the features of the site.	
OSPAR Convention	Legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. Each feature has a case report identifying its status in each OSPAR country, threats they face and recommendations on the actions and measures that could be taken to ensure their conservation and monitor progress of these actions	Seagrasses are listed on the OSPAR list of threatened and/or declining species and habitats, identifying them as in need of protection and as a priority for further work on the conservation and protection of marine biodiversity under Annex V of the OSPAR Convention

Table continued…

Protective statute	Requirements	Relevance to seagrass protection
National		
SSSI (Sites of Special Scientific Interest) for geological features and species listed under the UK Wildlife and Countryside Act	Conservation objectives to appropriately manage and monitoring to maintain favourable condition	SSSI do not cover the subtidal,but subtidal seagrass communities are, however, protected under the SSSI if they extend into the intertidal within a site.
Marine (Scotland) Act		Seagrasses are listed as a Priority Marine Feature for the selection of Scottish marine protected areas under this act.
Marine and Coastal Access Act	Creation of a network of Marine Conservation Zones.	Seagrasses are listed as Features of Conservation Importance (FOCI) (both in terms of Broad-scale habitats and Habitats of Conservation importance) for the proposed Marine Conservation Zones (MCZs) and Reference Areas (RAs).
Natural Environment and Rural Communities Act 2006	All public bodies to have regard to biodiversity conservation when carrying out their functions. This is commonly referred to as the 'biodiversity duty'	Seagrass listed in Section 42 list of Habitats of Principal Importance for Conservation of Biodiversity in Wales. Section 41 for England.
UK Wildlife and Countryside Act (WCA 1981)	The Act makes it an offence (subject to exceptions) to intentionally kill, injure or take any wild animal listed on Schedule 5, and prohibits interference with places used for shelter or protection, or intentionally disturbing animals occupying such places.	As a habitat for seahorses (in particular *Hippocampus guttulatus*) UK seagrasses gain some level of protection, since disturbing the habitat of seahorses is a licensed activity in the UK. Also see Section 140 (offences) of the Marine and Coastal Access Act.
Biodiversity Action Plans (BAPs) are a result of the 1992 Rio Earth Summit	aims to assess the feasibility of restoration of damaged or degraded seagrass beds	Although seagrass does not have a species Biodiversity Action Plan (BAP) it is covered by a Habitat Action Plan (HAP). The UK BAP lists seagrass as a priority habitat occurring in two broad habitat types depending upon the species present. Now replaced by UK post-2012 Biodiversity Framework.
UK post-2012 Biodiversity Framework	UK Government's response to the new strategic plan of the United Nations Convention on Biological Diversity (CBD), Aichi targets.	Renewed motivation for reaching goals of the CBD. Focus on resilience and ecosystem services.
Town and Country Planning Regulations 2011 (UK enactment of Council Directive 97/11/EC) and the Marine Works (Environmental Impact Assessment) Regulations 2011	UK developers have a legal obligation to consult with the relevant planning authorities prior to any proposed development and if necessary carry out an EIA. Also see the Marine and licensing provisions of the Marine and Coastal Access Act.	Given its conservation status seagrass beds would be addressed in any EIA.

Management of the endogenic (within system) pressures described above can improve the overall health of the seagrass and its resilience to exogenic pressures (those coming from out side the system, such as pressures associated with climate change) which cannot be controlled at a local scale. Current and future exogenic pressures to seagrasses include disease, ocean acidification, sea level rise and climate change (including sea temperature rise, increase in storm activity and shifts in prevailing wind direction). Response of seagrass plants to a pressure is related to the proximity of the site to the natural limits of the seagrass species and the other pressures the bed in question has been exposed to.

Examples of responsive or preemptive management actions include technological advances, limiting or removing damaging activities and using deterrents. It is important to consider that reactive management approaches or responses can be directed at the underlying socio economic drivers of the pressures which result in an unacceptable change in seagrass state (for example, food labelling); at the pressures themselves (for example, MPAs, no anchoring zones, using eco-friendly moorings); at the state change (for example, by promoting resilience, carrying out restoration) and can even be directed at human welfare change (for example by providing compensation and mitigation).

Non-prescriptive approaches, which rely on public and stakeholders choosing to change their activities to help protect seagrass beds, have had varying degrees of success. These approaches include codes of practice, local agreements, planning processes and education. Success often occurs in projects focused on the similar goals of different groups (for example the boaters did not want to go aground, damage their propellers or become snagged on seagrass when anchoring). Education is a powerful management tool for the protection of seagrass. Informing people about seagrass biology and its importance can allow people to make a decision about whether they care about the habitat. It is also important that people are informed of ways they can help alleviate a problem as an individual or group.

Management recommendations

The current report proposes that at a site level managers should consider the following steps to build an appropriate knowledge base for protecting seagrass habitats:

- Map out all the stakeholders and relevant legislation/policy and agreements.
- Collate all available data on state and pressures for the site from past surveys.
- Carry out a gap analysis to ascertain missing information or critical research requirements.
- Carry out a full character assessment map of the seagrass bed at the site (environmental conditions such as depth, sediment, wave exposure, but also human pressures).
- Using the character assessment assess sensitive and vulnerable parts of the beds, natural limits and identify potential indicators of functional aspects of the meadow in terms of ecosystem service delivery.
- Identify the potential natural limits of the seagrass beds and ensure protective boundaries allow possible recovery of outer limits.

Based on the review of the ecology, pressures and management options, and building on previous recommendations from the OSPAR seagrass case report, the current sudy recommends the following for the future management of seagrass beds in the UK:

Legislative:

1. Protect seagrass beds.
2. Include *Zostera marina* and *Z. noltii* in the list of priority species in the *Natura 2000* list of species.

3. Control and treat urban and industrial sewage to reduce the loading of nutrients, organic matter and chemicals.
4. Regulate land use in catchment areas to reduce nutrient runoff and siltation from soil erosion.
5. Regulate aquaculture, fisheries and clam digging in or adjacent to seagrass beds.

Monitoring:

6. Develop baseline maps of seagrass meadows to allow monitoring of changes in distribution and abundance.
7. Long-term monitoring including abiotic factors.
8. Implement monitoring programmes that provide feedback on the results of coastal management. If management strategies do not meet their objectives, they must be adapted to achieve their goals.
9. In addition to common standard monitoring, monitoring at an individual site should target specific pressure responses and environmental and annual variation (for example, spatial variability).

Education/Research:

10. Raise awareness of the importance of seagrasses.
11. Implement codes of conduct to reduce small-scale disturbances.
12. Improve the links between local, national and international seagrass research.
13. Research gaps in knowledge, in particular, determine appropriate levels of quality for maintenance of habitat functions).

Enforcement:

14. Enforce the legislation of protection.
15. Examine cost effective methods for enforcement, such as Vessel Monitoring Systems (VMS) and self regulating options.

Promoting resilience:

16. Identify and fully protect or restore seagrass communities that are at low risk of succumbing to climate as these communities will serve as refugia to help seed the recovery of damaged areas.
17. Protect potential seagrass areas. Studies on the interannual dynamics of seagrass populations highlight the need to protect potential growth areas as well as existing seagrass beds to promote resilience.
18. Reduce the risk of loss of seagrass communities from climate change impacts by protecting the full range of seagrass communities (for example, across environmental gradients and geographical areas).
19. Identify patterns of connectivity between seagrass beds and adjacent habitats, for example, juvenile and adult habitat, to improve the design of marine protected area networks and allow for ecological linkages and shifts in species distribution.

Monitoring

Monitoring seagrass habitats and understanding the causes of changes observed is an important component of adaptive management. The first step in any monitoring program should be to understand the ecology of the habitat (see Section 1) and the specific environmental conditions and human pressures at the site being monitored.

The principle source of information used by Natural England to assess the interest features of European Marine Sites is currently given in ‘favorable condition’ tables provided in the Regulation 35 (recently changed from Regulation 33) advice for each site. Attributes are monitored according to Common Standards Monitoring Guidance. Those attributes common to all sites are extent, spatial configuration/ patchiness and density.

OSPAR-proposed monitoring for seagrass beds includes high-level monitoring of seagrass distribution using remote sensing data and fine-scale diver assessments of depth limits, degree of cover, health and biomass or shoot density along depth gradients. In addition, OSPAR recommends that the upper and lower depth limits should be monitored to give a robust indication of overall status. OSPAR recommend that monitoring associated fauna may provide important information on the functioning and ecosystem service delivery of the habitat.

Marine angiosperms (i.e. seagrasses) are a biological quality element required for assessment of environmental condition (Good Ecological Status) under the Water Framework Directive (WFD, 2000/60/EC). Under the Marine Strategy Framework Directive (2008/56/EC) EU Member States are obliged to assess Good Environmental Status of their seas under a set of 11 descriptors, of which seagrass relates primarily to Descriptor 1 ‘Biological Diversity’ and Descriptor 6 ‘Seafloor Integrity’.

In addition to monitoring the seagrass attributes and some of the main pressures, monitoring or collating additional data on environmental conditions such as relative wave exposure, storm events, temperature and rainfall, is necessary to distinguish between natural and anthropogenic pressures.

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1. Seagrass ecology and potential threats

Biology and ecology of seagrass

1.1 Despite their name seagrasses are not true grasses or algae. Unlike most marine plants they are angiosperms (flowering plants) their closest relatives being in the Lily family, with stems and leaves, roots and flowers (Dawes, 1981). Seagrasses can form large, dense and highly productive meadows. To be a true seagrass Aber (1920) suggested four indispensable criteria:

i. they must be adapted to a saline medium;
ii. they must be able to grow completely submerged;
iii. they must withstand tidal action and waves; and
iv. they must be able to carry out hydrophilous pollination and seed dispersal.

1.2 In brief they must be adapted to submerged conditions (hydrophytes). Den Hartog (1977) added a fifth parameter; the ability to compete with other organisms under the more or less stable conditions of the marine environment. True seagrass are able to meet these criteria through various adaptations. Like terrestrial plants they are able to take up nutrients through their root systems, but the leaves are also able to take up nutrients and inorganic carbon for photosynthesis from the water column. In common with all flowering plants, a seagrass plant reproduces by producing pollen which attaches itself to other flowers and fertilises it to produce seeds. They do all this underwater, with strands of gelatinous pollen drifting in the water currents until they come into contact with a flower. The flowers themselves are small, pale white and enclosed in a spathe (Dawes, 1981).

1.3 There are over 55 species of seagrass worldwide (Green and Short 2003b). In Europe there are currently four recognized species of seagrass, these are *Zostera marina*, *Zostera noltii*[1], *Cymodocea nodosa* and *Posidonia oceanica*, the latter is endemic to the Mediterranean. *Cymodocea nodosa*, known as Seahorse grass, is a southern European species, found in the Mediterranean. In the UK there are two known species of seagrass, eelgrass (*Zostera marina*) and dwarf eelgrass (*Zostera noltii*). A third species is also often quoted, *Zostera angustifolia*, however there is an ongoing dispute as to whether *Zostera angustifolia* is a separate species closely related to *Zostera marina* (Tutin, 1936). Current consensus is that *Zostera angustifolia* is simply a variety of *Zostera marina*; *Zostera marina var. angustifolia*, with narrower leaves and an annual life history strategy reproducing less by vegetative means in favour of seed production. These are possibly adaptations to its less stable habitat. *Zostera angustifolia* is an accepted species on the World Register of Marine Species. Van Lent and Verschuure (1994), who do not distinguish *Z. angustifolia* as a separate species, suggest that there is a continuum of life history strategies exhibited by *Z. marina* for survival in a range of environments. De Heij and Nienhuis (1992) concluded that an intertidal brackish form of *Z. marina* found in the Netherlands was genetically slightly different from subtidal forms in the region, perhaps a phenotypic reflection of habitat. A recent genetic

[1] Dwarf eelgrass is currently undergoing a review of its scientific nomenclature. In the scientific literature it is referred to as *Z. noltii* (see Green and Short 2003) and will be called that in this review so as to avoid confusion with cited literature cited. However, in the World Register of Marine Species *Zostera noltii* is not accepted and is instead *Zostera noltei*. Currently, reviews by Tomlinson and Posluzny (in prep) are suggesting that this species is in fact a separate genus and may soon be accepted as *Nanozostera noltii*.

sequencing study of *Zostera* worldwide showed no justification for considering *Z. augustifolia* as a separate species (Coyer, in prep).

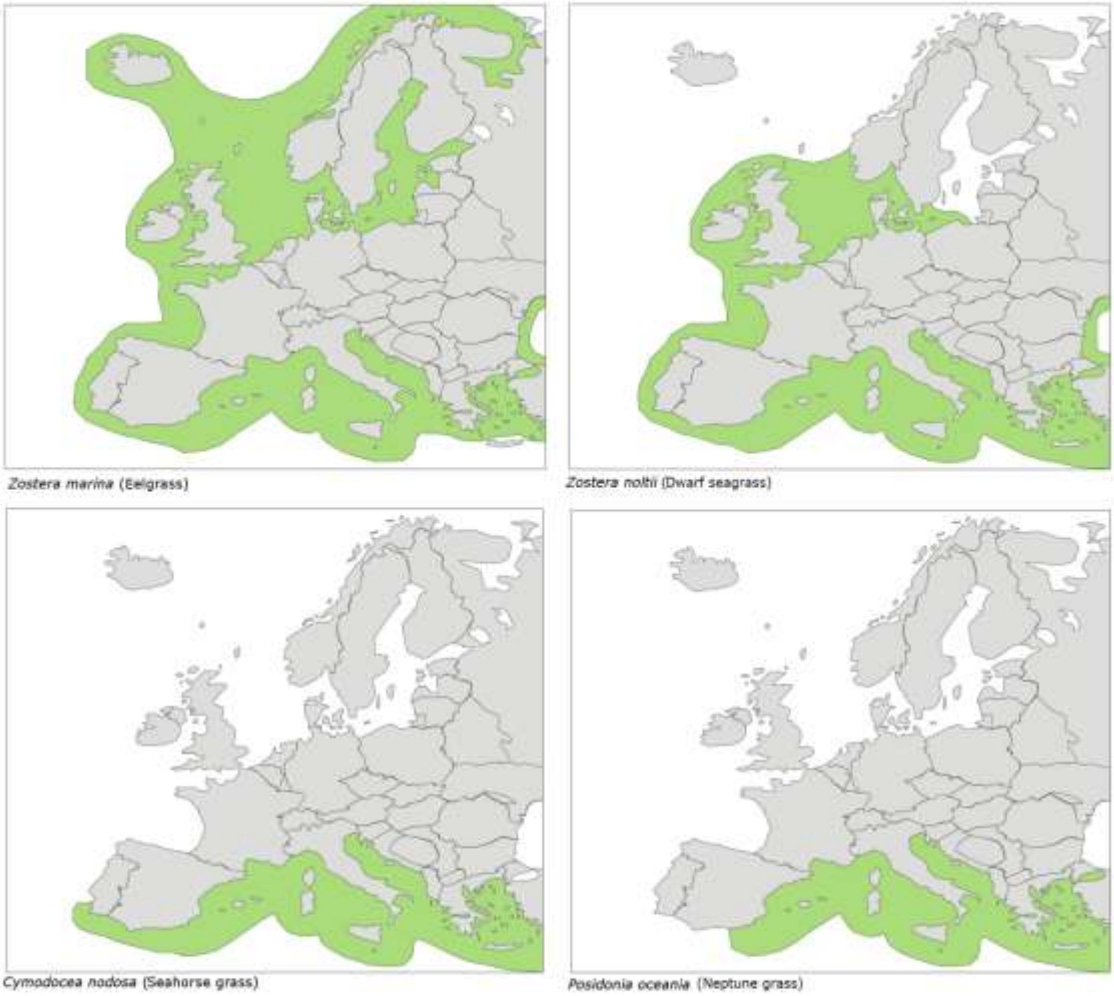

Figure 1 European distribution of the four main species of seagrass (Adapted from Borum *et al.* 2004)

1.4 *Z. noltii* is primarily an intertidal species with a higher tolerance to desiccation than *Z. marina*. *Z. noltii* also occurs subtidally but often seems to be outcompeted by *Z. marina* where the water cover is permanent (Borum *et al.* 2004). As the smallest British seagrass, *Zostera noltii* has 2-5 non flowering leaves, 10 to 25 cm long and up to 0.5 to 2mm wide. Some confusion can occur between *Z. noltii* and small seedlings of *Z. marina*. The main distinctive features are that in the rhizomes of *Z. noltii* the vascular bundle is in the innermost layer (outer for *Z. marina*), also *Z. noltii* seeds are smooth and have retinaculae (a small projection).

1.5 *Z. marina* grows to depths of 10m depending on water clarity. The shoots of *Zostera marina* have 3 to 7 leaves. Leaf width varies between 2 mm for young plants and up to 10 mm for large individuals. The leaves are usually 30 to 60 cm long but may be up to 1.5 m in beds on soft sediments at intermediate depths. Although, *Zostera marina* is mainly a subtidal species, it can occur in the lower intertidal of shallow lagoons, on sand, mud or a mixture of sand gravel and mud.

1.6 In comparison to *Z. marina*, which is almost purely subtidal in its habitat, *Zostera marina var. angustifolia* is found intertidally from about mid tide to low water spring tide. *Zostera angustifolia* is more slender than *Z. marina* with non-flowering shoots 150 to 400 mm and about 3 mm wide. This species has a wider salinity tolerance than *Z. marina* and is distinctive in that it survived the wasting disease which destroyed *Z. marina* populations in the 1930's (Rasmussen, 1977).

1.7 A comprehensive review of all European seagrass species has been carried out by Borum (2004): the current review will focus on UK species of seagrass. *Zostera marina* has a much wider distribution than the intertidal *Z. noltii* and therefore a greater amount of work has been carried out on this species. This review uses mainly *Z. marina* examples, but will highlight any important differences to consider with regards to the intertidal species, *Z. noltii*. The term seagrass will be used to describe statements which apply across species of seagrass, otherwise the specific species name will be used. It should also be noted that across their geographic range both species show a degree of variation between sub populations (phenotypic plasticity) in terms of size and tolerances (Hughes *et al.* 2009).

Growth and distribution of seagrass

1.8 Recruitment and growth in seagrasses can occur by both sexual (flowering and seed dispersal) and asexual (vegetative propagation) processes. *Z. marina* is a subtidal, perennial species which uses a large proportion of its resources for root and rhizome maintenance, reproducing mainly by vegetative propagation. Even so, one plant can produce 200 seeds per season. Seed dispersal is usually the result of shoot detachment once the seeds are fully developed. Seeds either settle within the bed or the shoots float, and can be dispersed by tidal or wind driven currents away from it. Seeds are also thought to be spread by ducks and geese feeding on the eelgrass (Ganter 2000). Germination and growth to a mature plant can take between 1 and 2 years (Dawes 1981). Flowering in *Z. marina* has been shown to be triggered by an increase in water temperature (De Cock 1981). Pollination is hydrophilous and is assumed to be limited to the extent of the source meadows. In addition seed dispersal and survival is unpredictable due to stochastic events (Orth *et al.* 2006) and seedling mortality is usually high (Duarte and Sand-Jensen 1990, Paling *et al.* 2001, Orth *et al.* 2002). Therefore the formation of new patches outside existing perrennial *Zostera marina* meadows by sexual propagules or drifting rhizome fragments is rare, which means that the natural recovery of locations where seagrass has been lost is often very slow.

1.9 Successful seagrass seedlings can expand into large meadows via the clonal or vegetative growth of the root rhizomes. Genetic analyses found that a 1 km^2 meadow of *Z. marina* in the Baltic was over 1000 years old and originated from a single seed (Reusch *et al.* 1999). Rhizome elongation rates vary (1-500 cm yr^{-1}) with seagrass species and in response to sediment texture and chemistry (nutrient availability) and light (Marba and Duarte 1998). Patch growth is centrifugal and self-accelerating, which is responsible for asymmetry in seagrass patch shape, exponential increase in shoot density with increasing patch age, and increased patch formation rates over time. Thus, the capacity of seagrasses to occupy space by clonal growth is a key factor in appearance, development and maintenance of seagrass landscapes, in terms of coalescing of patches and recovery of scars (Boström *et al.* 2006a).

1.10 Within seagrass patches, reproductive output (flowering of the plants) shows high temporal variability, but also distinct spatial patterns only recently revealed by genetic analysis. For example, clone maps of *Z. marina* meadows have revealed a strong positive correlation between number of flowering shoots and clone size; more patches and a greater number of smaller clones characterize physically disturbed environments (Hämmerli, 2002). Also plant growth rates can vary by position within the patch, with higher shoot density, above-ground biomass, and leaf area index at the centre of the patch (Brun *et al.* 2003). Thus fragmentation of seagrass meadows (where by the amount of core area decreases and edge increases) may accelerate losses at rates faster than the seagrass can recover.

1.11 Seagrass beds are very dynamic, showing variation in growth rates, morphology and configuration at various geographic and temporal scales (Durako 1994). For example, *Z. marina* undergoes natural cycles of accretion and erosion which shape the landscape configuration (Marba and Duarte 1995, Marba *et al.* 1996, Vidondo *et al.* 1997, Ramage and Schiel 1999, Plus *et al.* 2003). In annual populations the seagrass beds completely die back in winter, including the roots. Regrowth is dependent on local seed supply and therefore factors effecting reproduction can have significant implications for these populations. In perennial populations the leaves often senesce in autumn, but die-back of below ground parts of the plant (roots and rhizomes) is minimal. The general configurations of perennial beds are maintained across years, whereas in annual populations, subsequent years' distributions significantly differ, which has important implications for monitoring extent. In the UK the majority of *Z. noltii* are annual and *Z. marina* perennial, but elsewhere this is reversed. For example in the Wadden Sea *Zostera noltii* is a perennial, regenerating from overwintering rhizomes (Hootsman *et al.* 1987).

1.12 Although such dynamism should buffer the effects of perturbations many seagrass loss events have often been catastrophic, suggesting that there is a critical threshold in fragmentation whereby the negative effects that seagrass loss initiates (for example sediment resuspension and reduction) further accelerate losses at rates greater than the seagrass can recover. For example Olesen and Sand-Jensen (1994) examined mortality and patch size in the Limfjorden, Denmark. They found that patches of <32 shoots m^{-2} which were less than 5 years old showed very high mortality. They found that mortality reduced sharply with increasing age and size of patch, due to improved anchoring capability and physical integration between shoots.

1.13 Species of seagrass from the genus *Zostera* and *Cymodocea* are monomorphic and do not have any vertical rhizomes (Duarte *et al.* 1994). This restriction to horizontal elongation of the roots explains why large continuous meadows are only found in gently sloping locations. Sudden changes in sediment depth can inhibit recovery of the seagrass into bare patches. Hence the depression of the seabed caused by a disturbance or mounding of the sediment caused by waves and currents can restrict the expansion of seagrass. In comparison *Posidonia oceanica* rhizomes can extend both horizontally and vertically, increasing the ability of this species to colonise rugged seabeds.

1.14 The configuration of a seagrass landscape describes the individual layout of the bed and includes the pattern of seagrass patches, bare areas within the bed, size, shape, amount of edge (total edge of each seagrass patch) and core area (area beyond a certain distance of edge, where conditions may be more stable). Landscape configuration is a result of a combination of internal regulatory mechanisms (for example seed dispersal and germination, growth rates) and external processes (for example disturbance events, hydrodynamic activity and the underlying geomorphology of the area)(Boström *et al.* 2006a). Fragmentation of the landscape can be challenging to identify against the natural clonal growth of seagrass beds. Fragmentation is a process and it is not possible to determine whether it is occurring without the availability of time series data (studying changes over time), genetic markers or a clearly demonstrated cause and effect of a disturbance (see Figure 2) to be sure that patches of seagrass are a reduction in a prior continuous bed, rather than not simply clumps of new growth.

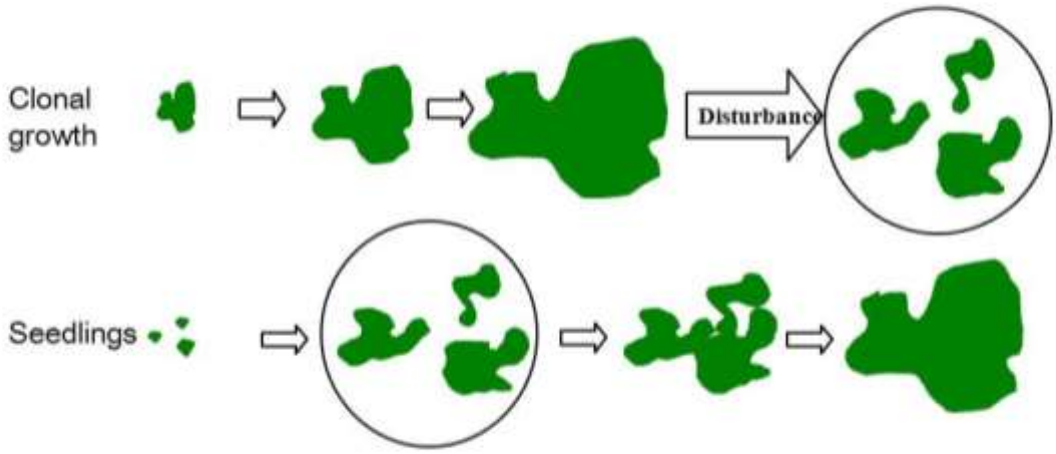

Figure 2 Seagrass landscape configuration can be a result of fragmentation or fusion (schematic provided by Christoffer Boström)

Environmental regulating factors

1.15 The main factors regulating the colonisation, growth and health of seagrasses are light, substratum and wave exposure, but the presence and distribution of seagrasses at different localities are also regulated by a number of other site specific physical, chemical and biological factors.

Light

1.16 Light for photosynthesis is a main requirement of seagrasses and therefore both water column transmissivity and depth will control the lower depth limit of seagrass (Dalla Via *et al.* 1998). Seagrasses have light requirements an order of magnitude higher than other marine macrophytes, ranging from 2% to 37% of in-water surface irradiance (SI) (Oleson and Sand-Jensen 1993, Erftemeijer and Robin Lewis III 2006). The critical thresholds for light availability for *Z. marina* range from 11 to 37% of SI, but for *Zostera noltii* it is only 2% SI. The high light requirements are a result of inefficient carbon uptake in seagrasses (Agustí *et al.* 1994). Any factors reducing carbon uptake, for example epiphyte growth (which increases the thickness of diffusion layers on the leaf blades), will effect depth limits.

1.17 Physical, biological and chemical parameters that alter light availability (depth, storm events, epiphyte biomass, dissolved inorganic nitrogen and phosphorous, suspended chlorophyll concentration) are commonly listed as habitat requirements for seagrass colonisation and growth. Such parameters have been used in predictive models of habitat suitability (Koch 2001, Bos *et al.* 2005) and *Zostera* depth limits have been used as a bioindicator under the Water Framework Directive (WFD)(Krause-Jensen *et al.* 2005).

1.18 Using a dataset from the Danish Monitoring program Krause-Jensen *et al.* (2003) found that photon flux density (PFD, the light intensity illuminating a surface area per unit of time), relative exposure index (REI, the relative wave energy a specific point of time is exposed to), and salinity were the main factors affecting *Z. marina* cover, while littoral slope had no significant effect. *Z. marina* cover increased with increasing PFD at water depths of more than 2m, whilst in shallow waters cover was inversely related to REI. In coastal environments turbidity levels can fluctuate rapidly as a result of biological (for example plankton blooms) and physical (for example storm events) factors. Prolonged increases in turbidity will affect light reaching the seabed and therefore reduce the depth limit of seagrasses (Hemminga and Duarte 2000). Around the UK the typical maximum depth limit of *Z. marina* is between 0.5 and 4m, but in clear waters can reach up to 10m (Davison and Hughes 1998). *Zostera* *noltii* is predominantly intertidal as it is able to tolerate greater levels of dessication than the competing *Zostera marina*. The lower depth limit of *Zostera noltii* is primarily driven by competition from by *Zostera marina*, water currents and wave energy.

1.19 Light availability has a number of consequences on the productivity and distribution of seagrasses. Low light availability reduces productivity, reducing the amount of oxygen for respiration by the roots and rhizomes and lowering nutrient uptake (Figure 2). Resulting hypoxic conditions lead to a build-up of sulphides and ammonium (see paragraph 1.41 and 1.111), which can be toxic to seagrass at high concentrations (Mateo *et al.* 2007). Lower productivity and toxic stress will lower the resilience of the plant to other perturbations. Reduced root biomass has implications for stability of sediments.

1.20 Experiments have shown that *Zostera noltii* can survive light intensities below their requirements for only 2 weeks, whereas *Heterozostera tasmanica* could survive up to 10 months at 9% surface irradiance. The ability to survive for long durations is dependent on the species carbohydrate storage capacity (2006). The same review also identified critical thresholds for sedimentation for different species, which ranged from 2 (for example *Z. noltii*) to 13 cm yr^{-1}.

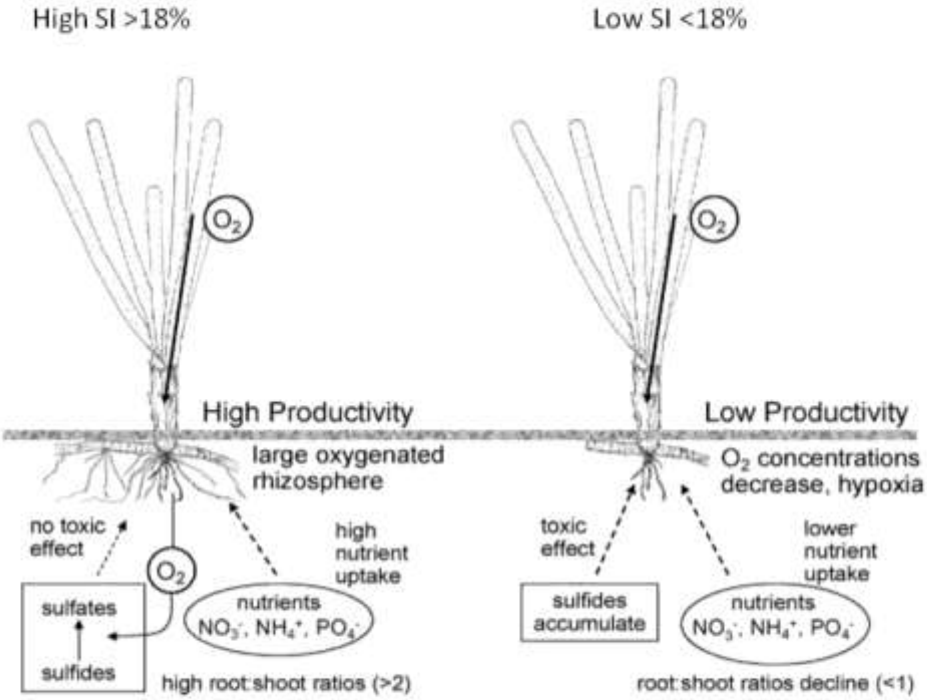

Figure 3 Effect of light availability (SI – Surface Irradiance) on seagrass productivity, sediment chemistry, nutrient uptake and root: shoot biomass

Hydrology

1.21 Whilst light availability controls the lower depth limit of seagrasses, currents, wave action and tide control the upper depth limit. Waves which reach the shoreline and “touch” the seabed continually mobilise sediments, which can in turn influence the light climate of the water column through re-suspension (Koch 2001). High wave and current exposure can reduce vegetative (rhizome) spreading, inhibit seedling colonisation and decrease the accumulation of fine sediments and organic matter (Fonseca *et al.* 1983). There is a complex interaction between seagrass and local hydrology as water movement affects the distribution of seagrasses, but the seagrasses themselves mediate water movement (Madsen *et al.* 2001). The capacity of seagrass beds to attenuate waves can be reduced through degradation, fragmentation or loss of the seagrass.

1.22 Within the confines of their physically defined niche (see below) seagrass landscapes are very dynamic, although at broader scales their occurrence is fairly predictable. Such local dynamism should buffer the effects of perturbations though seagrass loss events have often been catastrophic, suggesting that there is a critical threshold in fragmentation whereby the negative effects that seagrass loss initiates (for example sediment re-suspension and reduction) further accelerate losses at rates greater than the seagrass can recover.

Wave action

1.23 Wave energy is influenced by wind energy, depth of water offshore and fetch (Brown, et. al., 1989). Seagrass beds therefore tend to be located in sheltered locations or areas where long gently sloping shorelines dampen wave energy Moore (1963). Evidence from known sites of seagrass in Orkney suggest a similar situation, as over 86% of sites have distances out to the 10m isobath of over 1 km (Jackson 1998). Although seagrass beds are limited by high wave exposure, reports exist of *Zostera* growing in wave stressed environments (Tutin, 1938; Mann, 1972).

1.24 Low wave exposures may have benefits to the plants in terms of the reduction of epiphytic biomass, which may shade the seagrass from light and make the leaf blades more prone to detachment (Kendrick and Burt 1997). Wave exposure and currents also influence the sediment grain size, with areas of high wave exposure having coarser sediments with lower nutrient concentrations, but are less anoxic.

1.25 Koch (2001) suggests that if waves also force the seagrass to inhabit deeper waters (due to sediment resuspension in areas shallower than the wave mixing depth; see Figure 4), then the minimum depth of seagrasses in an area should be determined by the mean low water (tide) plus the wave mixing depth. Other pressures can also affect the upper limit including grazing by waterfowl and physical disturbance by humans (for example anchoring or landing boats). Upper depth limits of seagrasses are also a result of the resistance of some species of seagrass to desiccation. Large tidal amplitudes force subtidal seagrass to grow deeper (where there is less chance of exposure to the air). Shallow parts of a seagrass bed can become exposed to the air, rain and extremes of temperature. The lower depth limit of intertidal species such as *Zostera noltii*, which can tolerate emmersion for significant periods of time, will also be dictated by the mean low water and mixing depth.

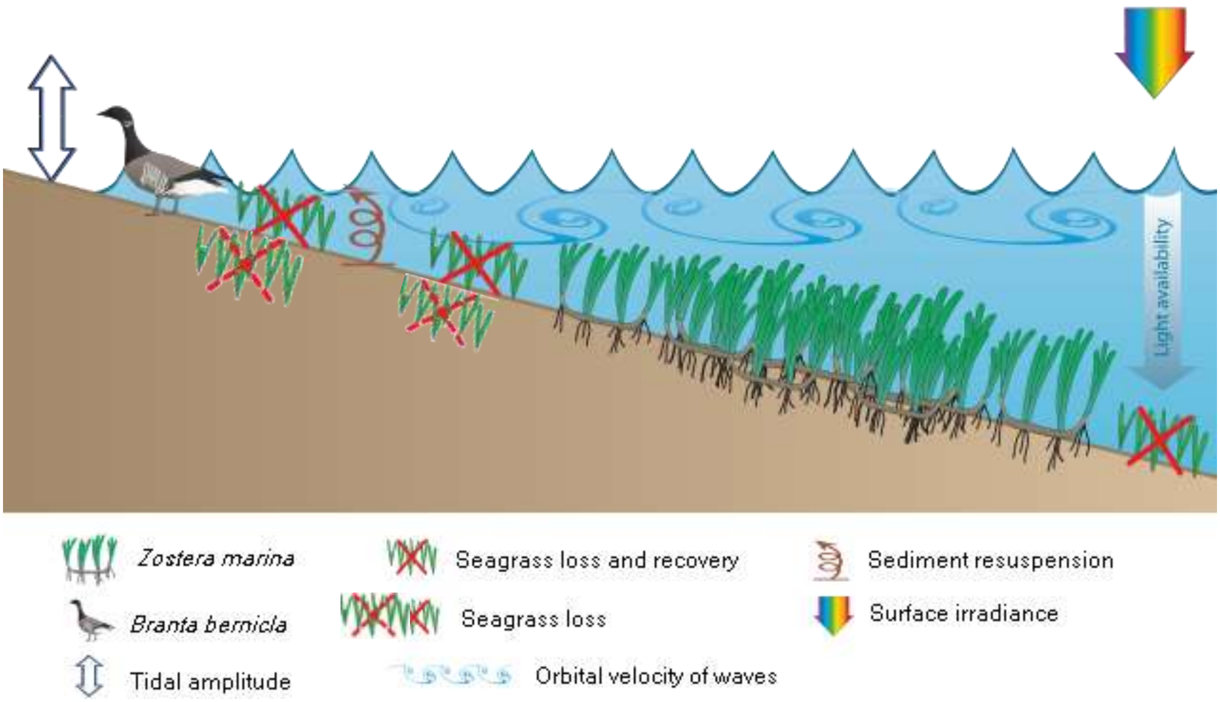

Figure 4 Biological and physical factors influencing the vertical depth range of seagrass at a location

1.26 Since seagrasses spread via vegetative growth the deeper parts of the meadow can convey energy (translocation via rhizomes) to shallow parts to aid recovery (Koch and Beer 1996). However if the shallow parts of the bed become fragmented from the rest of the meadow this ability will be disrupted (Koch 2001). The consideration of overall vertical range of seagrass in an area by managers is, therefore, important because in areas of large tidal ranges seagrass beds may be more vulnerable to changes in light availability.

1.27 Kenworthy *et al.* (1982) suggested that the relative wave exposure within different parts of a seagrass bed may modify shoot density through indirect effects on the depositional environment such as sediment nutrient reserves. Others have found a negative correlation between sediment particle size and organic content, and wave exposure (Pihl 1986, Gray and Elliott 2009), where greater wave exposure led to coarser sediments, less organic matter. Such conditions were linked to reduced vegetative spreading of seagrass and inhibited seedling colonisation, which has implications for the vulnerability of the seagrass at different locations.

Currents

1.28 The lower limit of current velocities (i.e. the slowest) which seagrasses can tolerate is determined by the physiology of the plant species, whereas the upper limit is purely mechanical. In a review of the literature Koch (2001) found that the minimum current velocity for *Z. marina* was 5 cm.s^{-1} and the maximum that this species could tolerate in the field was 180 cm.s^{-1} (c. 3.5 knots).

1.29 The minimum limit in current velocity relates to oxygen availability (see paragraph 1.41). At low current velocities not only is there a greater concentration of sulphide in the sediment due to reduced pore water advection[2] (Koch 1999), but diffusion of nutrients into the leaves of the plant is also inhibited by thicker diffusion boundary layers (DBL) on the surface of the leaf (a thin layer of water created by friction on the leaf's surface). As the current velocity

[2] This relates to the transport of water across the water sediment boundary and within the sediment itself.

decreases there is a critical DBL thickness, where the flux of carbon to the plant does not meet the requirement to support maximum photosynthesis (Jones *et al.* 1999). Low current velocities do convey some advantages, in particular a reduction in self shading (leaves of plant more erect) and reduced sediment re-suspension and erosion, all mean that there is greater light availability (Fonseca and Bell 1998). There is also greater nutrient availability in the sediments and greater settlement of algal spores and faunal larvae which may result in higher diversity than seagrass beds found under higher current velocities.

1.30 There is a maximum (i.e. fastest) current velocity which seagrasses can tolerate, beyond which sediment re-suspension and erosion rates are greater than the seagrasses ability to bind sediment and attenuate currents. Under very strong current velocities seagrass blades may lie flat on the sea bed reducing erosion under the leaves but not on the unvegetated edges which begin to erode. Strong currents can thus influence the configuration of patches within a meadow, creating striations and mounding in the seagrass beds [differences in sediment height between seagrass (higher) and unvegetated regions (lower)]. Such turreted profiles are thought to be the result of increased deposition and binding of sediment by the rhizomes where there is seagrass, combined with increased, channelled current strength between seagrass patches (Jackson 2003a), see Plate 1. Plate 1. Typically, mounding is observed under high current regimes (Fonseca *et al.* 1983) and wave exposure (Fonseca and Bell 1998), however, Fonseca *et al.* (1983) suggested it might simply be the result of reduced erosion and increased sediment trapping by the seagrass canopy.

Plate 1 Aerial photograph showing a striated seagrass bed off the island of Tresco, Isles of Scilly [Photograph by Blom Aerofilms Ltd, courtesy of the South West Coastal Monitoring Programme]

Geology

1.31 With the exception of *Posidonia* and *Phyllospadix* species, which are able to colonise rocky substrate, seagrasses require a soft substrate of gravel, sand or mud, were rhizomes can elongate and roots can fasten. *Zostera* can colonise a wide variety of sediments, from sheltered gravel to sand or mud (Den hartog 1977, Cleator 1993). For example, *Z. marina* beds in the Severn occur in an area of mixed cobbles, sand and mud with large boulders. There are also disparities between the species. *Zostera noltii* is described as preferring mud or detritus rich sand (Den Hartog 1970) and *Z. marina var. angustifolia* is more often associated with mud and muddy sand than with sand or gravel (Cleator 1993). Underlying geology can influence the growth, morphology and landscape configuration of seagrasses (Short 1987; Demas *et al.* 1996; Livingston *et al.*1998; Touchette and Burkholder 2000a) due to erosional/depositional processes as well as the availability of nutrients and phytotoxins (Marba and Duarte 1994; Dan *et al.* 1998; Koch 1999; Robbins and Bell 2000). Sediment may also be an important factor in the initial colonization of a site by seagrass. Moore *et al.* (1993) found that *Z. marina* seeds need to be buried in at least 0.5 cm of anoxic sediment to germinate.

1.32 A common observation is that sediments within seagrass beds are finer than those in adjacent unvegetated areas (Scoffin 1970; Wanless 1981; Almasi *et al.* 1987). In finer sediments porewater exchange with the overlaying water column is decreased (Huettel and Rusch 2000), which may result in increased nutrient concentrations (Kenworthy *et al.* 1982) but also phytotoxins such as sulphide (Holmer and Nielsen 1997). In finer sediments animal biomass is frequently higher resulting in greater bioturbation and nutrient flux, which may benefit the seagrass (Asmus *et al.* 2000). Where seagrasses colonise coarser sands, the exchange of porewater with the overlaying water column is higher and therefore nutrient availability in the sediment may be lower (Idestam-Almquist and Kautsky 1995).

1.33 Seagrass growth may also be limited by the physical and geochemical processes associated with a certain sediment type and not by the grain size (fine to coarse). For example Barko and Smart (1983) suggest that the growth of seagrass is limited to sediments containing less than 5% organic matter.

1.34 Grain size, wave exposure and current velocities will all influence the mobility of the sediment at a particular location (Soulsby, 1997). Entrainment of sediment is caused when the forces exerted by water movement (lift and drag) overcome the forces of gravity and friction (Middleton and Southard, 1984). Sediments become re-suspended and transported when the velocity of the water is sufficient to overcome gravitational and frictional forces acting on the sediment grains, increasing the erosion potential. The fine fraction of sediment (<0.063 mm, classified as clay and silt) is easily eroded from an unvegetated sandy seabed. Falco *et al.* (2000) argued that the sediment composition, especially the fine sediment fraction, could be used to explain the distribution of seagrasses (greater colonisation on finer sediments). In a study by Collins *et al.* (2010b) the sediment in unvegetated areas linked to anchoring and mooring disturbance were less cohesive, contained less organic material and had a lower silt fraction than surrounding habitats where seagrass was present.

Temperature

1.35 Temperature is considered the overall parameter controlling the geographical distribution of seagrass species. All enzymatic processes, related to plant metabolism are temperature dependent and specific life cycle events, such as flowering and germination, are often temperature dependent (Phillips *et al.*, 1983). Temperature affects all biological processes by increasing reaction rates of biological pathways. Photosynthesis and respiration increase with increasing temperature (until a point where enzymes associated with these processes are inhibited), but at high temperatures respiration of the seagrass plant will be greater than photosynthesis resulting in a negative energy balance. So at very low temperatures growth will be minimum and at very high temperatures the plants will be under a great deal of environmental stress and more susceptible to disease (Rasmussen 1977). Different seagrass species vary in their temperature tolerances.

1.36 *Z. marina* is generally adapted to temperate latitudes where annual water temperatures range from -1 to 25°C, although the optimum conditions for growth are thought to be between 10 and 15°C and 10°C for seedling development (McRoy 1966, Hootsman *et al.* 1987). Temperatures above 25 °C have been found to cause death if they persist for long enough (Biebl and McRoy 1971b). Despite such preferences the species has a distribution that ranges from the Arctic Circle to the Tropic of Cancer in both the Pacific and Atlantic (Den Hartog 1970, Green and Short 2003b).

1.37 *Zostera noltii* can endure slightly higher temperatures, and requires higher temperatures for flowering which may limit the northern distribution of this annual species. *Posidonia oceanica* and *Cymodocea nodosa* grow in the Mediterranean with temperatures ranging from approximately 10ºC up to about 30ºC. Despite these tolerances, studies have shown that *P. oceanica* is highly sensitive to seawater warming, with mortality rates in natural populations increasing threefold with a 3 °C increase in maximum annual seawater temperature (Marbá and Duarte 2010), which under current climate change predictions of sea water temperature may mean that this species will become functionally extinct in the Mediterranean by 2060 (Jorda *et al.* 2012).

Oxygen

1.38 Seagrasses require a constant supply of oxygen to sustain aerobic metabolism in both the above and below ground parts of the plant. Seagrass roots and rhizomes often experience oxygen deprivation for longer periods than the leaves, but they exhibit physiological adaptations which allow them to rely on an anaerobic fermentative metabolism. This anaerobic metabolism has side effects (lower efficiency, accumulation of toxic metabolites, so there are advantages in maintaining oxygen supply to the roots (see Figure 3).

1.39 Coastal marine sediments where seagrasses grow are often anoxic due to the high levels of organic matter and slow diffusion of oxygen from the water column to the sediment (Borum *et al.* 2006).

1.40 Seagrasses have become anatomically adapted to low oxygen by having a system of air filled lacunae extending from the leaves to the roots. Diffusion of oxygen into seagrass leaves is inhibited by a diffusive boundary layer of water surrounding the leaf surface, the thicker the layer the more difficult and slower the diffusion of oxygen. The thickness of this layer is related to water current velocity (thinner in higher current velocities) and by factors such as the density of epiphytes on the leaf blade (increases in thickness with density of epiphytes). If oxygen supply to meristems and roots of the seagrass is inhibited for long periods of time the plant risks reduced growth rates or even mortality. Roots which are normally protected by an oxic layer become vulnerable to toxins such as sulphides (Borum *et al.* 2006, Hatcher 2009). Exposure of seagrasses to high sulphide concentrations have resulted in reduced photosynthetic activity and growth and degeneration of meristems (Holmer and Bondgaard 2001) leading to possible die-off of shoots in the seagrass beds.

Salinity

1.41 Reports on the distribution of *Zostera* indicate that the species of seagrass found in the UK have different salinity preferences, which is related to their position on the shore. The intertidal species *Zostera noltii* and *Z. marina var. angustifolia* are able to thrive in low salinity (brackish) conditions, whereas the subtidal *Z. marina and C. nodosa* are commonly found in a more marine environment. *Posidonia oceanica* requires marine conditions, but cannot tolerate hyper saline conditions, for example those found in the proximity of desalination plants (Sánchez-Lizaso *et al.* 2008).

1.42 The occurrence of *Zostera* species in estuaries and on the intertidal may indicate a lower tolerance of variable salinities by *Z. marina,* however studies have shown this species to be relatively euryhaline, sustaining growth in a wide range of salinities, 10 to 31 (Biebl and McRoy 1971a, Mathieson *et al.* 2000). Even lower salinities (as low as 1), have been shown to be beneficial for optimum seedling development in *Z. marina var. angustifolia* and *Zostera noltii*, and optimum seed germination in *Z. marina* (Steinacher *et al.* 2009). Although established beds of subtidal *Z. marina* rely more on vegetative than generative production (Van Lent and Verschuure 1994), salinity may have influenced the recolonisation (by sexual reproduction) of beds destroyed by the 1930's wasting disease (Cottam and Munro 1954). Hence it is hypothesized that fresh water influence may be a determining factor in seagrass distribution in the UK. The daily and seasonal salinity of coastal waters is often variable, especially in those areas close to a terrestrial input of freshwater.

1.43 Whilst seagrasses can maintain a positive carbon balance (that is net photosynthesis) across a wide range of salinities they do not thrive equally well at all salinities and studies have shown that survival, growth and reproduction are affected by extreme salinities (Agustí *et al.* 1994). Nejrup and Pedersen (2008) found that the optimum salinity for *Z. marina* was between 10 and 25 (in terms of shoot mortality and elongation rates). There are also interactions between salinity and other environmental factors. In higher salinity environments, seagrass is thought to need sediments which are more oxygenated (coarser) and in which sulfide levels can be reduced via higher porewater advection rates (Fine and Tchernov 2007), see Section 1 above.

Nutrients

1.44 Seagrasses need inorganic carbon for photosynthesis. The leaves have a low capacity for extracting inorganic carbon from the water column and therefore seagrasses may become carbon limited under high light conditions (Lee *et al.* 2010). For this reason it has been proposed that seagrasses may profit from increases in atmospheric CO_2 (carbon dioxide) and subsequent ocean acidification (Invers *et al.* 2002). In water, inorganic carbon exists in three forms: CO_2, HCO_3 (hydrogen carbonate) and CO_3 (carbonate) depending on the pH of the water, and both CO_2 and HCO_3 are assimilated by seagrasses during photosynthesis.

1.45 In addition to Carbon, seagrasses also require a number of different kinds of inorganic nutrients, the most important of which are nitrogen and phosphorous. Nutrient requirements for seagrasses are lower than for other aquatic organisms such as macro algae and phytoplankton. It is estimated that seagrasses requires about four times less nitrogen (N) and phosphorous (P) in the water column per weight than phytoplankton cells (Hemminga and Duarte 2000).

1.46 Although it is debated, in general seagrasses growing in sandy or organic sediments are regarded as N-limited, and those in carbonate sediments as P-limited (Touchette and Burkholder 2000). By examining the deviation of nutrient ratios from the standard fixed ratios of seawater (known as the Redfield ratio: C:N:P = 106:16:1) it is possible to determine nutrient limitation of seagrasses (Kaldy 2009). If N:P is less than 16 the system is considered nitrogen limited and if N:P is greater than 16 the system maybe phosphorous limited. Reviewing the literature Kaldy (2009) identified that seagrass C:N:P was about 400:20:1, suggesting they are Phosphorous limited, however it has been shown that carbonate dissolution from seagrass organic acids may meet seagrass phosphorous requirements (Berkenhagen and Ebeling 2010).

1.47 Algae are, in general, able to out-compete seagrasses for water column nutrients since they have a higher affinity for nitrogen (so can take up water column nutrients faster)(Touchette and Burkholder 2000). However unlike algae, seagrasses have access to both water column and sediment nutrients, via their roots. The latter can account for up to 30% of nutrient uptake, but the importance of leaf versus root nutrient acquisition depends on enrichment conditions. Under enriched conditions there is a shift in reliance on the water column for nutrients (Touchette and Burkholder 2000). Many seagrasses respond favorably to low or moderate Nitrogen and/or Phosphorous enrichment, but excessive loads can inhibit seagrass growth and survival, not only indirectly through light reduction resulting from increased algal growth (for example epiphytes and macroalgae), but also directly in terms of the physiology of the seagrass. Physiological impacts are most pronounced for plants growing in sandy sediments (nutrient-poor). Studies have shown that *Z*. *marina* is physiologically inhibited by pulsed water-column nitrate enrichment conditions as low as 3.5–7 mM NO [†] (Touchette and Burkholder 2000). In contrast, sediment nutrient enrichment can stimulate growth of *Z*. *marina.*

1.48 Marine sediments typically have higher nutrient concentrations than the water column and in seagrass beds they are even greater. One reason for this is the efficiency of the seagrass canopy in trapping and retaining suspended organic particles, from which nutrients are re-mineralised in the sediment and taken up by the roots. In some cases this organic matter is from the seagrasses themselves. Hemminga *et al.* (1999) showed that internal resorption of nitrogen and phosphorous can help to meet the requirements of the plant. The ability to access sediment nutrients gives seagrasses a competitive advantage over other primary producers in oligotrophic (nutrient poor) marine environments (Duarte and Cebrian 1996, Victor *et al.* 2005). However in eutrophic (nutrient enriched) environments algae may have the competitive advantage. This may be a particular disadvantage when overgrowth of algal epiphytes and macro alga reduce the amount of light reaching the already light limited seagrass.

Competition

1.49 Competition between different species of seagrass will also set limits to growth and distribution. For example, *Z. noltii* often colonises the intertidal zone or the shallow waters where other species cannot establish populations. In deeper waters where *Z. marina* can establish, they apparently have a competitive advantage and *Z. noltii* beds will disappear.

1.50 Coexistence between *Z. marina* and the blue mussel *Mytilus edulis* is commonly seen in coastal areas of the northern temperate zone, such as the Baltic Sea and the Canadian east coast (Reusch 1998) and has also been found at the east coast of the USA (Bologna *et al.* 2005) and the UK (Torbay, Jackson, pers. obs). Bivalves can have a beneficial role by removing suspended matter from the water column and depositing faeces and pseudo faeces in the sediment which can be mineralized. The nutrients are subsequently released and made available for uptake by the seagrass (Peterson and Heck 1999). Sometimes this coexistence is more competitive. Mussels (*Mytilus edulis*) may compete with seagrass for the occupation of space and mussel spat occasionally settle on the leaves of *Z. marina* in very high numbers (Connolly 1994). As they grow and become larger they eventually cover the bottom suppressing plant growth. In their study on a mixed mussel/seagrass bed Vinther *et al.* (2008) identified increased hydrogen sulphide concentrations in the sediment attributed to a build up of pseudofaeces (see paragraph 1.40) . There is also evidence of competition with invasive species (for example *Sargassum muticum*) see page 34.

[†] Micro moles of Nitric oxide.

Grazing

1.51 Intertidal *Zostera noltii* and shallow *Z. marina* are an important food source for a number of water birds in northern Europe, including swans, ducks, coots and geese. Of these the most significant in the UK are Brent Geese (*Branta bernicla*), as this species is more dependent on seagrass than other species (being exclusively herbivorous), but wigeon (*Anas penelope*) can also be a significant pressure where locally abundant. Studies have also shown that Brent geese demonstrate a preference for *Zostera* over other food sources and that they can consume large amounts (both leaves and rhizomes)(see comprehensive review by Ganter 2000).

1.52 Brent geese are non-diving birds and can only reach about 40 cm below the water surface when up-ending (Clausen 1994), therefore they are only able to feed on the intertidal *Zostera noltii* and shallow margins of *Z. marina*. Their preference for *Zostera* comes from its high digestibility and nutritive value and the fact that it can occur in large expanses in areas often historically undisturbed by humans. The geese are able to ingest large quantities of seagrass in order to build up body reserves for long distance migrations to Northern breeding grounds. Dark-bellied brent geese, *B. b. bernicla* over winter in southern England and France, where they feed on *Zostera* as long as it is available (Jacobs *et al.* 1981, Tubbs and Tubbs 1982, Percival and Evans 1997, Ganter 2000). In fact, in many locations where Brent geese are known to feed, they are often quoted as feeding on *Zostera* for “as long as it is available” or “until it is depleted”, indicating that the geese can have a significant impact of the shallow margins of a seagrass bed (See Figure 4). Exclosure studies examining the impact grazing geese have on *Zostera* biomass, have shown significant declines, with cases of up to 50% of the *Zostera* standing stock being removed by birds in autumn and winter (Jacobs *et al.* 1981, Tubbs and Tubbs 1982). These and similar studies have also identified “giving up densities” of seagrass, where at seagrass covers of less than 15% grazing becomes unprofitable (see references within Ganter 2000). Studies have also shown that under low grazing intensity seagrass shows compensatory growth (Clausen, 1994). As density of seagrass increases there is also an increase in feeding on the rhizomes (Percival and Evans 1997), which will have implications for the recoverability of the plant.

Disease

1.53 According to historical reports seagrass beds were once very common along Europe’s shorelines, but have since declined due to the impact of a wasting disease which resulted in black lesions on the leaf blades which potentially lead to loss of productivity, degradation of shoots and roots, and in extreme cases loss of large areas of seagrass (Den Hartog 1987a). Two distinct periods of the disease in Europe have been identified, the first immediately after World War 1, and the second between 1931 and 1932. By 1933 the beds had started to recover. As of yet *Zostera* beds have not since regained their former distribution. There is the view that although the 1930’s wasting disease wiped out most of the seagrass and it never recovered, those surviving today are much more resilient to the disease. The other point is that the genetic diversity of *Zostera* population is very high, particularly in the NE Atlantic (Olsen *et al.* 2004) and have possible high variability in their susceptibility to the disease (Hughes and Stachowicz 2004a, Provan *et al.* 2008).

1.54 Early investigations lead to the conclusion that *Labyrinthula macrocystis*, an infectious slime mold protist, was the organism responsible. However this theory lost credibility when *Labyrinthula* were found in large numbers on otherwise healthy plants. Short (1988) suggested that there were two forms, only one of which was pathogenic. Other theories on the cause of the disease included correlations with extremes of precipitation (Martin 1954) and *long-term* increases in water temperature (Rasmussen 1977), both of which caused stress that reduced the plants resistance to infection. There is evidence to suggest that unusually warm summers on the south-west coast of England during the 1980's may have stressed *Z. marina* beds. A rise in temperature and decreased irradiance resulted in respiration outweighing photosynthesis and hence a reduction in the amount of available fixed carbon (Cleator 1993). Whilst a past epidemic cannot be regarded as a potential threat, recent discoveries of diseased plants have led scientists to believe that the wasting disease outbreak of the 1930's was not a unique event (Short *et al.* 1988, Cleator 1993). Although a natural event such as the wasting disease may be difficult to prevent with current knowledge, curtailing of stress factors such as pollution, may improve the *Zostera*'s survival ability in the event of another epidemic.

1.55 Around the UK, losses were observed mostly in the intertidal (Davison 1997) although losses in the subtidal may have gone unnoticed. Wilson (1949) observed the development of the wasting disease in the *Zostera* beds on the shores of the Salcombe Estuary (Devon, UK). In 1931 he observed the first signs of the disease, blacked leaves, before the eventual die off of all the above ground material. The root rhizomes remained for some time (as late as 1935), but when they did eventually decay, the sand, no longer bound, was washed away by currents (Wilson 1949). By 1948 the seagrass bed at Mill Bay (Salcombe) had almost completely disappeared and the shore level had fallen dramatically (Wilson estimates a drop of almost 1 m), reducing the area of beach exposed at low tides. Despite these losses and subsequent changes in the sediment, intertidal *Z. marina* in Salcombe has recovered although it is unclear to what extent since the habitat is impacted by other pressures (Goumenaki 2006).

1.56 In the Wadden Sea, it was the subtidal seagrass beds that never fully recovered after the wasting disease (Vergeer and Den hartog 1991). In 1919, seagrass coverage in the Wadden sea was estimated at 150 km^2 but by 1971 only 5 km^2 remained (Giesen *et al.* 1990). It was proposed that large scale damming may have contributed to a lack of recovery (increased turbidity or sediment mobility adjacent to the dams) (Reise 2005). Further declines in intertidal seagrass beds in the southern and central Wadden Sea between the 1970s and the early 1990s were attributed to increasing eutrophication, intertidal fisheries and turbulence (De Jonge and De Jonge 1992, Schanz and Asmus 2003, Reise 2005) and by 1994, seagrass (mainly *Z. noltii*) covered only 2 km^2 (Giesen *et al.* 1990).

Seagrass ecosystem functioning and ecosystem services

1.57 Seagrass beds are stated as providing a number of ecosystem services from provisioning, regulating and cultural categories (Barbier *et al.* 2011). They function as important nursery and foraging habitat for fish, shellfish (Jackson *et al.* 2001a, de la Torre-Castro *et al.* 2009, Warren *et al.* 2010) and wildfowl (Ganter 2000). They are also thought to oxygenate and stabilise sediments, providing shoreline stabilisation and protection from erosion (Koch *et al.* 2009b), and are natural hotspots for carbon sequestration and nutrient cycling (Kennedy *et al.* 2010). Seagrasses are considered a foundation species, that is a species that provides habitat and enhances ecosystem biodiversity and is home to intrinsically valuable species such as the seahorse(Curtis and Vincent 2005, Garrick-Maidment *et al.* 2010a). They are also an important sentinel of system health, due to their sensitivity to both water quality and physical disturbances, and were developed as an indicator for the Water Framework Directive (Ward 1987, Foden and Brazier 2007). The landmark Costanza *et al.* (1997) paper ranked seagrass meadows, at US\$3.8 trillion yr^{-1}, amongst the three most valuable ecosystems on earth on a per hectare basis, despite only the nutrient cycling function being considered. In the UK, the National Ecosystem Assessment highlight the ecosystem services provided by seagrass, and their importance in terms of biodiversity, although no valuation was attempted (Norris *et al.* 2011), (See Figure 5).

1.58 Although seagrass habitat's ability to enhance local biodiversity has been examined and confirmed for the UK (Webster *et al.* 1998, Attrill *et al.* 2000, Bowden 2001), other functions have only been examined outside of the UK and, in some cases, outside of Europe, where conditions and species composition are significantly different. Even then, the link between seagrasses and the processes underpinning the delivery of these ecosystem services is still uncertain. What is certain is that all seagrass beds do not function in the same way or provide services to the same extent, yet they are currently all given equal status with regards to decisions of which landscapes to protect. In the following sections we review the evidence for different ecosystem service provision by seagrasses and examine the structural and functional characteristics of the habitat which underpin these services, and hence the appropriate indicators of change.

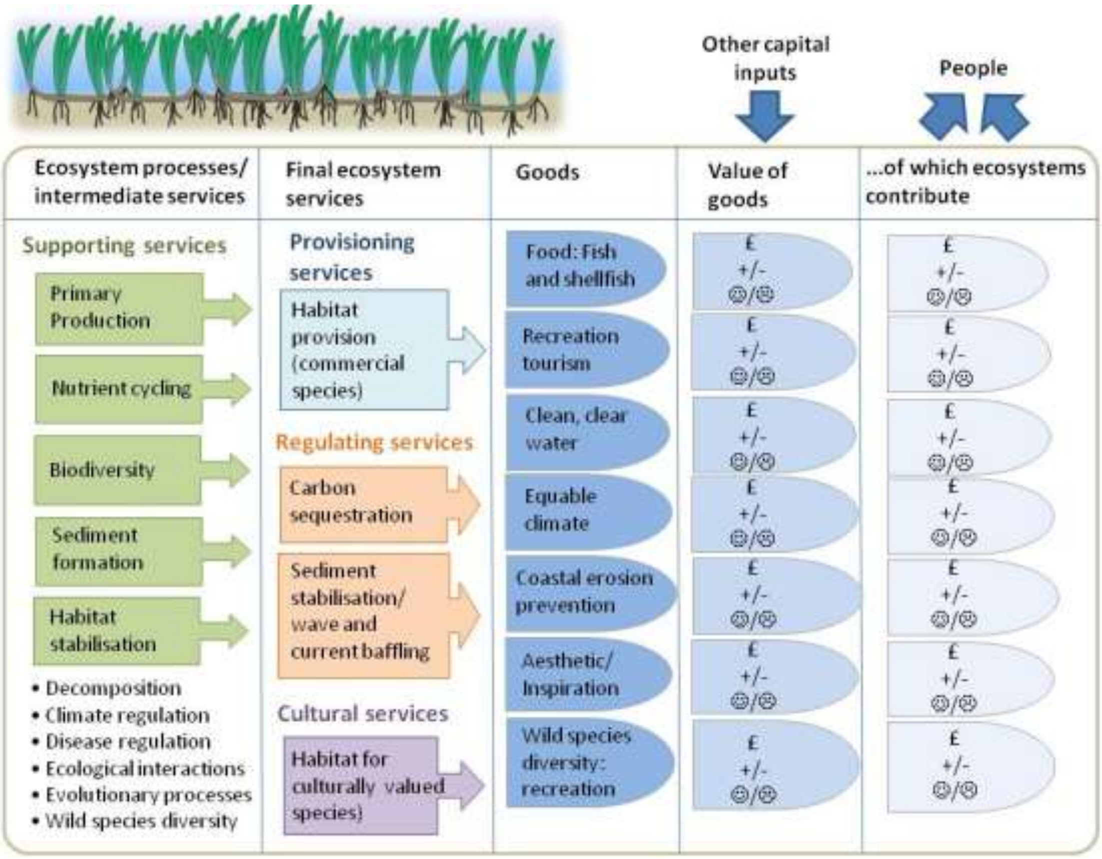

Figure 5 Schematic of the main seagrass ecosystem processes and services illustrating how these processes link to final ecosystem services and the goods and values they generate for people. (Adapted from the National Ecosystem Assessment, 2011)

Supporting services

1.59 Seagrass beds have an important role in coastal primary production. The ecology of primary production in a seagrass meadow is complex, involving six different plant groups, the seagrass itself, microepiphytic algae, macroepiphytic algae, benthic microalgae, benthic macroalgae and phytoplankton (Moncreiff *et al.* 1992).

1.60 The fate of seagrass primary production varies, primarily by location and species of seagrass (Duarte and Cebrian 1996). In 1997 Cebrián *et al.* examined the fate of leaf-blade production of four Mediterranean seagrass species including *Z. marina* and *Zostera noltii.* They found that *Z.marina* transferred twice as much production to consumers as *Z. noltii* and that most of the production was decomposed by detritivores (Cebrián *et al.* 1997). Consumption of seagrass leaf production by herbivores was higher for *Z.noltii* than for *Z. marina*. Excess production (not consumed nor decomposed) during the first year ranged from 9.2% for *Z. marina* to only 1.5 % for Z.*noltii*). This difference was attributed to the faster-growing leaves of Z. noltii which lost a higher percentage of production to herbivores and recycling most of the residual detrital production, therefore storing relatively small pools of refractory detritus (Cebrián *et al.* 1997).

1.61 Much seagrass detritus would appear to settle within the seagrass or in nearby sediments. Excess production settling within seagrass beds could become buried and stored (see page 23). It has also been suggested that the presence of seagrass may lead to organic enrichment of unvegetated sediments nearby, thereby enhancing food production for fishes (Shaw and Jenkins 1992) and that in many cases seagrass may form the basis of coastal nutrient cycles and promote the health of fisheries even in areas distant from the actual meadows. Jenkins *et al.* (1993) reported that Australian juvenile greenback flounder (*Rhombosolea tapirina*) may benefit indirectly from seagrass through organic enrichment of sediments and corresponding elevation of food production. The role of seagrass primary production is not limited to the immediate area. Thresher *et al.* (1992) used stable carbon isotope analysis, and reported that the food chain supporting the larvae of the blue grenadier (*Macruronis novaezelandiae*) in the Pacific was not based on either phytoplankton or terrestrial organic matter, but that seagrass (*Z. marina*) was the basis of this offshore food web. Others have also used stable isotopes analysis (Fenton and Ritz 1988) to track seagrass in food web dynamics, Dauby *et al.* (1998) measured the carbon isoptope ratios of over 100 species of plants and animals along the Brittany coast (France) and traced the input of carbon from distinct producer groups, particularly *Z. marina*.

Provisioning services

1.62 Historically, *Z. marina* had a number of varied direct uses (raw material and food) across Northern Europe and North America (McRoy and Helfferich 1980). Cottam and Munro (1954) reported that *Z. marina* ash found at ancient village sites in Denmark may be due to the plants being burnt for salt, soda or just warmth. Coastal Danes used *Zostera* leaves for a tough long lasting roof thatch and the Dutch built strong, durable dikes. During the first World War, Germany found seagrass to be a convenient cotton substitute in the manufacture of nitrocellulose (McRoy and Helfferich 1980). Seagrasses are still harvested in some countries for fertilizer (Hemminga and Duarte 2000, de la Torre-Castro *et al.* 2009) and in Chesapeake Bay, USA, seagrass by-catch or beach-cast is used to keep crabs moist during transport. In parts of Africa seagrass is eaten and used to make jewellery and potions during rituals (de laTorre-Castro and Rönnbäck 2004, Fletcher *et al.* 2012). Currently in the UK there is no major direct use of seagrass, instead seagrass beds are thought to have a fundamental role in maintaining populations of commercially exploited species.

Habitat provision for commercially exploited species

1.63 The habitat provision role of seagrasses in terms of commercially exploited species includes one or more of the following: (1) a permanent habitat, allowing completion of the full life cycle, (2) a temporary nursery area for the successful development of the juvenile stages, (3) a feeding area for various life-history stages and (4) a refuge from predation (Jackson *et al.* 2001a). A number of reports have correlated diminishing seagrass cover to declining fish catches. Examples include the King George whiting (*Sillaginodes punctata*) in Westernport Bay Victoria, Australia (Kikuchi 1974, Bell & Pollard 1989) and soft-shell blue crab

(*Callinectes sapidus*) in Chesapeake Bay, USA (Shabmann & Capps 1985). Bell & Pollard (1989) commented that fisheries are likely to depend heavily on seagrass only where harvests are made in very enclosed estuaries and bays, where seagrass provides the only shelter and where the exploited species spawns within the bay or estuary.

1.64 In terms of a foraging area for exploited species there are only a few examples of species that feed directly on seagrass. Francour (1999) found that Mediterranean saup (*Sarpa salpa*) fed primarily (although not exclusively) on *Posidonia oceanica* and the adults of the commercially fished echinoid *Sphaerechinus granularis* also feed directly on *Z. marina* in northern France (Guillou & Michel 1993). Of more importance to commercially important species foraging in seagrass beds, is the high density of potential faunal prey items present (Adams 1976b, Webb 1991, Tupper & Boutilier 1995). Seagrass beds are highly complex diverse habitats in terms of both the landscape configurations and the microhabitats provided by the plant structure, supporting a diverse and productive fauna (See Figure 6). Tupper and Boutilier (1995) hypothesised that the complexity of the seagrass (*Z. marina*) community in St Margrets Bay, Nova Scotia, meant that there was a greater range of prey items available to young-of-the-year cod, which resulted in better growth and better survival after leaving the seagrass bed. Similarly, Valle *et al.* (1999) suggested that the occurrence of juvenile barred sand bass almost exclusively within *Z. marina* was due to greater prey availability, enabling faster growth to a size that is less vulnerable to predation. In Limfjord (Denmark), hatchery-reared cod were released to seagrass (*Z. marina*) beds to improve their initial survival (Støttrup *et al.*, 1994).

1.65 By far the most studied, and frequently quoted, role of seagrass beds is as a nursery ground for many marine species, including those of commercial and recreational value (Bell & Pollard, 1989; Heck *et al.*, 1989; Gray *et al.*, 1996; Jenkins *et al.*, 1997a,b; Rooker *et al.*, 1998a,b). Evidence of a nursery function in seagrass beds is often confined to studies which identify high juvenile density (Valle *et al.*, 1999; Stoner, 1983; Rooker *et al.*, 1998a,b, Thayer and Chester, 1989; Perkins-Visser *et al.* 1996). The question is whether seagrass beds merely concentrate juveniles, or whether the residents actually gain a selective advantage over individuals inhabiting other habitats.

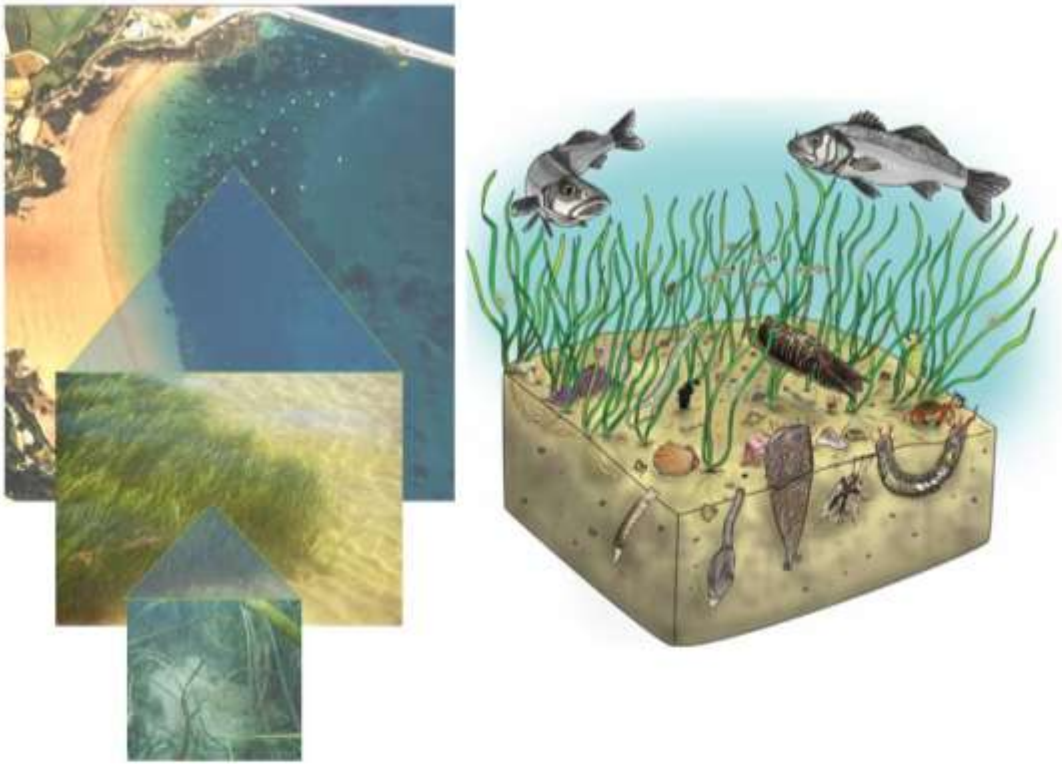

Figure 6 A hierarchy of seagrass structural complexity influences ecosystem service provision (Drawing by Jack Sewell)

1.66 A true nursery is a habitat that contributes more per unit area to the production of individuals that grow, survive and recruit to the adult population than other coastal habitats (Beck *et al.* 2001). If the juveniles in seagrass beds don't reach maturity, then these habitats do not function as productive nurseries. Seagrass may improve survival by providing shelter and food. They may also promote the settlement of planktonic larvae and, for those species that do not have a pelagic larval phase, they may act directly as spawning areas (for example the cuttlefish *Sepia officinalis*). Nursery value of a specific seagrass bed is therefore dependent on a number of pre and post settlement processes, including the availability and settlement of larvae, food availability and predation pressure (Jackson *et al.* 2001a).

1.67 Levin *et al.* (1997) suggested that, whereas the associations of fishes within seagrass meadows can be explained by either larval supply or selection of habitat, the emphasis is very much on variability in the supply of recruits. Eckman (1987) suggested that predation is less important than hydrodynamics in determining the abundance and distribution of early juvenile stages in seagrass beds (see also Eckman & Nowell, 1984; Olney & Boehlert, 1988; Boström & Bonsdorff, 1997; Jenkins *et al.*, 1997b, 1999; Hannan & Williams, 1998; Loneragan *et al.*, 1998). Whilst investigating spatial variability in larval supply and settlement, Bell *et al.* (1988) suggested that temperature and salinity tolerances are the ultimate causes of larval settlement in estuaries, whereas spawning location, nature of eggs, length of pelagic larval phase and larval behaviour are proximate causes. Knowledge of all these factors, and the consideration of life-history strategies, may aid in the judgement of the relative importance of a seagrass bed to juveniles of particular commercial species (Sogard *et al.*, 1987; Tolan *et al.*, 1997).

1.68 Settlement of exploitable species to seagrass beds may be through either active selection of a seagrass bed (Worthington *et al.*, 1991) or passive settlement (Eckman, 1987), the latter enhanced by the ability of seagrasses to dampen currents and increase deposition (Fonseca & Fisher, 1986). Settlement processes are species specific but understanding whether the settlement of the larvae of a fishery species is an active or passive process may be valuable if decisions are to be made on the relative value of different seagrass beds (see figures on hierarchical temporal and spatial scales in seagrass in Jackson *et al.* 2001). If settlement is a result of active selection, then seagrass beds of a particular morphology or structure may be the priority for protection. Alternatively, if settlement is passive, the location of the beds (for example their position in relation to the mouth of the estuary or depth) may be a more important consideration (Hannan & Williams, 1998). Whilst important, knowledge of the settlement patterns of a particular exploited species is often insufficient information for predicting the value (in terms of their survival) of a seagrass bed. Post settlement processes such as food availability and accessibility, predation risk and manoeuvrability will influence growth and survival of juveniles (Schmidt *et al.* 2011). Olney and Boehlert (1988) questioned whether seagrass affords predator protection for early life-history stages of fishes. They remarked that any degree of protection would be afforded only to those individuals able to orientate to the seagrass blades, for example pipefish and seahorses.

1.69 Processes of bottom-up control of the recruitment, abundance and diversity of species in a seagrass meadow operate at a range of hierarchical spatial and temporal scales. These nested hierarchies operate from the structure of the plant to the landscape scale, and from the diel through to the seasonal (Boström *et al.* 2006c, Jackson *et al.* 2006b, Unsworth *et al.* 2007a, Unsworth *et al.* 2007b). Conservation decisions regarding protection of seagrass habitat (for example their inclusion within marine protected areas) are more likely to be at the scale of a seagrass bed rather than parts of individual beds and recent research has identified a need for seagrass habitat management plans to be based on landscape-level as this is a more appropriate scale for mobile fauna (Connolly and Hindell 2006).

1.70 Although landscape approaches are being applied increasingly to the study of fauna utilizing seagrass beds (Robbins and Bell 1994, Salita 2000, Pittman *et al.* 2004, Boström *et al.* 2006b), they often focus on the fauna inhabiting seagrass patches rather than sampling the seagrass landscape as it exists in a mosaic of habitats, dominated by seagrass (Eggleston *et al.* 1998, Hovel *et al.* 2002, but see Salita *et al.* 2003). In a model proposed by Salita *et al.* (2003), as fragmentation increases, the number of small (for example juvenile) and cryptic fish species decreases and the number of larger benthic predators increases (Figure 8a). Their explanation was that in very fragmented seagrass habitats there were high numbers of large benthic feeders (Salita *et al.*, 2003). However, in more continuous seagrass beds, these were replaced by high numbers of small, juvenile or cryptic species feeding on small epifauna or nekton where protection from visual predators was afforded and the movements of larger species impeded (Salita *et al.*, 2003). In a hierarchical landscape approach, Pittman *et al.*, (2004) found an increase in faunal densities with an increase in the heterogeneity of the seagrass landscape, however at <20% seagrass cover there was an abrupt decline in assemblage density and species richness.

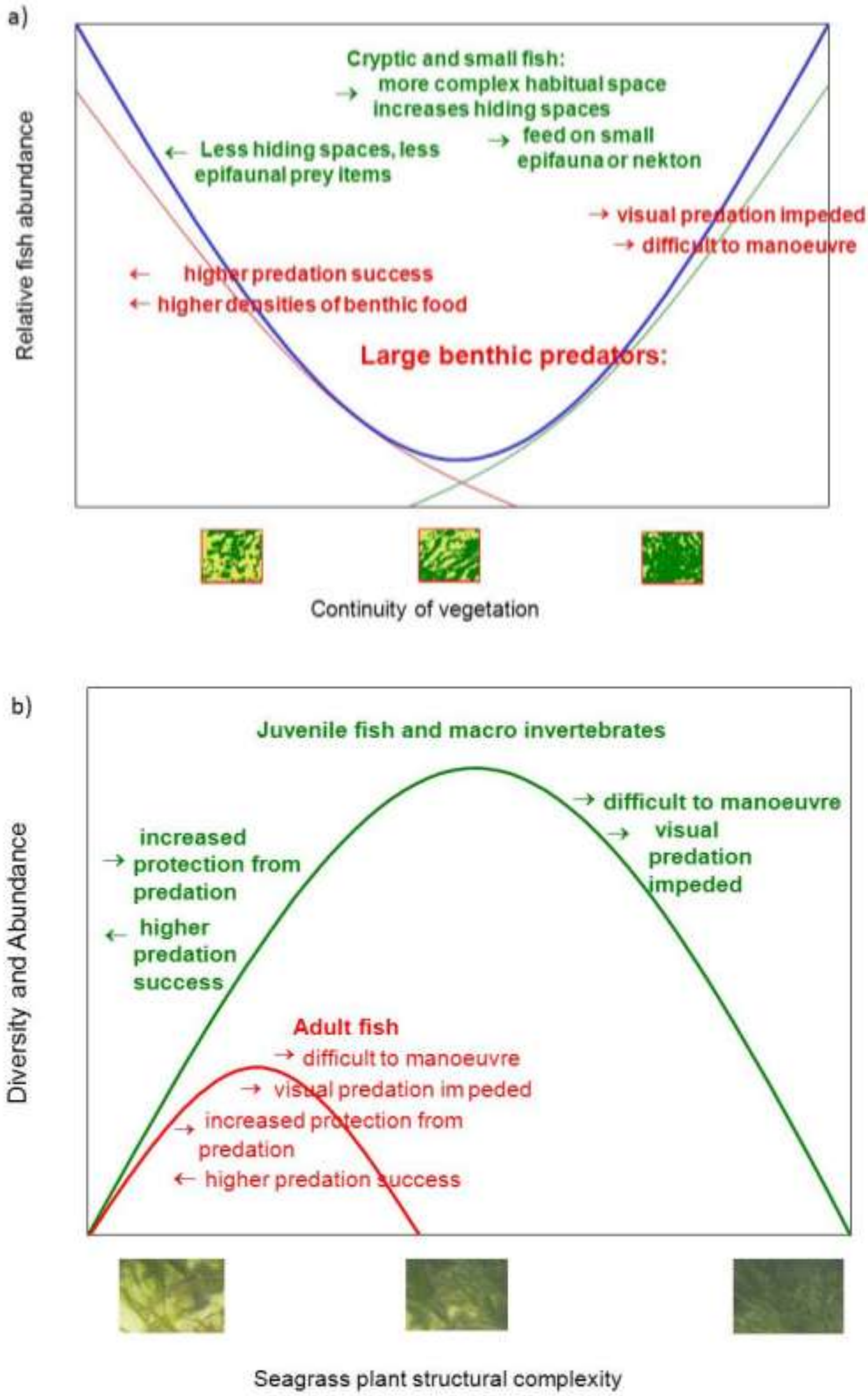

Figure 7 Representations of two models predicting the responses of fish (a and b) and macroinvertebrates (b) at a landscape level (a) (adapted from Salita, 2000) and plant level (b). (Adapted from Heck and Orth, 1980)

1.71 Results of a comparable study in Jersey (English Channel Islands) examining seagrass habitat complexities at different scales and relating them to changes in different groups of fish (Jackson 2003a, Jackson *et al*. 2006a) showed that, while small juveniles of larger species (including, pollack, bib and black bream, three economically valuable species) decreased with fragmentation of the seagrass bed, the number of small permanent residents increased. Jackson *et al.* (2006) concluded that the survival of temporary juvenile fish may be improved in the contiguous seagrass landscapes, due to protection from predation, higher densities of smaller food items and greater environmental stability associated with larger 'core' areas (Bowden *et al.*, 2001; Hovel and Lipcius, 2001; Salita *et al.*, 2003).

1.72 Since the 1980s, seagrass research has focused on the role of small-scale structural complexity (such as biomass, density, canopy height and percentage cover) in determining faunal species richness and density. Heck and Orth (1980) proposed the model that seagrass canopy protects juvenile fish and mobile invertebrates from predation (providing increased hiding places, Sebens, 1991) and so their survival and density increases as canopy complexity increases, up to a point where the seagrass impedes movement. A similar pattern was suggested for adult fish but at a lower canopy complexity level (Figure 7b).

Regulating services

Coastal protection

1.73 It is estimated that coastal erosion will cause losses of up to £10 billion of economic assets over the coming decades and the Environment Agency allocated over £745 million of funding to reduce the risk of flood and coastal erosion in England and Wales for the year to March 2011 (Environment Agency 2011). Properly informed management of natural resources including seagrass beds to help reduce coastal erosion therefore has clear and substantial potential socio-economic benefits. Hydrodynamic damping and sediment binding by seagrasses is well studied (see paragraph 1.23).

1.74 Although these ecosystem functions of seagrass may result in coastal protection, it cannot be assumed that the presence of seagrass will lead to the full provision of this ecosystem service (Barbier *et al.* 2008, Koch *et al.* 2009b). Wave attenuation and reduction in current velocity is a function of density of the seagrass bed (van Keulen and Borowitzka 2002). The hydrodynamic conditions of the area (reduction greater in tide-dominated versus wave-dominated areas; Koch and Gust 1999), as well as the depth of the water column compared to the height of the seagrass determines the impact seagrass has on the water movement (Koch 1999). The balance between forces of sedimentation and accretion is shown to be important in *Zostera* bed (Koch 1999). Control may also be temporary as the fine sediment that is trapped in the growing season can be released during the winter storms (Bos *et al.*, 2007). It is also important to note that the role of seagrass in coastal protection may vary temporally (Koch *et al.* 2009a), for example annual seagrass beds which die off in the winter may not play the same role as perennial beds which only die back slightly in the winter.

Water purification

1.75 Seagrass beds can remove detrimental inputs to coastal waters via two processes: nutrient uptake and suspended particle deposition (Short and Short 1983). Seagrasses remove nutrients from the sediments and both seagrass and their associated plant groups (for example epiphytes) remove nutrients from the water column (Short and Short 1983, Thomas *et al.* 2000). The nutrients incorporated into the tissue of seagrasses and algae may be released, slowly, back into the water column once the plants decompose or they may be buried within the seagrass or elsewhere and stored for a longer period (Romero *et al.* 2006). Seagrass beds can contribute to improved water column transparency through two main pathways. The attenuation of waves and baffling of currents by the leaf blades and associated epiphytic algae increases the sedimentation rate (Koch and Gust 1999) and suspension and deposit feeding animals actively remove small particulate matter (Gacia *et al.* 1999).

1.76 Like many plants seagrasses are able to take up and concentrate heavy metals, organic compounds and substances such as Tributyltin (TBT), without any apparent adverse effects. Francois and Weber *(1988)* studied the decomposition of TBT in the tissue of *Z. marina* and found that the plants acted as detoxifiers, releasing monobutyltin in to the surrounding water. Chemical oceanographers are appreciating that seagrasses represent biotic heavy metal reservoirs (McRoy & Helfferich, 1980). Where the burial of seagrass detritus is high the seagrasses may act as heavy metal sinks, elsewhere however seagrass communities may remobilise and transport these elements to higher trophic levels.

Carbon sequestration

1.77 Seagrasses ability to attenuate water currents and stabilize sediments results in organic matter and nutrients become stored within the accreting sediments, sequestering C, N and P, while the remaining organic material is recycled or exported (Kennedy and Björk 2009, Nellemann *et al.* 2009). A global assessment of seagrass meadows as carbon sinks by Kennedy *et al.* (2010), showed that seagrass meadows were important repositories of carbon produced not just from the seagrass but elsewhere (for example terrestrial and plankton), at a ratio of 50:50. Kennedy *et al.* (2010) also noted that a large proportion of seagrass can be exported to adjacent beaches or even the deep sea, the latter constituting a site of long term storage.

1.78 Despite its recognised importance there have been few studies assessing the carbon burial rates, and knowledge of the sequestration capacity of *Z. marina* beds is rudimentary. One of the few published estimates of *Z. marina* carbon burial rates was from seagrass meadows in Cala Jonquet, Spain at 0.52g C ha^{-1} yr^{-1} *(Cebrián et al. 1997)*. These values were determined from short-term carbon budgets and are production in excess of the first year of decomposition, so may be over estimates. Seagrass sediments are largely anaerobic, consequently seagrass-derived organic matter can be preserved for long-time periods (Mateo *et al.* 1997, Orem *et al.* 1999), but this storage can be difficult to quantify, especially where bioturbating benthic infauna may transport oxygen and redistribute nutrients. Spatial and temporal variability in sequestration capacity may be linked to changes in the physical environment and vegetative traits of the seagrass. For example accretion rates (and consequently burial rates) of carbon vary from site to site due to currents, growth rates and wave exposure. Also, whilst most data on carbon burial rates are obtained on a short term basis accretion varies over time due to mortality and erosion events (Kennedy *et al.* 2010).

Cultural services

1.79 Seagrasses are the primary food source for a number of culturally valuable species, for example manatees and dugongs (Lefebvre *et al.* 2000), green sea turtles (Lal *et al.* 2010), and critical habitat for thousands of other animals which are of non-use value, for example seahorses (Curtis and Vincent 2005, Teske and Beheregaray 2009). The habitat value is attributed to lower predation risk (Choat 1982, Orth *et al.* 1984, Hindell *et al.* 2000), greater food availability (Edgar 1990), increased sediment stability, and refuge from hydrodynamic forces within seagrasses (Lewis 1984).

1.80 In the UK the culturally important Long snouted Seahorse (*Hippocampus guttulatus*) is commonly associated with seagrass (Garrick-Maidment *et al.* 2010a). This species of seahorse is commonly associated with seagrass meadows (Lourie *et al.* 1999). In 2008, the two species of seahorse found in the UK, *H. guttulatus* and *H. hippocampus,* were given legal protection from disturbance under the Wildlife and Countryside Act (England only). The identification of both species of UK seahorses and evidence of breeding in Studland Bay, in Dorset has led to a significant increase in the number of divers visiting the area (Warner, pers.comm.).

1.81 Although some baseline data exist with respect to the occurrence of seahorse in seagrass in the UK, evidence of the functional importance of seagrass in providing bottom-up control of their abundance is limited. In 2005 Curtis & Vincent examined the effects of seagrass bed structural complexity on the habitat partitioning of the two species of seahorse found in the UK , *Hippocampus guttulatus* and *H. hippocampus* in the Ria Formosa lagoon in southern Portugal (Curtis and Vincent 2005). They sampled populations of seahorses over landscape (100s to 1000s m, using an index of habitat cover) and microhabitat scales (<1 m, looking at holdfast selectivity). At a landscape scale, *H. guttulatus* abundance was positively correlated with an index of habitat complexity (the percentage of substrate covered by seagrass and sessile fauna). Conversely, *H. hippocampus* used more open and less specific habitats. At a microhabitat scale *H. guttulatus* grasped all types of structure with equal probability while *H. hippocampus* avoided fauna and flora that formed large colonies or tracts of dense vegetation. The Ria Formosa is located in the middle of the geographical range of these species and therefore the result may not be applicable to the UK which represents the northern edge of these seahorses' distribution.

1.82 Intertidal *Zostera noltii* and shallow *Z. marina* are an important food source for a number of water birds in northern Europe, including swans, ducks, coots and geese. Of these the most significant in the UK are Brent Geese (*Branta bernicla*), as this species is more dependent on seagrass than other species (being exclusively herbivorous)(Cottam *et al.* 1944). The Brent goose is an Amber List species in the UK because of the significant numbers found at just a few sites. Studies have also shown that Brent geese demonstrate a preference for *Zostera* over other food sources and that they can consume large amounts (both leaves and rhizomes)(see comprehensive review by Ganter 2000). The sudden decline of *Zostera* after the 1930s wasting disease (Den Hartog 1987b) coincided with population crashes of Brent geese on both sides of the Atlantic. Although exact counts of the total population are missing, the reduction in the population size of Atlantic Brant on the east coast of North America was estimated to be as much as 90% (Cottam *et al.* 1944). Estimates for the population losses of dark-bellied Brent geese in Europe range from 75% to 90% (Ogilvie and Matthews 1969), with only about 15,000 birds left in the early 1950s. Because of their heavy reliance on *Zostera* as a main food source, the distribution of Brent geese outside the breeding season is to a large extent determined by the distribution of *Zostera* (for example Prokosch 1984; Clausen 1994).Consequently, changes in *Zostera* abundance will impact the distribution or, if changes occur on a large enough scale, the population size of the birds.

Loss and degradation of seagrass

1.83 In a review of seagrass global state change Waycott *et al.* (2009) found that seagrasses have been disappearing at a rate of 110 km^2 yr^{-1} since 1980 and the rate of loss is increasing (Waycott *et al.* 2009)(Figure 8). Seagrass beds are in decline in OSPAR Region II (Greater North Sea - The North-East Atlantic) and under threat in all areas where they occur (Tullrot 2009).

1.84 There have been severe losses of *Z. marina* in the North East Atlantic over the last 60 years. For example, in the Glenan Archipelago of the west coast of France, Glémarec *et al.* (1997) used historical aerial photographic surveys over a 60 year period to identify changes in the cover (in the form of four cover indices, C.I.), of *Z. marina* and surface suitable for growth (Glémarec *et al.* 1997). The relative amount of the C.I. 2 (20-50% cover) was identified as a useful index for evaluating inter-annual fluctuations in overall cover. Declines in the Glenan Archipelago in the 1930's were attributed to the "wasting disease", possibly initiated by warm temperatures (Baden *et al.* 2003). However, in the nearby Bay of Morbihan, similar declines in the 1960s were followed by a period of recovery which peaked in 1972 (Denis and Mahéo 1979). Before that human activities such as clam and oyster dredging, eutrophication (and associated increased turbidity) and grazing by wildfowl had caused the decline. Such activities are minimal in the Glenan Archipelago (although some pleasure boat anchoring was identified and maerl dredging in Northern regions increased turbidity) and the declines since the late 1970's have been attributed to increases in temperature.

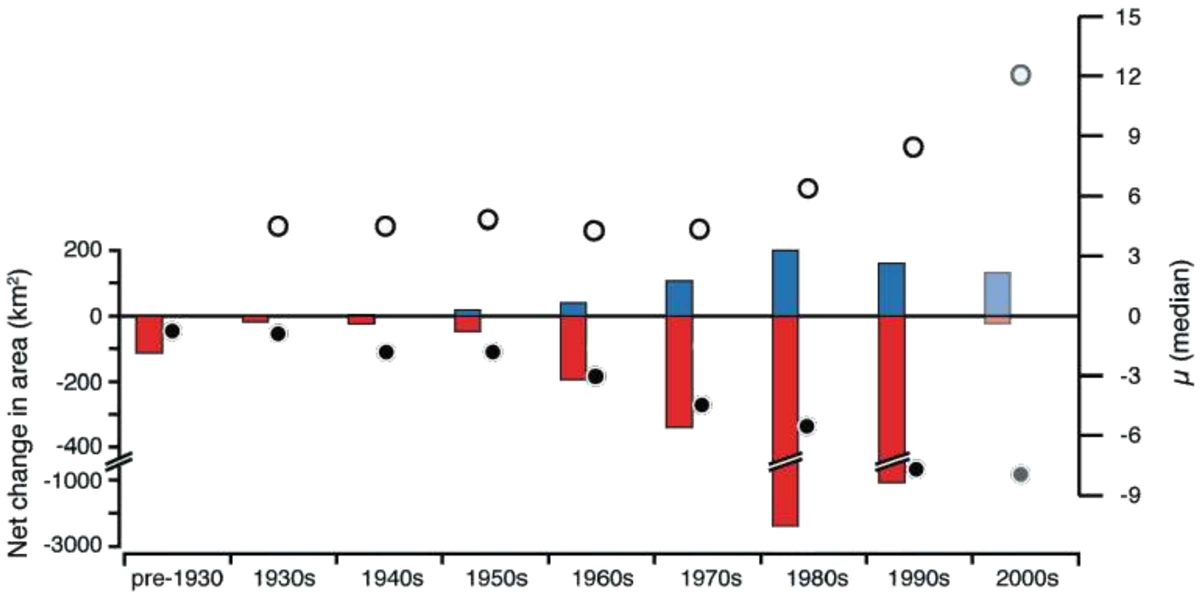

Figure 8 Global rate of change of seagrass (circles are median rates of change). (Source: Waycott *et al.* 2009)

1.85 Baden *et al.* (2003) compared *Z. marina* distribution on the Swedish Skagerrak coast between the 1980s and 2000 and showed that the extent of *Z. marina* decreased 58% in 10–15 years (with great regional variation). The decline was mainly in the shallow parts of the meadow and die backs were attributed to prolonged increases in turbidity and the resulting reduction in light penetration (Baden *et al.* 2003). Frederiksen *et al.* (2004a, 2004b) studied the long-term changes in area for shallow-water eelgrass stands in Denmark from the 1940/50s to the 1990s using aerial photography. Once again the seagrass stands appeared to be in a phase of recovery following the wasting disease of the 1930s and, although one site showed declines in recent years, changes in seagrass area did not correlate with any available long-term records of natural and human-induced disturbance parameters. Therefore, the shallow water beds may not have shown a decline in response to eutrophication that was shown by deeper beds (Frederiksen *et al.* 2004b).

1.86 In the UK, *Zostera* is nationally scarce and a recent WWF Marine Health Check reported that UK seagrass beds were in severe decline (estimated at between 25% and 49% in the last 25 years) (Hiscock *et al.* 2005). An update of this report downgraded this status to degraded (Wilding *et al.* 2009). Although turbidity and nutrient loading have been the primary cause of seagrass decline globally (Waycott *et al.* 2009), improvements in water quality through better sewerage treatment and national regulations resulting from the Urban Waste Water Treatment Directive and Water Framework Directive are starting to negate these pressures.

Even so continued direct physical pressures on seagrass beds are increasingly resulting in fragmentation and even losses of many beds (Goumenaki 2006, Rhodes *et al.* 2006, Suonpää 2009). Finally, repeated outbreaks of wasting disease led to further losses in the Solent during the 1990s (Den Hartog 1994) and despite slow recovery in some areas, UK eelgrass beds have still not recovered to their pre-1920s extent, due to significant changes in the sediment dynamics after the loss of the seagrass.

1.87 Natural causes for seagrass decline include storms, hurricanes, earthquakes, disease and grazing by herbivores (Short & Wyllie-Echeverria, 1996). However in conserving these habitats the focus must be on anthropogenic manageable impacts.

Anthropogenic impacts on seagrasses

1.88 Duarte (2002) defined two categories of anthropogenic pressures on seagrasses. Firstly direct proximal pressures, which affect seagrass beds locally and secondly indirect pressures which have the potential to affect beds on a larger and even global scale. In terms of management Elliott (2011) identified these as endogenic managed pressures and exogenic unmanaged pressures. Indirect pressures (exogenic unmanaged) include climate driven changes, changes in global sea levels, increases in both CO_2 and UV rays, as well as anthropogenic impacts on marine biodiversity leading to changes in oceanic food webs. These indirect impacts have the potential to have devastating effects on the world's seagrass habitats, but due to the scale of the problem, are very difficult to control. Direct impacts (endogenic managed) on the other hand, tend to be on a much smaller scale, including; mechanical damage as a result of development in the coastal zone, mobile fising gear and recreational boating activities, and eutrophication, siltation from agriculture, urban waste and aquaculture (Short and Wyllie-Echeverria, 1996).

Endogenic managable pressures

1.89 During a Dahlem workshop carried out as part of the EU FP7 Consortium project ELME (European Lifestyles and Marine Ecosystems, Langmead *et al.* 2007) scientists identified the potential pathways (Drivers – social and economic activities which cause a pressure which results in a change in the state of an ecosystem) of loss and degradation in European seagrass meadows (Figure 9). Indirect global drivers of change were considered separately.

1.90 A number of potential activities were identified as causing either physical, chemical or biological environmental change (exposure pressures in Figure 9) which may result in a specific state change to the seagrass beds (manifested as a change in depth limit, fragmentation or cohesion) by changing those factors which limit seagrass growth and health, as discussed on pages 5-14 of this review, and summarised in the Marine Life Information Network Sensitivity matrix for *Zostera marina (Tyler-Walters 2008)*. Potentially negative and positive pathways of change were considered. Whilst this model is not exhaustive, it provides a framework to look at pathways of how different activities influence the seagrass via the exposure pressures. This is important when assessing the vulnerability of different seagrass beds (and even within a seagrass bed in one location) to different activities and builds on commonly employed impact matrices (Tillin *et al.* 2010). For example, the exposure pressures from deposition of physical material, physical oceanographic change and over stimulation of biota all affect the seagrass by reducing available light for photosynthesis (Figure 10). Deposition of physical material in this context relates to smothering via increased sedimentation (Taner 1999) or direct dumping of sediment (Borg and Schembri 1993) onto the seagrass beds. Physical oceanographic change relates to increased turbidity resulting from suspension of fine sediments (Bourcier 1983) but also covers changes in current and wave regimes, and over stimulation of biota includes increased phytoplankton (Peres and Picard 1975, Boudouresque *et al.* 2000), epiphytic algal biomass or drift macroalgal blooms (opportunistic species) (Boutiere *et al.* 1982, Bach *et al.* 1993). Some seagrass beds and deeper parts of an individual seagrass may be more light limited than others, so the main repercussions of such exposure pressures is the reduction in the lower depth limit of the seagrass distribution or a loss of deeper or more light limited seagrass beds under these conditions. In contrast mechanical disturbance physically damages seagrass beds by ripping up the plants and damaging rhizomes (Scardi *et al.* 1989, Sanchez Lizaso *et al.* 1990, Francour *et al.* 1999, Ardizzone *et al.* 2000) irrespective of the seagrass location, although this may influence recovery potential.

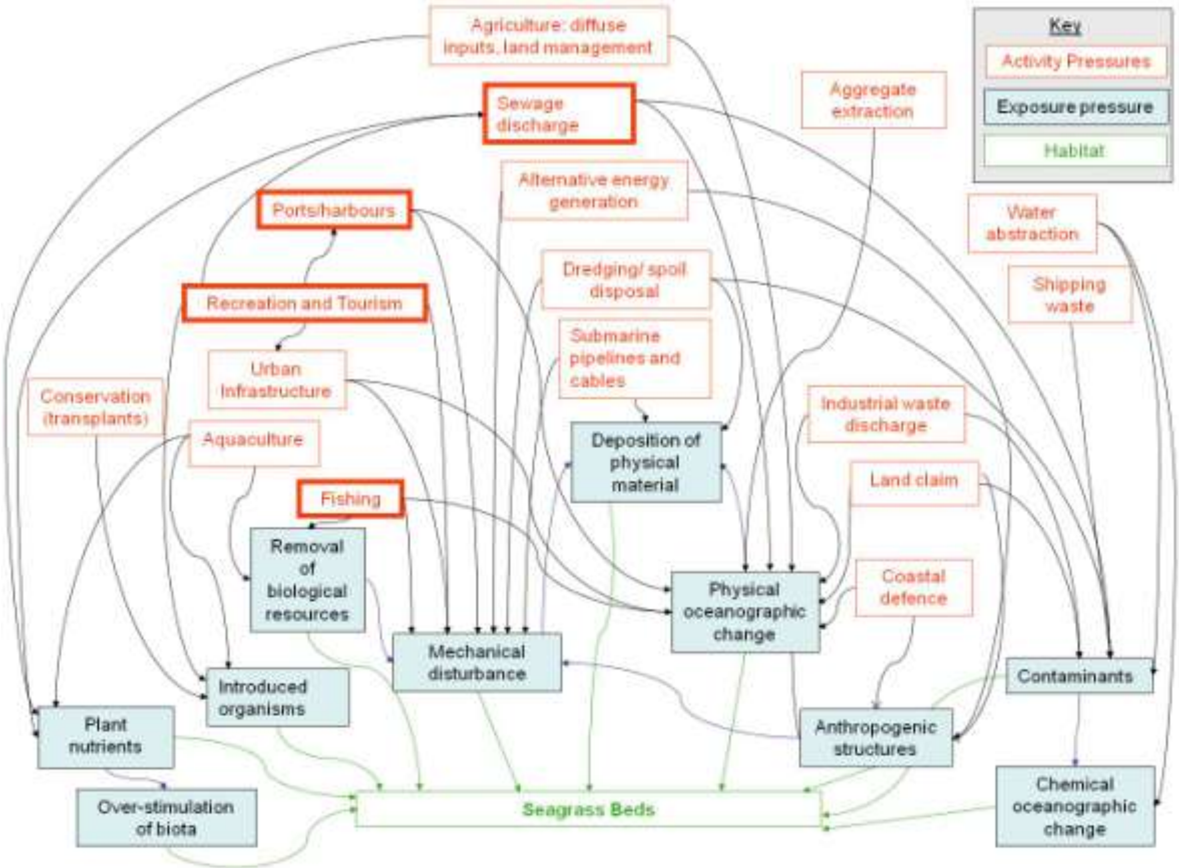

Figure 9 Driver Pressure state change conceptual model of the pathways of loss and degradation of European seagrass meadows

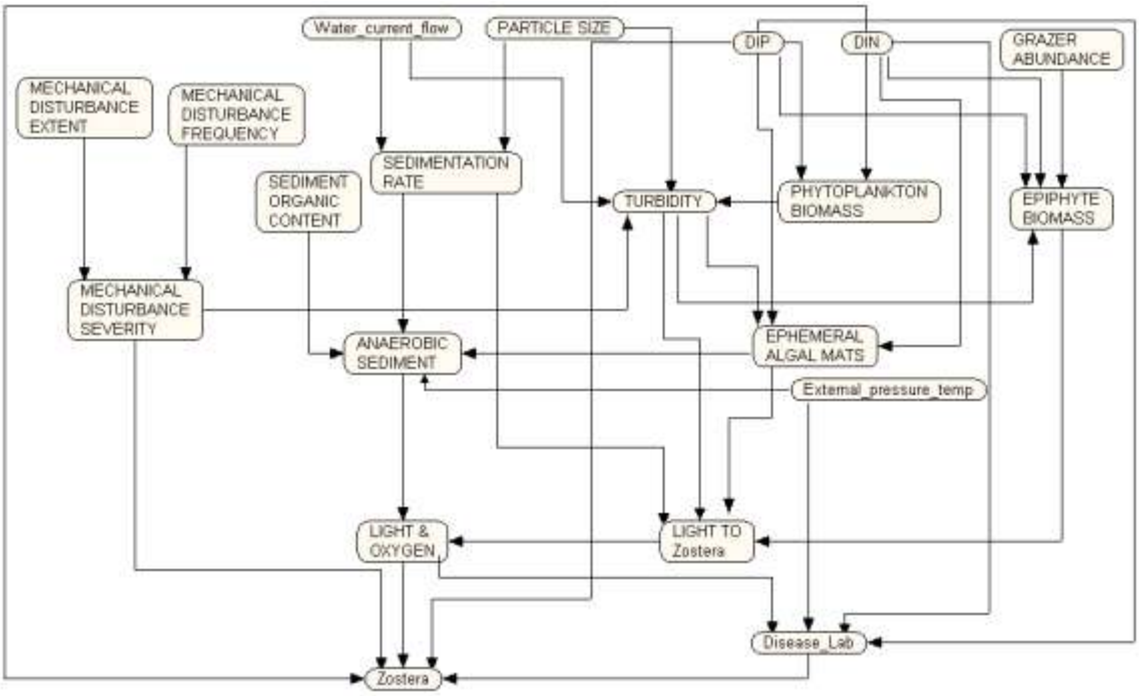

Figure 10 Conceptual model of the pathways of loss for North East Atlantic seagrass beds

Nutrient enrichment and the overstimulation of biota

1.91 The most catastrophic losses of seagrass meadows since the 1930's wasting disease have been correlated with nutrient enrichment (Burkholder, *et al.*, 1994). Nutrient enrichment due to sewage, agricultural runoff and more localised inputs (for example from boating and aquaculture) have all been correlated with increased growth of epiphytic algae (in particular filamentous), drift algae and phytoplankton. Each of these plant groups has the potential to compete with the seagrass for nutrients and reduce the amount of light reaching the plant (Den Hartog, 1987). Loss of the seagrass exposes the seabed to wave action causing resuspension, which further increases turbidity, thereby creating one of several positive feedback loops of eutrophication, hampering the remaining benthic flora (Duarte 1995).

1.92 Huge declines of *Zostera noltii* in the Mondego estuary, Portugal were linked to the occurrence of blooms of ephemeral green algae which resulted from eutrophication in the 1980s (Cardoso *et al.* 2004). In 1998, management efforts to protect the seagrass (including decreasing the nutrient loading and increasing water transparency and velocities) led to a slight recovery of the beds (Cardoso *et al.* 2004). Den Hartog (1994) reported that mats of *Enteromorpha radiata* (now recognised as *Ulva radiata*) suffocated an entire intertidal bed (10ha) of *Z. noltii* in Langstone Harbour, after a warm dry summer contributed to the concentration of effluents from two sewage works, illustrating the importance of interactions between human pressures and natural climate fluctuations. The decaying algal mats resulted in severe anaerobic conditions and toxic effects on the seagrass, combined with a shading effect which resulted in reduced photosynthesis of the angiosperm (Den Hartog 1994). The duration of these conditions was considered to be a major factor contributing to the loss of the seagrass bed.

1.93 In 2003 Hauxwell *et al*. quantified the relationship between nitrogen load, algal growth dynamics, and *Zostera marina* productivityand overall decline in estuaries of Waquoit Bay (USA). They found that at nitrate loadings of approximately 30 kgN ha^{-1} yr^{-1} upto 96% of seagrass bed area was lost and loads greater than 60 kg N ha^{-1} yr^{-1} resulted in complete disappearance of *Zostera marina*. Interestingly the study found that whilst growth rates didn't differ significantly there was an exponential decrease in shoot densities and area of seagrass, suggesting that the decline under higher-nitrogen was due to lack of recruitment and mortality of established shoots. Hauxwell *et al.* (2003) showed that the pathway of loss was indirect with the increased nitrogen stimulating growth of algae which in turn led to severe shading of eelgrass

1.94 As plants themselves seagrasses also require nutrients (see page 12) and some studies have shown that nutrient enrichment may increase production in *Zostera* (Tubbs and Tubbs 1983. , Fonseca *et al.* 1994). Other studies have indicated that water column nitrate enrichment could change internal nutrient balances and impair carbohydrate metabolism in *Z. marina* visible as reduction in density, canopy height and possibly fragmentation (Burkholder *et al.* 1992).

1.95 Whilst epiphytic algae have some known benefits for seagrasses, for example as UV filters and reducing desiccation in intertidal populations, most impacts are negative (Brandt and Koch, 2003). These negative impacts include:

- a reduction in light availability to the seagrass leaf for photosynthesis;
- a reduction in diffusion rates across the leaf (Nutrients, CO_2); and
- an increase in drag, making the leaves more susceptible to breakage during storm events.

(Source: Brandt and Koch, 2003)

1.96 Nutrient enrichment has been linked to an increase in epiphyte growth both in the field and in laboratory mesocosms (see comprehensive review by Nelson 2009). In most cases an increase in nutrients or proximity to an outflow (for example, sewage) resulted in an increase in epiphyte biomass (but see Burkholder *et al.* 1992, Williams and Ruckelshaus 1993, Moore and Wetzel 2000). Nutrient enrichment effects on epiphyte growth were greatest under higher temperature and light levels. Studies which showed no or minimal increases in epiphytic biomass with nutrient enrichment tended to be ones in which epiphyte grazer abundances were high (Burkholder *et al.* 1992, Ballesteros *et al.* 2007).

1.97 Under natural conditions epiphytes may be controlled by grazer populations (top down control) and competition for nutrients between different plant components within the seagrass (Wooldridge and Done 2004). Factors affecting grazer abundance can have significant impacts on the growth of epiphytic algae under nutrient enriched conditions. For example, Hughes *et al* (2011) suggest that overfishing of top predators can lead to increased numbers of smaller piscivorous fish, a reduction in herbivore predators and a resulting increase in grazers which may offset eutrophication effects (Figure 11). The subtle knock on effects and interactions depends very much on food-web structure and diversity of different groups (Duffy *et al.* 2003, Björk *et al.* 2008).

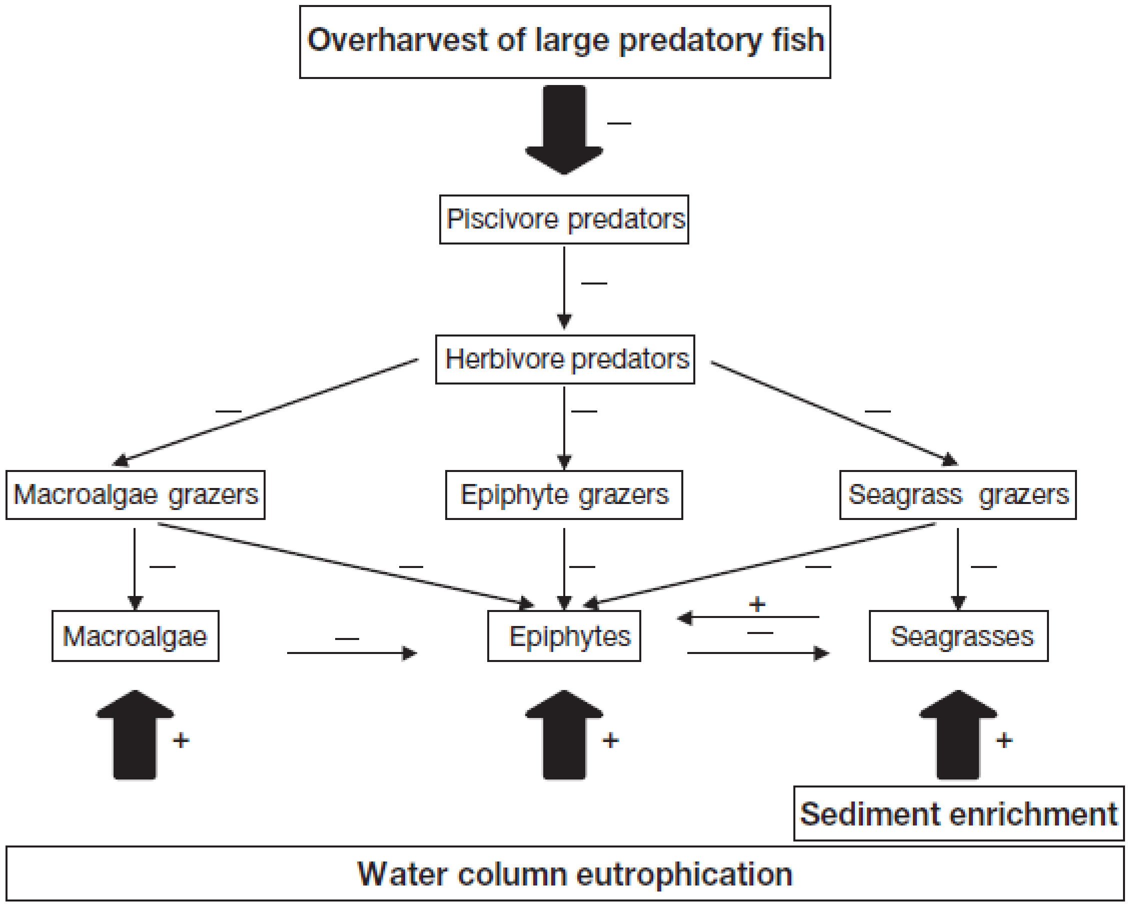

Figure 11 Top down, bottom up and competitive pathways affecting epiphytic algal biomass on seagrasses

1.98 Hydrodynamics may also determine the level of impact nutrient enrichment can have on seagrasses in terms of epiphytic load. Schanz et al (2002 found that epiphyte biomass was highest in areas of stronger water movement, which inhibited abundances of the small gastropod grazer *Hydrobia*. In comparison, Caine (1980) found that epiphytes were positioned lower down the leaf blade in stronger currents, but in their study location the dominant grazer was a Caprellid amphipod capable of clinging to the seagrass, thereby highlights the importance of understanding the community composition of the grazers.

Physical disturbance

1.99 *Zostera* is not physically robust, as the root systems are typically located within the top 20 cm of the sediment and can therefore be easily uprooted (Fonseca 1992). Physical disturbance can occur on both intertidal and subtidal seagrass beds. It may be caused by trampling, dredging, use of mobile fishing gear, as well as land claim and adjacent coastal development. Intensive boat activity may result in direct physical damage to the seagrass beds by propeller (see Plate 2), anchor or mooring scarring, or hull grounding during shore landings. Each of these is discussed below.

Plate 2 Example of propeller scarring, Salcombe, Devon

Mobile fishing gear

1.100 Mobile fishing gear has also been shown to physically damage seagrass beds. Fonseca *et al.*, 1984 examined the impact of scallop dredging on *Z. marina* beds in North Carolina. Unsurprisingly, they found that dredging led to significantly lower overall biomass of eelgrass. In many parts of the Mediterranean trawling in the vicinity of seagrass beds is banned. However, illegal otter trawling has been identified as one of the most important direct causes of large scale degradation of *P. oceanica* meadows, particularly deep meadows (between 15 and 30 m depth, Ardizzone and Migliulo, 1982; Ardizzone and Pelusi, 1983; Ardizzone *et al.*, 2000). Repeated passes of a trawl removes leaves and roots mechanically disturbing the seagrass beds. Gonzalez-Correa *et al* (2005) reported that the abrasive trawling gear eliminated approximately 60% of the cover of *Posidonia oceanica* from the seafloor and reduced the shoot density in the mattes that survived by more than 40%. These effects were the result of a highly destructive trawling gear that can remove between 100,000 and 360,000 shoots/h (2004). Such is the problem of illegal trawling in seagrass beds in the Mediterranean, that anti-trawling artificial reefs are now widely used (Guille´n *et al.*, 1994; Ramos *et al.*, 2000).

1.101 There is less evidence of mobile fishing gear damaging seagrasses in the UK. There are a few reports of locations where a reduced lower depth limit of seagrass beds may be the result of close inshore trawling (Flint 2006, 2008). Trawl scars often dissect a seagrass bed channelling water currents which inhibit recovery (Cole 2012). Further study is required to assess the extent of these disturbances in UK seagrass beds.

Other fishing impacts

1.102 Mechanical disturbance is not limited to subtidal seagrass beds. Intertidal seagrass is subject to trampling, bait digging and bivalve harvesting. *Zostera noltii* in the Ria Formosa lagoon (southern Portugal) showed significant decline as a result of large scale commercial clam harvesting using a hand-blade which cuts and removes roots and shoots (González-Correa *et al.* 2005). Eckrich and Holmquist (2000) experimentally examined the effects of trampling on a bed of *Thalassia testudinum* in Puerto Rico. With exceptions at one site, heavy trampling (50 passes per month for four months) resulted in reduced rhizome biomass of up to 72% and loss of standing crop up to 81%. Seagrass recovery was incomplete seven months after trampling ceased and reduced cover was still visually distinguishable at several study sites after 14 months. Eckrich and Holmquist (2000) reported that rhizome biomass loss was greatest at sites with softer substrates. It is not just trampling by foot that causes damage. Hodges and Howe (1997) documented the impact of vehicular access on *Z. angustifolia* beds in Angle Bay, Wales after the Sea Empress oil spill. Vehicle use, required for the initial clean up, resulted in patchy beds, criss-crossed with wheel ruts up to 1 m deep. In a review of the effects of trampling Tyler Walters et al (2009) summarized that the effects of trampling on seagrass beds are more pronounced in soft mud habitats (Eckrich and Holmquist, 2000; Major *et al.*, 2004) and that repeated heavy trampling results in large losses of seagrass biomass and standing crop, compounded by a slow recovery rate (Eckrich and Holmquist, 2000).

Anchoring

1.103 Anchor damage to seagrasses occurs during anchor deployment, during chain and anchor dragging whilst the boat is at anchor and during retrieval. An anchor landing on a patch of seagrass can bend, damage and break shoots (Montefalcone *et al.* 2004). A poorly set anchor will drag as the boat moves under wind or tide, causing damage to the seagrass. Evidence of anchor damage on seagrass beds is limited for *Z. marina* but extensive for other species of seagrass, for example the Mediterranean endemic *Posidonia oceanica* (Hatcher 2009, Barnfield and Fisher 2011). Creed and Filho (Porcher 1988, Garcia Charton *et al.* 1994, Francour *et al*. 1999, Milazzo *et al.* 2004, Montefalcone *et al.* 2004, Montefalcone *et al.* 2008) found that 0.5% of the *Halodule wrightii* seagrass beds at their site in Brazil were damaged by anchor scarring and that the mean size of an individual scar was $0.16m^2$.

1.104 In a study considering the effect of anchor type (Hall, Danforth and folding grapnel) and the stage of anchoring on seagrass disturbance Milazzo *et al.* (1999) found that damage by the folding grapnel was greater than the other two. They also showed that the most damage occurred, for all three anchors, during the weighing stage (lifting the anchor) and that the average number of shoots uprooted was 5.5 for the grapnel and 1.8 for both the Hall and Danforth. In a similar experiment, Francour *et al.* (1999) found that anchoring uprooted 34 shoots about 50 per m^2 on average (20 shoots during the locking in stage and another 14 during the weighing). Milazzo *et al.* (2004) suggested that difference between impacts was caused by a heavier anchor and larger boat used by Francour *et al.* (1999). The heavier anchor was expected to sink deeper in the bottom and larger boat to cause more pressure on the anchor. Both these studies were carried out on *Posidonia oceanica*, a species of seagrass capable of vertical and horizontal rhizomatous growth, which grows on robust root rhizome mats and they saw only damage to the orthotrophic (vertical rhizomes). *Z. marina* can only grow horizontally and the root rhizomes are confined to the top 20cm, and are therefore easier to uproot.

1.105 Montefalcone *et al.* (2008) studied the anchoring effects up to 4 months after the anchoring and found that shoot and rhizome decline continued up to 4 months after the anchoring event in deeper areas for the slow growing *Posidonia oceanica*. For a faster growing seagrass, in a warm climate *Halodule wrightii,* Creed & Filho (1999) found that nine months after simulated anchoring seagrass rhizome and biomass densities had recovered to control levels.

Traditional moorings primary effects

1.106 Traditional swing moorings have a chain attached to an anchoring block on the seabed and then either directly to a buoy at the surface or to an intermediate rope. The chain lies on the seabed (moving around with the wind and tide) to buffer any direct force on the permanent anchor block. As the chain pivots on the block it scours the seabed and in seagrass beds usually removes not only the seagrass' above ground parts (leaves and shoots) but also the roots and often a layer of sediment. Sediment scour may also occur around anchoring blocks due to eddying of currents, and the anchors themselves may creat a hard structure for the settlement of competitive algae. Seagrass loss as a result of boat moorings has been considerable in some areas around the world.

1.107 Walker *et al* (1989) found that boat moorings caused circular or semi-circular depressions of bare sand within seagrass beds, ranging between 3 and 300m^2 (depending on boat size). Initially, these values may appear to be insignificant, but where high densities of boats are moored, significant areas of seagrass have been lost. Walker *et al* (1989) showed that in a bay where 344 boats were moored, an estimated 2.45ha of seagrass was lost due to mooring damage. Additionally, Hastings *et al* (1995) identified a loss of 18% of total seagrass coverage at Rottnest Island, Western Australia, between 1941 and 1992. It was estimated that 13% of this loss occurred between 1981 and 1992, which coincided with an increase in the number of moorings from 81 in 1977 to more than 190 in 1992. Similar mooring scarring has been observed in and around the UK (2004). Surveys in 2008 and 2009 examining the impacts of moorings in Porth Dinllaen in the Pen Llyn a'r Sarnau Special Area of Conservation, Wales, found an average scour area of 10m radius (Jackson 2003a, Wilkinson 2003, Rhodes *et al.* 2006, Collins *et al.* 2010b, Egerton 2011, Jackson *et al.* 2011).

Plate 3 Intertidal mooring scar (Salcombe, Devon), illustrating the sediment depression created in areas of high water movement

Implications of physical disturbance and recovery

1.108 Duarte (2002) predicted that reductions in seagrass habitats will lead to a subsequent loss of associated functions and services in the coastal environment. The loss of seagrass canopy leaves the underlying sediment vulnerable to resuspension, which in turn, leads to deteriorations in light levels, and to further reduction in seagrass survival (Dawes *et al.*, 2004). Further community changes are also predicted, as reduced levels of oxygen in the sediment leads to anoxic conditions (Duarte, 2002). However, increases in habitat fragmentation are thought to be more damaging than the total area of seagrass lost. Hastings *et al* (1995) calculated that in Rocky Bay (Rottnest Island, Western Australia) the length of exposed edge increased by 230% between 1981 and 1992. This increase in habitat fragmentation can channel water movements, increasing erosion potential at the damaged sites. Increased sediment mobility will impede recovery and may also reduce growth rates of surrounding seagrass (Hastings 1995). Recovery is therefore likely to be lower, not only in deeper parts of the seagrass, but also in more wave and current swept parts of the meadow. In a study assessing the impacts of anchoring in Studland Bay, Dorset (UK), Collins *et al.*, (2010a) measured the bed shear stress (fluid force per unit area on the sea bed) of undisturbed seagrass patches versus unvegetated patches attributed to anchor and mooring damage. Collins *et al.*, (2010) found that the latter were less cohesive, contained less organic material and had lower infaunal richness and abundance. Continued scouring of the unvegetated patch (either by the mooring chain or water currents) can result in a depression in the sediment. *Z. marina* expands via horizontal elongation of the roots, which is why large continuous meadows are only found in gently sloping locations, sudden changes in sediment depth can inhibit recovery of the seagrass into bare patches Plate 3. The recolonisation of seagrass after disturbance is discussed in more detail on page 40.

1.109 The frequency, persistence and extent of mechanical disturbances are important factors in relation to the recovery of the seagrass. In terms of the impacts on seagrass meadows it is important to differentiate between anchoring and mooring damage. Firstly there is a disparity in the size of disturbance created in the seagrass. Observations within Studland Bay, Dorset, showed that mooring scars are often tens of metres in diameter (see MAIA Part 2, Section 3), whereas anchoring scars were typically 1-4m² (Collins *et al.* 2010a). Secondly, permanent moorings mean persistent pressure, as the chain scours the seabed with every change in wind or tidal current direction. In many locations boats are moored on a semi-permanent basis throughout the year. In comparison, anchoring events are spatially and temporally unique, with the relative damage primarily correlated with the intensity of anchoring but also on the type of anchor or vessel (Collins *et al.* 2010a). Unlike moorings, evidence from previous studies suggests that the chain on an anchor may actually limit the damage to the seagrass bed as it stabilises the position of the anchor, but this is likely to depend on environemtnal conditions such as the strength of wind, current and tide. In tourist spots anchoring intensity is often related to good weather conditions (Milazzo *et al.* 2004), which means that intensity is likely to be at its height at the same time as seagrass growth, with implications for recovery. Despite these differences, evidence from various species of seagrass show that anchoring is still a damaging activity on seagrass beds.

Turbidity and sedimentation

1.110 Increased water turbidity is another threat to seagrasses (see page 5) and any disturbance that lowers the light availability to the plant will likely reduce photosynthesis and, accordingly, the seagrass leaves will form less oxygen for transport towards the root system (Borum *et al.* 2005). Geisen *et al.* (1990) suggest that turbidity caused by eutrophication, sand extraction and dredging activities were major factors in the decline of *Zostera* in the Wadden Sea. In a comprehensive review Erftemeijer and Robin Lewis (Alexandre *et al.* 2005) identified that dredged material may come into suspension and affect water turbidity during dredging itself as a result of disturbance of the substratum, during transport to the surface, overflow from barges or leakage of pipelines, during transport between dredging and disposal sites, and during disposal of dredged material. The response in terms of the health of seagrass will be a result of the reduction in light available for photosynthesis and duration of the exposure.

1.111 Increases in turbidity over long periods of time often manifest as a reduction in the lower depth limit of the seagrass bed. In the Provence and French Riviera region of France GIS Posidonie monitor 33 sites as part of the *Posidonia* Monitoring Network (Erftemeijer and Robin Lewis III 2006), 24 of which have been surveyed since 1988. The monitoring has shown that over these 15 years of monitoring losses to the upper limit of the *Posidonia* decreased, however there was an increase in losses at the lower limit. This regression of deeper seagrasses has been observed across Europe and has been attributed to increases in turbidity (mostly resulting from inadequate sewage treatment) (Boudouresque *et al.* 2000).

Introduced organisms

1.112 *Sargassum muticum,* a perennial brown alga originating from Japan is one of the most successful invasive algal species, spreading across two continents outside its natural range (Boudouresque *et al.* 2000). *S. muticum* is commonly found growing in seagrass beds and in 1973 Druehl expressed concerns that *S. muticum* may displace *Z. marina (Critchley et al. 1990)*. Others disputed these concerns claiming that the alga required a solid substrate for attachment and with *Z. marina* occurring solely on soft sediments the two species should coexist without apparent competition (North 1973, Fletcher & Fletcher 1975, Norton 1977, Thomsen *et al.* 2006). In 1997 den Hartog concluded that due to the contrasting substratum preferences, the beds of the two species would remain well separated. He reported, however, that although *S. muticum* was not able to invade closed *Z. marina* beds on soft substrata, the alga was able to replace *Z. marina* in littoral pools with mixed substratum containing sand, gravel, stones, and shell grit. However, if *Z. marina* retreats from an area, *S. muticum* will fill the void 'almost immediately' thus interfering with the regeneration of the *Zostera* bed. Givernaud *et al*, (1991) found the same interaction in France as did Critchley, (1980) in the UK.

1.113 In 2008, *S. muticum* plants were discovered in Salcombe seagrass meadows (Devon, UK) devoid of a holdfast and in others the holdfast was not attached to any form of hard substrate (rock, stone, shell, etc.), but instead was buried, with the weight of sand around the holdfast and primary lateral providing the attachment, see Plate 4 (Orth and Van Montfrans 1984). Further investigation found evidence that *S. muticum* is able to successfully colonise soft sediments and, furthermore, that the presence of *Z. marina* may aid attachment by trapping drifting fragments and allowing viable algae to settle on the seagrass matrix in an otherwise unfavorable environment (Tweedley *et al.* 2008). The consequences for the invasion of seagrass beds by *S. muticum* may therefore be more severe than previously thought.

Plate 4 *Sargassum muticum* attached to the root rhizome complex within a seagrass meadow in Salcombe, Devon, UK

Chemical pollution

1.114 Studies examining the impacts of chemical pollutants on seagrass health and survival are very limited. The majority of studies focus on determining contaminant concentrations in the seagrass tissues and identifying the physical and chemical factors affecting the magnitude of bioaccumulation. Seagrasses, have been shown to concentrate and retain nonessential chemicals in their tissues, which is considered beneficial for improving water quality and *Z. marina* has even been recommended as a bioindicator of environmental condition and as agents for phytoremediation due to their bioaccumulation ability (Lewis and Devereux 2009). However, it is generally considered that potentially phototoxic, nonnutrient chemicals may also be a contributing factor to seagrass losses and there is a need for more research (Lewis and Devereux 2009).

1.115 Terrestrial herbicides have been found to inhibit growth and cause decline in *Z. marina* (Delistraty & Hershner 1984) as have marine biocides. Since the ban on using tributyltin (TBT) as an antifouling agent on vessels under 25 m, paint manufacturers now often utilise the organic biocides for example Irgarol 1051 and Diuron now two of the world's most prevalent herbicides (Thomas *et al.*, 2001b). Irgarol 1051 and Diuron have been shown to occur together in concentrations above 0.5 μg/l [3] and in a study examining the interactive effects of the two antifouling agents, Chesworth *et al.* (2004) found that the growth of plants exposed to Diuron plus the Irgarol 1051 EC_{20} were significantly reduced when compared to plants exposed to Diuron alone. It is unlikely that such concentrations will accumulate in a seagrass bed unless it is in close proximity to a marina where good practice is not employed with regards to antifouling of hulls, however in areas were boat densities are high, assessments of the concentrations of these checmicals maybe informative.

1.116 There are also indirect impacts of chemical pollutants. Loss of grazing prosobranchs due to TBT contamination in the leaves or externally may result in excessive algal fouling of leaves, poor productivity and possible smothering (Williams *et al.*, 1994).

[3] A microgram (μg) is a unit of mass equal to one millionth (1/1,000,000) of a gram

Exogenic unmanaged pressures

1.117 Whilst it is often not possible to manage indirect pressures on seagrasses, such as climate change and ocean acidification, understanding how these pressures may impact on their health and survival is important. Managing the endogenic pressures, as discussed above, can improve the overall health of the seagrass and its resilience to the exogenic pressures which cannot be controlled (at least at a local scale)(Scarlett *et al.* 1999). The main exogenic pressures already impacting seagrasses, or likely to in the future include disease, ocean acidification, sea level rise and climate change (including sea temperature rise, increase in storm activity and shifts in prevailing wind direction.

Increased carbon dioxide and ocean acidification

1.118 As a result of burning fossil fuels, levels of carbon dioxide (CO_2) in the atmosphere have increased from 280 parts per million (ppm) in 1880 to nearly 380 ppm in 2005 this is despite almost 30% of all atmospheric CO_2 being taken up by the Oceans (IPCC, 2007). As plants, an increase in CO_2 is likely to have a positive direct effect on seagrass productivity (photosynthesis and growth). In a recent meta-analysis Seagrasses showed as much as a fivefold increase in growth rates (Björk *et al.* 2008). Although short term studies have confirmed this theory (Thom 1996), a long term study carried out by Palacios and Zimmerman (2007) showed no change to above ground productivity, although under high light conditions, shoot proliferation was greater. Of course, increased CO_2 may also be beneficial to epiphytic algae increasing shading and competition for other resources (Beer and Koch 1996).

1.119 Increasing CO_2 is also making the oceans more acidic. In solution CO_2 forms an equilibrium with carbonic acid which dissociates to add protons to the water (thus lowering pH)(Hendriks *et al.* 2010). The IPCC predict an increase of dissolved inorganic carbon and decrease in seawater pH of up to 0.5 units by 2100 (the largest shift in the last 1000 years). Ocean acidification effects the relative concentrations of the other dissolved inorganic carbon forms in seawater, for example reducing HCO_3, but since seagrasses use CO_2 at a higher affinity than HCO_3 this would not inhibit photosynthesis and may increase the compensation depth (Beer *et al.* 2006).

1.120 Although the effects of ocean acidification may be beneficial to the seagrass plants productivity (Duarte 2002), the effects on the associated biota may not and there are likely to be ecosystem wide impacts (Björk *et al.* 2008) and changes in ecosystem functioning. Studies have shown that the level of acidification predicted for 2100 can alter many benthic and planktonic organisms. Using elevated CO_2 partial pressure in aquaria (similar to those predicted for 2100), studies have shown a reduction in the calcification, rates and ultimately the abundance, of both calcareous epiphytes on seagrass and molluscan grazers with calcareous shells (Invers *et al*., 2002). Whilst a reduction in calcareous epiphytes may be beneficial to the seagrass, reductions in grazers may result in an increase in filamentous algal epiphytes and result in greater shading of the seagrass (Duarte 2002). Originally it was considered that reduced rates of calcification may be a shock response as the majority of studies where very short term, however in the last 5 years studies have been carried out adjacent to volcanic vent area where a seagrass habitat has been exposed to fluctuating CO_2 levels for decades (Hall-Spencer *et al.* 2008). Martin *et al.*, (2008) showed that bryozoans were the only calcifiers present on seagrass blades at mean pH 7.7 where the total mass of epiphytic calcium carbonate was 90% lower than that at pH 8.2.

Climate change

1.121 Potential threats to seagrass beds from climate change include sea level rise (when the landward extension of the bed is limited by human constructions such as seawalls), changing tidal regimes, damage from UV radiation, sediment hypoxia and anoxia, increases in sea temperatures and increased storm and flooding events.

1.122 Models of the thermal expansion of ocean water and the melting of ocean glaciers predict that there will be a 1-5m rise in seawater levels by 2100 (McKay *et al.* 2011). The potential effects of sea level rise on seagrass habitat are both direct and indirect. In terms of direct impacts, the depth distribution of seagrass beds will undoubtedly alter in response to sea level rise due to increasing water depths, but the upper limit may be constrained in areas of coastal development and defences resulting in a restricted depth distribution, which in turn may affect the resilience of the bed to other pressures. Also sea level changes are likely to alter currents causing erosion and increased turbidity, and will likely lead to seawater intrusions higher up on land or into estuaries and rivers (favouring land-ward seagrass colonisations (Short *et al.* 2001). Indirectly sea level rise has implications for management and planning in anticipation of this event for example building seawall defensive structures (Colantoni *et al.* 1996).

1.123 Sea temperatures are projected to warm between 2-4°C by 2100 (Sheppard and Rioja-Nieto 2005). Temperature is an important factor regulating the growth and distribution of seagrasses (see page 10). Temperature stress on seagrasses will result in distribution shifts, changes in patterns of sexual reproduction, altered seagrass growth rates, metabolism, and changes in their carbon balance (Short *et al.* 2001, Short and Neckles 1999). At species specific upper thermal tolerance limits respiration may exceed photosynthesis, resulting in a negative energy balance in seagrasses and the reduced productivity will cause them to die (Coles *et al.* 2004) (Neckles and Short 1999). *Z. marina* has an upper temperature tolerance of 38ºC, and *Zostera noltii* has a tolerance of up to 25ºC. *Zostera noltii* has a tolerance for cooler water but is at the limit of its northern distribution in the UK. It's likely therefore that *z.noltii* distribution could be constricted by rising sea temperatures with the chances of northwards distribution dispersal in the UK. Sea temperature have already risen by >1°C in the last hundred years.

1.124 For subtidal *Z. marina*, experiments showed that a 5°C increase in the normal seawater temperature caused a significant loss in shoot density; however, it seemed that the genetic diversity of this species provides it with the possibility to recover from such extreme temperatures (Reusch *et al.* 2005, Ehlers *et al.* 2008). At the margins of temperate and tropical bioregions (Short *et al.* 2007), and within tidally restricted embayments where plants are growing at their physiological limits, increased temperature will result in losses of seagrasses and/or shifts in species composition. Seagrass distribution and abundance may also be altered through the effects of increased temperature on flowering and seed germination (de Cock, 1981, McMillan 1982, Durako and Moffler 1987, Harrison 1982, Phillips *et al.* 1983).

1.125 Elevated temperatures may also increase the growth of competitive algae and epiphytes, which can overgrow seagrasses and reduce the available sunlight they need to survive (Peirano *et al.* 2005). Similarly temperature increases will increase metabolism of microbes. This would include including the slime mold protest *Labyrinthula* which causes the wasting disease in *Zostera*, outbreaks of which have been linked to changes in temperature and salinity (see page 14).

1.126 An increase in storm activity (Trenberth 2005) may effects seagrass by reducing the available light to the seagrass causing a depth squeeze and therefore a loss of area (Bourcier 1989) and more turbulent conditions may destabilise sediments and uproot the plants (Short *et al.* 2006).

1.127 In addition this may increase coastal erosion which may cause an increase in smothering of the seagrass or more suspended sediment (turbidity) in the water column. There may also be more rainfall causing more run-off from the land, further increasing turbidity of the water and hence restricting light availability to the seagrass beds (Guidetti & Fabiano 2000)(Preen *et al.* 1995).

Adaptation, resilience and recolonisation

1.128 The repercussions of the various pressures discussed above are very much dependent on the vulnerability and resilience of the seagrass to the various perturbations, and their recovery potential. The first part of this review looked at the environmental regulators of seagrass growth and distribution. As a general rule, seagrasses growing at the upper or lower limits of one or more of these factors are more likely to be vulnerable to anthropogenic disturbance and less able to recover.

1.129 Human pressures often cause rapid change to seagrasses and so their natural ability to adapt is compromised. The term adaptation is often used to imply adjustments to long-term continuous changes in the environment such as caused by global change. This review has illustrated how different species of seagrass have different tolerances to changes in environmental factors and human disturbance (see previous sections), but even within a species genetic diversity of different populations can influence resilience (as illustrated by the wasting disease, see page 14). Under these sorts of slower changing environments, genetically diverse seagrass populations have a higher chance of success than do genetically conserved ones. The genetic diversity of Zostera population is very high, particularly in the NE Atlantic (Hall-Spencer *et al.* 2008, Martin *et al.* 2008) and evolutionary change in seagrasses can occur within a few generations (Rice and Emery 2003). In 2008 Ehlers *et al.* showed that genetic diversity in *Z. marina* could help the plants to cope better with high summer temperatures (Ehlers *et al.* 2008).

1.130 The impact of more rapid direct human pressures, for example physical disturbances resulting from boating activities, mobile fishing gears and dredging will be less about adaptation and more about tolerance and recovery potential. For example, turbidity changes induced by dredging have been shown to only result in adverse environmental effects when the turbidity generated is significantly larger than the natural variation of turbidity and sedimentation rates in the area (Stern and Stickle, 1978; Orpin *et al.*, 2004). In short, any given extent, magnitude or duration of exposure pressure in one site/area is likely to have a very different effect (in terms of state change) at another site/area, depending on the nature of the receiving environment.

1.131 Seagrass recolonisation of a disturbed area can occur through sexual (seed supply) and asexual (vegetative growth from adjacent rhizomes), although the latter is more common particularly for *Z. marina.* Rasheeda (1999) examined the rate of recovery, relative importance of sexual and asexual reproduction and the role of the seed bank on recovery of experimentally cleared plots within a *Zostera capricorni* meadow. Rasheeda (1999) found that recolonisation was mainly through asexual growth from surrounding rhizomes and that seeds stored in sediments played no role in recovery. The rate of recovery corresponded to the length of the growing season, which generally decreases with latitude.

1.132 In a *Halodule* seagrass meadow in Queensland Australia, Creed and Filho (1999) also found that recolonisation of cleared plots was by primarily by vegetative elongation and that after nine months short shoot, rhizome and root biomasses and densities were similar to controls. Rates of recovery in experimentally cleared plots are likely to be dependent on the size and shape of the plots. They also observed that recovering seagrass sent up more short shoots per length of rhizome than plants in undamaged areas.

1.133 In a similar experiment Boese *et al.* (1999) examined the recolonisation of experimental created gaps within intertidal perennial and annual *Z. marina* beds. They looked at two zones, the lower intertidal almost continuous seagrass and an upper intertidal transition zone where there were patches of perennial and annual *Z. marina*. They found that recovery began within a month after disturbance in the lower intertidal continuous perennial beds and was complete after two years. However plots in the transition zone took almost twice as long. This would indicate that whilst scars created within a subtidal perennial seagrass bed may recover rapidly (within two years), intertidal patches of seagrass prone to disturbance from boat grounding are more vulnerable and less likely to recover.

1.134 The experiments described all used different sizes of cleared plots. Whilst it is difficult to compare due to the different environments and species, larger plots are likely to take longer to recover than smaller scars. Creed & Filho (1999) also suggested that the shape of the scar is an important factor influencing the recovery rate. Narrow furrows left after anchoring can recover more easily because of large edge to area ration and related availability of plants for recolonization. The horizontal expansion by rhizome growth is usually faster in patch edges where newly available bare-ground is available (Vermaat *et al.*, 1996).

1.135 As already stated, *Zostera* are monomorphic and do not have any vertical rhizomes (2009). This restriction to horizontal elongation of the roots explains why large continuous meadows are only found in gently sloping locations. Sudden changes in sediment depth can inhibit recovery of the seagrass into bare patches. Hence the depression of the seabed caused by a disturbance or mounding of the sediment caused by waves and currents, can restrict the expansion of seagrass.

1.136 The resilience of seagrass and its ability to recover from disturbance is a combination of the environmental conditions (including modifications resulting from the disturbance) of the site, growth rates of the seagrass and the frequency (repeated disturbances or a one off event versus) and intensity of the disturbance. This highlights the importance of considering the ecology of the seagrass bed, the environmental conditions and the types and nature of activities occurring, which may disturb the seagrass when considering the most appropriate management of a particular site.

2. Management of seagrass habitats

Introduction

2.1 Given the numerous ecosystem services provided by seagrass habitats and their sensitivity to various natural and anthropogenic pressures, it is not surprising that they are a high priority for conservation management in most areas where they occur. Advice, policy and management for the protection of seagrass habitats is tiered from international to local scales, and involves not only statutory bodies, but many non-governmental organisations, land owners and the wider public. Some management actions specifically target seagrass, whilst others aim to protect the wider ecosystem and biodiversity.

2.2 The following review examines some of the approaches taken to protect seagrass habitats; the policy instruments, on the ground management and new technologies and education. Monitoring of seagrass is an equally important aspect but is considered separately in Section 3 of the report. The review is separated into four main sections based on four broad management approaches. The first section examines the policy and legislation which directly or indirectly drives or influences the management of seagrass and the different organisations involved (prescriptive approaches). The second section looks at reactive management approaches, such as on the ground actions to address specific issues or pressures. Next the review identifies non prescriptive approaches, which relate to the wider education and includes codes of practice, local voluntary agreements and planning. Finally, good management of seagrass habitats requires not only the management of current pressures, but also of potential future pressures that may result in changes in seagrass health and distribution. Future drivers of change include sea temperature increases (and the potential for disease events), sea level rise and ocean acidification. In the final section of the review we will look at adaptive management strategies (including resilience building adaptation strategies) for seagrass. The focus of the review is on the North East Atlantic (NEA) and the predominant UK subtidal species Zostera *marina*, but examples from other species of seagrass and regions of the world are used where possible and particularly where NEA ones are not available or do not represent best practice. The review will act as a basis for detailing good practice for the management of UK seagrass beds.

Prescriptive and legal approaches

2.3 The legal protection of seagrasses ranges from local to regional-wide laws. In some countries the protection is overarching, that is all seagrasses have some level of protection, in others the protection comes from the association of the habitat with a marine protected area or an associated protected species.

2.4 Although there is no international legislation, the United Nations Environment Programme[4] (which sets global environmental agendas) has identified seagrass habitats as an important marine ecosystem in need of protection if the commitment to reverse the trend in loss of biodiversity is to be met. In 2003 the UNEP World Conservation Monitoring Centre (UNEP WCMC) produced a world atlas of seagrasses[5] to put this marine ecosystem, literally, “on the map”(Green and Short 2003a).

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[4] http://www.unep.org/
[5] http://www.unep-wcmc.org/world-atlas-of-seagrasses-2003_162.html

2.5 The Convention on the Conservation of European Wildlife and Natural Habitats 1979[6], also known as the Bern Convention requires the protection of endangered and vulnerable species of fauna and flora in Europe, and their habitats. Although the UK has signed up to the Berne Convention and *Zostera marina* (but not *Zostera noltii*) is listed in Appendix I as a floral species for which exploitation and other factors should be controlled, this is only for the Mediterranean and the convention provides no legal basis for its protection in the UK. Legal implementation of the Berne convention, for the relatively few UK species on it, is primarily through the 1981 Wildlife and Countryside Act and the EU Habitats Directive (see below).

2.6 The Convention on Wetlands[7] (known as the Ramsar convention) came into force for the United Kingdom on 5 May 1976. The definition of wetlands in the convention specifically covers seagrass beds, both intertidal and subtidal. The United Kingdom presently has 169 sites designated as Wetlands of International Importance. Six of these sites (eight including two sites in the Channel Islands) include seagrass beds (Larne Lough, Lough Foyle, Strangford Lough, Hamford Water, Lindisfarne and the Cromarty Firth). For all of these sites the Ramsar site location is coincidental with other types of protection such as European marine sites which encompasses both SPAs (Special Protected Areas for birds) and SACs (Special areas of Conservation for species and habitats, and national SSSI (Sites of Special Scientific Interest for geological features and species listed under the 1981 UK Wildlife and Countryside Act[8]). Apart from a few unique cases, SSSIs do not cover the subtidal, subtidal seagrass communities are, however, protected under the SSSI if they extend into the intertidal within a site.

2.7 Resolution V.7 adopted by the Ramsar Convention in 1993 requires that all Ramsar sites should have a management plan. All areas included within English Ramsar sites have some type of management plan incorporating conservation objectives for the Ramsar interests. New development proposals likely to affect a Ramsar site usually require an Environmental Impact Assessment under the Town and Country Planning (Assessment of Environmental Effects) Regulations 1988. Also any Ramsar site which is considered to have “undergone, to be undergoing, or to be likely to undergo change in their ecological character brought about by human action” may be placed on the Montreux Record which identifies the site to the Ramsar Advisory Mission who may provide technical assistance.

2.8 Under European legislation seagrasses are protected under the EU Habitats Directive[9]. The Mediterranean seagrass *Posidonia oceanica* is a named habitat on Annex I of the directive, whilst other seagrasses, including *Zostera marina* gain protection as named components of ‘Lagoons and Shallow Sandbanks’, ‘Large shallow inlets and bays’, ‘Intertidal mud and sand flats’, ‘Estuaries’ and ‘Sandbanks covered by sea water at all times’ on the Annex I list (Jones *et al.*, 2001). The European Habitats Directive does not give overarching protection to all seagrass habitats; instead protection is afforded by the designation of Special Areas of Conservation (SACS) for these features. Under this designation all existing, new or planned activities within a site must be assessed to ascertain whether they would hinder meeting the conservation objectives of the features of the site. Figure 12 illustrates those Special Areas of Conservation which include seagrass in England.

[6] http://jncc.defra.gov.uk/page-1364
[7] http://www.ramsar.org/cda/ramsar/display/main/main.jsp?zn=ramsar&cp=1_4000_0__
[8] http://jncc.defra.gov.uk/page-1377
[9] http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

2.9 Seagrass status is also used as one of the indicators of Good Ecological Status under the European Water Framework Directive[10] (Foden and Brazier 2006). Under this legislation seagrasses are afforded some level of protection and management consideration, irrespective of whether they occur within a marine protected area. An annual monitoring program, discussed further in the monitoring section, focuses on a number of reference sites to test for changes to previously undisturbed conditions, by measuring taxonomic composition (including presence of disturbance-sensitive taxa) and abundance (determined by seagrass shoot density and spatial extent), in both coastal waters and transitional waters (Foden and Brazier 2006). The requirements of the Water Framework Directive only extend to 1 mile offshore around the UK.

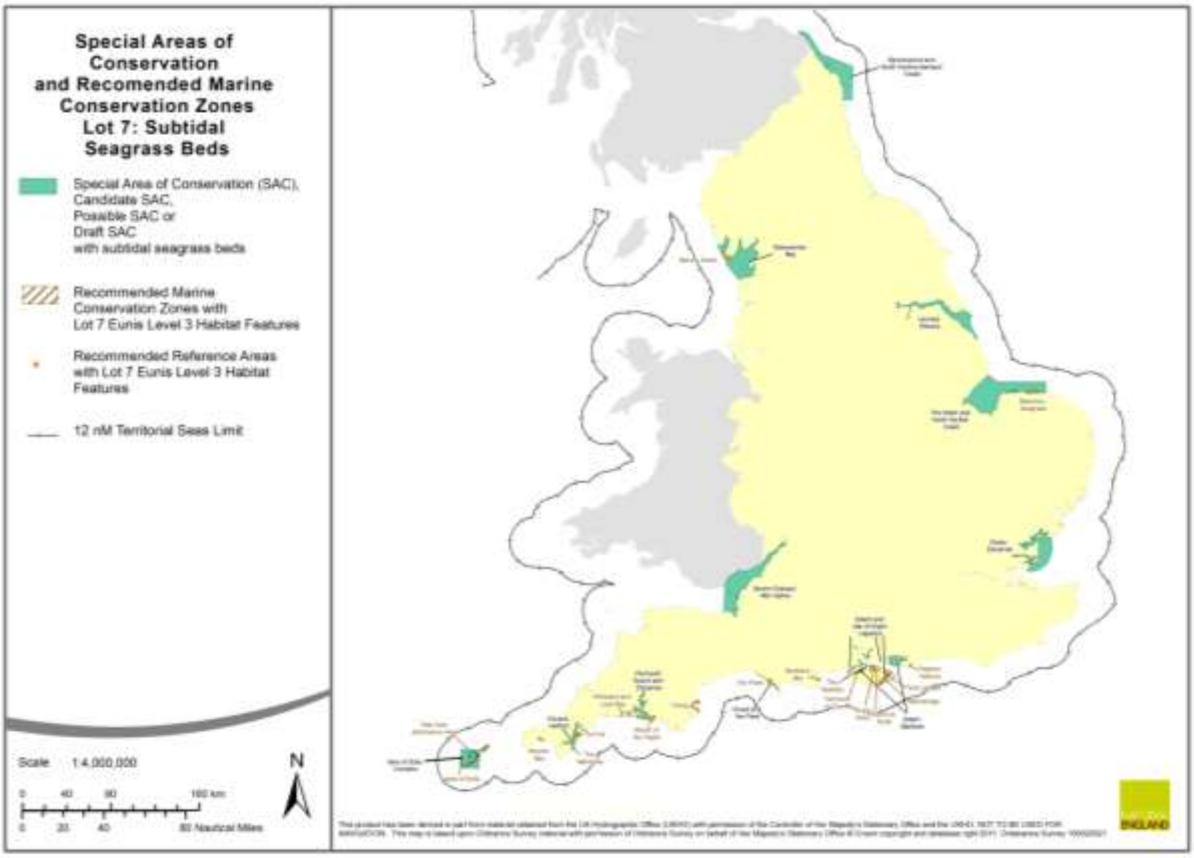

Figure 12 Map showing Special Areas of Conservation and Recommended Marine Conservation Zones (England & cross border sites) with subtidal seagrass beds present

2.10 Seagrass also gains indirect protection from a number of other EU Directives because of its need for good water quality and its importance as a habitat for some water birds. For example the European Nitrates Directive[11] (91/676/EEC), Urban Wastewater Directive[12] (91/271/EEC) and the Birds Directives[13] (79/409/EEC).

2.11 The Marine Strategy Framework Direcrtive[14] (MSFD) provides a general and inclusive obligation to achieve Good Environment Stuatu in EU waters by 2020. It acts to bring together the wide range of existing marine legislation and to fill any gaps. The targets for

[10] http://ec.europa.eu/environment/water/water-framework/index_en.html
[11] http://ec.europa.eu/environment/water/water-nitrates/index_en.html
[12] http://ec.europa.eu/environment/water/water-urbanwaste/index_en.html
[13] http://ec.europa.eu/environment/nature/legislation/birdsdirective/index_en.htm
[14] http://archive.defra.gov.uk/environment/marine/documents/legislation/msfd-factsheet5-conservation.pdf

achieving this in the UK are currently under consultation but will include benthic habitats such as seagrass.

2.12 At the scale of the North East Atlantic seagrasses are listed on the OSPAR[15] list of threatened and/or declining species and habitats (OSPAR, 2003), identifying them as in need of protection in the North-East Atlantic and as a priority for further work on the conservation and protection of marine biodiversity under Annex V of the OSPAR Convention. Each habitat and species has a case report (and background documents) identifying its status in each OSPAR country, the threats they face and recommendations on the actions and measures that could be taken to ensure their conservation and monitor progress of these actions (for seagrass see Tullrot 2009).

2.13 At a UK national level seagrasses are listed as a Priority Marine Feature in Scotland and in Wales they are listed as a priority habitat on the Natural Environment and Rural Communities Act 2006: Section 42 list of Habitats of Principal Importance for Conservation of Biodiversity in Wales. All habitats and species with some conservation value (particularly BAPs and HAPs), are provided with some legal protection through the NERC Act (2006) in England. Section 40 of the Act requires all public bodies to have regard to biodiversity conservation when carrying out their functions. This is commonly referred to as the ‘biodiversity duty’ (Defra 2007).

2.14 The Marine and Coastal Access Act 2009 makes provision for the designation of Marine Conservation Zones (MCZs) in English, Welsh and UK waters. In England seagrasses are listed as Features of Conservation Importance (FOCI) to be included into the MCZs (JNCC and Natural England 2010), and these recommendations for MCZs are being considered for designation by Defra. Protection will be afforded to seagrasses which are listed as features of an MCZ.

2.15 The Ecological Network Guidance (JNCC and Natural England 2010), which provides guidance on developing an MPA network (MCZ, EMS, RAMSAR and SSSI sites) which meets ecological coherence, proposes that within each of the four regional project areas, a minimum of two broadscale habitats and three FOCI should be included, and at least one reference area for each, where their distribution allows it. In addition to the existing MPAs, seagrass beds were replicated in 12 recommended MCZs and seven reference areas by the MCZ regional projects (see

[15] http://jncc.defra.gov.uk/page-1370

2.17 Table 1).

2.18 Patches of broadscale habitats should have a minimum diameter of 5km. For seagrass beds as a feature of conservation importance, the patch should be a minimum of 500m in diameter. Conservation objectives for these sites will be determined using scientific recommendations and evidence.

Table 1 rMCZs and rRAs proposed for the protection of seagrass (HOCI)

Project Region	Site code	Site Name
Balanced seas	rMCZ 6	Medway Estuary
	rMCZ 2	Stour and Orwell
	rMCZ 5	Thames Estuary (Leigh on sea)
	rMCZ 10	Swale Estuary
	rMCZ 25	Pagham Harbour
	rMCZ 24	Fareham Creek
	rMCZ 19	Norris to Ryde
	rMCZ 22	Bembridge
	rRA 17	King's Quay
Finding Sanctuary	rMCZ 15	Studland Bay
	rMCZ 22	Torbay Finding Sanctuary
	rMCZ 28	Whitsands and Looe Bay Finding Sanctuary
	rMCZ 33	Mounts Bay Finding Sanctuary
	rRA 10	The Fal
	rRA 6	The Fleet Finding Sanctuary
	rRA 9	Mouth of the Yealm
Net Gain	rRA 5	Blakeney Seagrass
Irish Sea	rRA W	Barrow South
	rRA Y	Barrow North

2.19 As a habitat for seahorses (in particular *Hippocampus guttulatus*) UK seagrasses also gain some level of protection under the UK Wildlife and Countryside Act (WCA 1981), since disturbing the habitat of seahorses is a licensed activity in the UK. This protection should cover all seagrass habitat irrespective of whether it occurs within a protected site. As a result seagrasses are considered under planning applications at a local scale. Also some seagrass habitat in the British Isles is protected de-facto by local fisheries bylaws which prevent the use of mobile gears in shallow areas, a certain distance from shore or areas where static gear is in use. For example, in Jersey the "Sea fisheries inshore Trawling, Netting and Dredging (Jersey) Regulations 2001 prohibit the use of trawls or dredges within many of the bays where seagrass is prevalent. Mooring areas may also provide de-facto protection for seagrass from mobile fishing gears (although they may cause their own damage to the meadows).

2.20 In addition to the statutory instruments listed above there are also a number of voluntary instruments aimed at protecting and restoring seagrass habitat. Biodiversity Action Plans (BAPs) are a result of the 1992 Rio Earth Summit and now BAPs are in place at a number of levels (National, regional, county and local). Although seagrass does not have a species Biodiversity Action Plan (BAP) it is covered by a Habitat Action Plan (HAP). The UK BAP lists seagrass as a priority habitat occurring in two broad habitat types depending upon the species present. These are littoral sediment, for seagrass beds of *Z. noltii,* and inshore subtidal sediment, for seagrass beds of *Z. marina*. Under the UK HAP for seagrass there are aims to assess the feasibility of restoration of damaged or degraded seagrass beds, however plans have been slow to be implemented due to limited information of baselines for identifying targets of areas to be restored (Anon 1995).

2.21 There are also broader HAPs which include seagrass. For example "The Nature of Devon: A Biodiversity Action Plan" (1998) lists "estuaries" as a priority ecological system and has specific targets for seagrass beds in the Action Plan. The overall aim of the Dorset Biodiversity Strategy (2003) plan is to ensure that there is no loss in the extent or quality of seagrass beds, within Natural Areas with the greatest potential for restoration and expansion.

This plan used data from county and regional sources to set the thresholds for seagrasses. HAP status does not afford the seagrass any legal protection, however these plans set out plans and targets for management (protection and restoration). One action at a national level was to suggest that *Zostera marina* be included on the Annex 1 list when the Habitats Directive are reviewed by the EC, which would provide the habitat with greater protection, but this review has not been carried out to date.

2.22 In 2012 the new UK post-2012 Biodiversity Framework was published[16] which replaces the previous UK level Biodiversity Action Plans. This framework is the UK's response to the 2010 Convention on Biological Diversity (Nagoya, Japan), when contracting parties renewed their commitment to take action to halt global declines of biodiversity. The CBD Strategic plan for biodiversity 2011-2020 has 5 strategic goals and 20 new global 'Aichi' targets (named after Aichi Province, Japan, where the targets were set). These targets address understanding the underlying causes of biodiversity loss, reducing pressures and underpinning resilience by safeguarding ecosystems, and have a more direct focus on protecting ecosystem services and exchanging knowledge. With a focus on resilience and ecosystem service delivery this new framework may provide a good opportunity to update the focus of seagrass protection in the UK.

2.23 Finally, seagrass occurs under many other types of nature conservation related sites, where although no legal protection is assigned, management may take into account the habitat, or the sites may have communication and education strategies which inform the public of the importance of these habitats. Table 2 shows the number and types of site were *Zostera marina* and *Zostera noltii* are found in the UK.

Table 2 Site classifications recorded for *Zostera sp.* in the UK

Site type	Total
Area of Outstanding Natural Beauty	13
Heritage Coasts	11
LBAP Areas	53
Local Nature Reserve	6
Marine Nature Reserve	8
National Nature Reserve	3
National Trust Boundaries	4
Nature Improvement Areas	3
NE Character Areas	18
Ramsar	6
Recommended MCZ Reference Areas	7
Recommended MCZ	12
RSPB Important Bird Areas	23
Site of Special Scientific Interest	33
SNH Natural Heritage Futures	50
Special Area of Conservation	47
Special Protection Area	28

(Source: NBN Gateway)

Planning processes and marine licensing

2.24 In the UK developers have a legal obligation under the Town and Country Planning (Environmental Impact Assessment) Regulations 2011 (UK enactment of Council Directive 97/11/EC) and the Marine Works (Environmental Impact Assessment) Regulations 2011, to

[16] JNCC and Defra (on behalf of the Four Countries' Biodiversity Group). 2012. *UK Post-2010 Biodiversity Framework*. July 2012. Available from: http://jncc.defra.gov.uk/page-6189.

consult with the relevant planning authorities prior to any proposed development. In the marine environment, a further marine licence is required under provisions of the Marine and Coastal Access Act. Relevant authorities include the Local Planning Authority, Statutory Conservation Agencies (for example Natural England) and for marine related developments the Marine Management Organisation. A pre-application assesses the need for an environmental impact assessment (EIA). An Environmental Impact Assessment involves the gathering information which enables the Local Planning Authority to understand the environmental effects of a development before deciding whether or not it should go ahead.

2.25 In addition to direct impacts from new developments (for example jetties, pontoons, aquaculture facilities, moorings), seagrass beds may also be subject to indirect damage due to onshore developments, for example increased runoff due to urban development resulting in increased turbidity, a new housing development increasing loading on sewage treatment plants, or increases in boat anchoring or mooring due to the installation of onshore facilities. EIAs require enough spatial and temporal scope to be able to assess impacts beyond the spatial and temporal boundary of the development, if adequate protection of the seagrass beds is to be met.

Reactive management approaches

2.26 Reactive management approaches are direct on the ground actions relating to the protection, maintenance, recovery or restoration of the seagrass habitat. Examples include relocating or limiting damaging activities (for example, banning mooring or anchoring, or using eco-friendly moorings). Under the Ecosystem Approach (as defined by the UN Convention on Biological Diversity), such management should, at the same time, deliver the services and benefits required by society, which requires marine scientists and managers to take a multidisciplinary approach covering natural and social sciences. Reactive approaches to managing disturbing effects (particularly outside protected areas) may involve technological advances, limiting or removing damaging activities or using deterrents.

2.27 Section 1 describes the pressures likely to produce a change in seagrass state, separated into endogenic (within the system) managed pressures and exogenic (outside the system) unmanaged pressures (sensu Elliott 2011). Examples of reactive management responses for each grouping are presented in Table 3. Whether a pressure, at the scale of the habitat, is exogenic and unmanageable or endogenic and manageable often comes down to the scale of the driver. For example for seagrass beds protected within an SAC, it is possible to manage pressures such as boat anchoring or dredging. For pressures such as nutrient inputsthat create a change in water quality, management responses would need to be taken at a catchment scale, and for climate change related pressures (for example, increased storms) a global response would be required.

Table 3 The advantages and disadvantages of different management responses for some of the main pressures influencing negative state change in seagrasses (N.B. Monitoring and restoration apply to all)

Pressure*	Driver*	Activity	Examples of management options	Advantages of management option	Disadvantages of management option
Endogenic managed pressures					
Nutrient enrichment	Agriculture	Agricultural runoff	Limit nutrient input (i.e. best practice for fertilizer application)	Reduced cost in terms of fertilizer for farmer. Reduced nutrient loading, less chance of runoff into coastal waters even during storm events	Reduction in fertilizer application may impact agricultural productivity
			Soft engineering – for example, Farm Integrated Management Runoff Plans	Buffers against run off during storm events. Applicable to arable and pastoral farming. Added advantages of limiting erosion and reducing turbidity in surrounding waters. Agri-environment grants available. Human Health Benefits in terms of Bathing waters.	Initial capital investment.
	Urban waste water	Sewage outflow	Increased sewage treatment level within catchment (Tertiary)	Also increases water clarity Human health benefits in terms of bathing waters.	Initial capital investment.
			Polluter pays – taxes on new developments	Money from taxes could be used to monitor nutrient levels	Payments may “give the right” to pollute. Does not remove the problem
	Tourism	Recreational boating waste	Codes of practice for waste disposal	Human Health Benefits in terms of Bathing waters.As above	Reliant on conscientious boat owners. No legal requirement to conform.
			Spot monitoring and fines	Human Health Benefits in terms of Bathing waters. As above	Difficult to enforce (costs and logistics of proving source)
	Aquaculture	Fish pens, shellfish farming	Spot monitoring and fines	Deterrent against polluting.	Difficult to enforce (costs and logistics of proving source)
			EIA for new developments	Potential impact on seagrass considered before damaging activities take place.	Costs of EIA processes.
			Codes of Practice	Low cost and may improve overall efficiency	No legal requirement to conform

Pressure*	Driver*	Activity	Examples of management options	Advantages of management option	Disadvantages of management option
Physical disturbance	Recreational boating	Mooring	MPAs: Ban on moorings with seagrass bed	Removal of the mooring pressure, seagrass may recover.	May see an increase in anchoring. Mooring scars in seagrass may not recover without intervention (for example, active restoration) in an acceptable time
			Restrict the installation of new chain moorings (limit on numbers, or installers must provide equivalent of EIA)	Low cost. Requires regulating, particularly in areas outside of harbour commission authority.	May see an increase in anchoring. Would not promote recovery of seagrass already damaged, only maintain current levels.
			Use of eco-moorings (see Table 4)	Reduce and remove damage to the seagrass from mooring chain and in some types the anchor block. Added advantage that some types are able to withstand storms better than traditional moorings. Prevent anchoring within an area.	Fears of boat owners. Problems with mixing eco-moorings and traditional moorings. Cost of replacing existing moorings. If replacing traditional moorings seagrass may not recover without additional aid. Initial capital investment
		Anchoring	No –anchoring zones with fixed penalties	Revenue from penalties can be put towards enforcement. “Polluter- pays” system fairer to those boat owners who do not cause damage .	Requires enforcement costs. Requires the provision of an alternative (for example, eco-moorings).
			Voluntary no anchor zones	Less enforcement costs.	Some boats will deliberately disregard. Require clear marking (with eco-moorings) and good communication. Some enforcement/patrol required.
			Use of eco-moorings	Reduce and remove damage to the seagrass from anchoring. Many eco-mooring types can withstand greater forces than traditional chain moorings	Greater number of permanent moorings may have visual impact. Concentration of moorings can result in increased chemical and nutrient contamination in poorly flushed areas. Demand for moorings is likely to increase with demand.
			Improving nautical charts to show vulnerable habitat	Engages conscientious boaters to avoid vulnerable areas.	Relies on boater compliance. Cost associated with production of paper

Pressure*	Driver*	Activity	Examples of management options	Advantages of management option	Disadvantages of management option
				Electroinic chart layers can be switch on and off. Cheaper to produce. Advises boaters who do not want to anchor on seagrass due to difficulties in hauling.	charts. For paper charts reliant on updates and purchase of these updates.
			Code of practice/ education	Reduces damage caused by boaters unaware of the consequences of their actions	Publication costs.
		Wave erosion from boat wakes	Speed limits	Additional benefits to public safety.	Enforcement required. Difficult to apply to large passenger ferries which responsible for largest and most regular wash.
		Boat landing on intertidal and anchor scarring	Designated swimming areas	Protect seagrass and protects bathers. Due to safety implications, these often self enforce.	Ignored during periods of poor weather or in winter
			Codes of practice based on avoidance of seagrass or only landing at high-tide	Low cost. Minimal impact on boating activities. Would account for ephemeral spatial distribution of seagrass.	Requires targeted education of visiting yachts. New visitors may be unaware.
			Designated landing areas	Easier to inform people (marker buoys). Added safety benefits for bathers	Area may become dangerously crowded at peak times. Does not account for ephemeral spatial distribution of seagrass.
	Fishing	Mobile fishing gear	Minimum depth restrictions on mobile fishing (licensing)		
			Marine protected areas (licencing)	Ease of communication. Would remove pressure and allow seagrass recovery.	
			Anti-trawling reefs	Fear of damaging nets would act as deterrent. No enforcement required.	Would need to be within a restricted mobile gear area. Would need marking on charts for navigation. Damage to seagrass of the structure itself.
			De-facto anti mobile gear	Self enforcement within the fishing and	Increase in static gear my impact on

Pressure*	Driver*	Activity	Examples of management options	Advantages of management option	Disadvantages of management option
			areas (for example, static gear areas, moorings areas – for example, eco-moorings in deeper parts of the seagrass)	boating community. Fear of damaging nets and entanglement would act as deterrent	the nursery function of the seagrass beds.
			Vessel Monitoring Systems (including small inshore vessels) and penalties	Would allow boats to fish in more areas, as long as they avoided the seagrass. Ease of enforcement.	
		Anchoring/ mooring	As above		
	Dredging	Capital and maintenance dredging through seagrass	Mitigation – transplant seagrass to an alternative location	Area of seagrass within a region maintained	Problems with finding suitable locations for transplants. “new” seagrass may not be functionally equivalent to the seagrass lost. Expensive.
Turbidity/ sedimentation	See nutrient enrichment				
	Dredging	Capital and maintenance dredging	Mitigate impact by planning dredging with consideration of seasonal, weather and tidal conditions	Allows the activity to go ahead. Knowledge of the local seagrass ecology may help to time subsequent dredging activities.	Dredging activities may need a lot of planning and may not be flexible.
		Spoil disposal	Monitor flumes and apply threshold for period of time for which water clarity is below limits for seagrass growth (if exceeded then site should be moved)	Allows the activity to go ahead. Knowledge gained through monitoring may help to locate subsequent spoil disposal sites.	Monitoring may be expensive. May be to late to avoid irrevocable damage
			Consideration of seagrass proximity and hydrology during spoil dump sighting	Removes the pressure from the seagrass	Other sites may be at a greater distance (cost) or may impact other habitats.
	Coastal protection	Shoreline modification/ smothering	Consideration of subtidal habitats within SMPs	Protecting the seagrasses may prevent shoreline erosion. Losing the seagrass may exacerbate the problem the activity is trying to resolve	Additional costs. Lack of research on which to base management decisions.

Pressure*	Driver*	Activity	Examples of management options	Advantages of management option	Disadvantages of management option
Chemical pollution	Marina/Port/ boat effluent	Antifouling/ herbicides (diffuse and from boat hull wash down)	Code of practice (for example, using suitable water pressure to leave paint intact when scrubbing down, use of plastic sheeting to collect scrapings)		Reliant on conscientious boat owners. No legal requirement to conform.
			Education on the most eco-friendly antifoulingpaints		Cost and difficulties in getting hold of eco-friendly paints. Some maybe less effective.
			Use of effluent collection system	Remove/reduce pollutants entering the water body.	Initial capital investment (although this can offset from levy's on boats using the harbor/marina)
	Tourism	Recreational boating waste (chemicals associated with cleaning toilets and boat decks)	Code of Practice	Prevent/reduce pollutants entering the water body. Health benefits for bathers and in terms of commercially exploited species using the seagrass.	
			Spot monitoring and fines	Human health benefits in terms of bathing waters.	Difficult to enforce (costs and logistics of proving source)
Exogenic unmanaged pressures					
Increased carbon dioxide and ocean acidification	Fossil fuel consumption Production of cement	All management relates to efforts to reduce the consumption of fossil fuels, but also to improving the resistance and resilience of the seagrass to such pressures.			
Climate change	Fossil fuel consumption				

*Not an exhaustive list, but represents the main pathways of seagrass loss.

2.28 It is also important to consider that reactive management approaches or responses can be directed at the socio economic drivers of the pressures which are resulting in an unacceptable change in seagrass state (for example, food labelling); at the pressures themselves (for example, MPAs, no anchoring zones, using eco-friendly moorings); at the state change (for example, by promoting resilience, carrying out restoration) and responses can even be directed at human welfare change (for example by providing compensation and mitigation) (Figure 13). An examination of different response options for different situations may help to avoid or minimise conflict, target monitoring more effectively and replace “cures” with “preventative measures”.

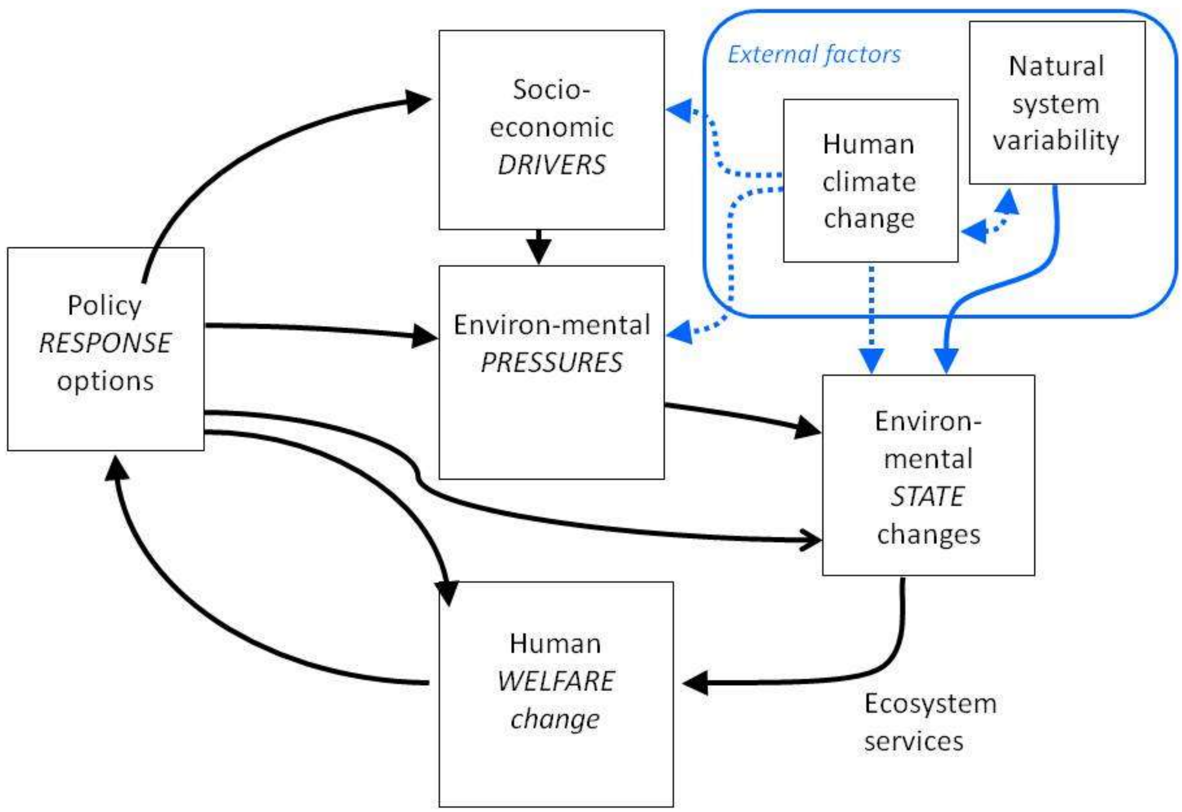

Figure 13 Driver-Pressure-State-Change-Welfare-Response (DPSWR) framework

2.29 Finally, it is important that a holistic approach is taken to the management of seagrass habitats. All natural resources are managed by regulating or influencing the activities and behaviour of those actors who extract and impact resources within the framework of policies and institutional structures (Potts *et al.*, 2012). One emerging approach to capture these frameworks is Rapid Policy Network Mapping (RPNM), which is based on the technique developed by Bainbridge *et al* (2011). The RPNM maps out the various actors (stakeholders, key institutions and policy makers) against key policy and legislation, identifying the roles of actors in terms of whether they are an “influencer”, “owner/decision maker” or “deliverer”. The method is based on the Ecosystem Approach, from the perspective that existing policy making institutions must be able to accommodate and adapt to a new multi-sectoral approach. Understanding how existing institutional structures function is an important first step towards this adaptation.

Managing physical disturbance

2.30 In the Mediterranean international concern about the conservation of this particular habitat led to the banning of trawling on seagrasses in EC waters (Regulation No 1626/94[17]), by banning all mobile gear in less than 50m depth (Tudela and Sacchi 2003). Although significantly reduced some trawling still continues (Tudela and Sacchi 2003) and in some areas illegal trawling was causing so much damage that managers put in place anti-trawling devices (Sanchez-Jerez *et al.* 2002). In the UK where seagrasses are outside MPAs there is little protection from trawling and evidence of trawling and dredging within seagrass exists (Cole 2012). Anti-trawling reefs could be an option in UK seagrass beds, but would need to be used within areas where trawling was already restricted, for example under local fishery bye-laws (for example, Devon and Severn Inshore Fisheries and Conservation Authority 2011), if compliance was shown to be an issue.

2.31 In offshore MPAs Vessel Monitoring Systems (VMS) have been used successfully to deter trawling in the areas of deep water coral reef (Shester and Ayers 2005). Regulation (EC) No 2371/2002 states that fishing vessels are prohibited from engaging in fishing activities unless they have installed VMS, but this only applies to boats exceeding 15m. VMS has now been trialled successfully in inshore areas on smaller vessels (for example within the Lyme Bay and Torbay cSAC). The trawlers were given access to the cSAC on the basis that they avoid reef habitat, and mobile phone technology was used to transmit satellite global positioning system (GPS) position reports from the vessel to secure servers (Devon and Severn Inshore Fisheries and Conservation Authority *et al.* 2012). The authors identified that whilst this approach requires strong collaboration between the regulators and the regulated, the advantages are that rather than blanket closures, fishing access can be granted to those using the system, while also protecting sensitive marine habitats (Devon and Severn Inshore Fisheries and Conservation Authority *et al.* 2012).

2.32 Disturbance to seagrass from boat anchoring and mooring is a particular problem in seagrass beds as the conditions which promote seagrass growth (for example, shallow, sheltered soft sediment seabeds) are also ideal for anchoring and mooring. Management responses to limit further damage or promote recover may include banning of anchoring and mooring in an area (although this is rare and conflicts with safety at sea laws), technological advances and capping the pressure at current levels. In Porth Dinllaen on the Llŷn Peninsula (Wales) the National Trust have capped the number of moorings in the inner harbor to 50 and a fee has been imposed for using the moorings which is charged weekly, monthly or on a seasonal basis (Egerton 2011). Fees for the use of traditional moorings are widespread and profits acquired could be used to invest in more eco-friendly moorings or restoration efforts.

2.33 Eco-friendly moorings (or eco-moorings) are moorings which minimise the impact on the seabed. Many of these systems have now been trialled in seagrass beds (Francour *et al.* 2006, Axelsson *et al.* 2011, Egerton 2011). PADI Aware produced a comprehensive management guide for those planning to install eco-moorings, which addresses communication plans, funding,

[17] applies to all fisheries and related activities pursued within the territory or the maritime waters of the Mediterranean of the east of line 5° 36' west falling under the sovereignty or jurisdiction of EC Member States with the exception of pools and lagoons

liabilities and legal responsibilities, and additional management implications (PADI 1996). The review states the importance of monitoring the recovery and also the differences in sites with and without eco-moorings. In terms of liability the review states that under most national laws mooring providers must “use reasonable care” to ensure that the buoys are properly installed (for example by experts), maintained (regular checks and servicing) and safe for their intended use (for example, by providing warnings of boat weight limits) (see van Breda and Gjerde 1996s for more detail on the legal aspects of providing moorings).

2.34 In the UK eco-moorings are already in use around Lundy and the Isle of Man. An appropriate eco-friendly mooring system should be able to securely moor a range of vessel types and capacities; have a minimum impact upon the seabed during deployment and maintenance (anchor element); and a minimum impact upon the seabed during service (riser element) (McKiernan 2011).

2.35 There are various different types of eco-moorings, the main differences between them are in regards to the rode and buoy system, and also in terms of the method of attachment to the seabed. All eco-moorings avoid scouring by having some kind of extendable rode (elasticated or spring loaded). Some eco-moorings are anchored in a similar way to traditional moorings (concrete blocks and anchors) whilst others cause less impact on the seabed by screwing into the sediment. Which type is used often comes down to the sediment type (Egerton 2011).

2.36 Many in depth reviews of eco-mooring already exist (see Francour *et al.* 2006, Egerton 2011, McKiernan 2011). These reviews examined different systems (see summary in Table 4). In considering the use of eco-moorings Egerton (2011) states that it is important that the right one for the situation is used with regard to vessel size, water depth and tidal range, and that at high tide the elastic should be taught but not stretched. Egerton (2011) also highlights that the installation of eco-moorings requires information about the seabed because a certain depth of sediment is required to provide the right strength for each system. As this varies with the size of the vessel Egerton (2011) recommended that each buoy be labelled with the max vessel weight. Insurance is an important consideration, previous schemes have been hampered by an unwillingness of insurance companies to cover boats attached to these moorings, but this has been resolved to a large extent by the manufacturers. Problems also exist with having a mixture of flexi moorings and chain moorings due to the differences in how the boats react/ move under different tidal and wind states.

2.37 Information about the moorings, including aspects of safety and comparisons with traditional moorings, should be clearly communicated to boats users, marina owners and harbour authorities, to encourage use. Whether eco-moorings are being used to replace existing moorings or to extend a mooring area is another important management consideration. When adding to existing moorings choosing sites close to the shore and in prime locations for access to facilities will encourage use. Also placing moorings in high density anchoring areas may help to remove this pressure from the seagrass (as boats will be less likely to anchor between moorings), giving an added conservation value to the approach. Replacing existing moorings, managers should consider that the sediment characteristics of the seabed may have changed. Not only may this affect the choice of attachment of the new system, but also natural recovery of the seagrass may no longer be possible and intervention may be needed (restoration or sediment infilling).

2.38 Reactive approaches to management are not limited to the removal of pressures, they could also include promoting recovery or actively restoring seagrass. Seagrass beds are naturally dynamic habitats and under the right conditions recovery can be rapid. Similar methods to those used in terrestrial environments could be translated to seagrass habitats, for example closing areas during vulnerable periods (for example during stormy seasons), or rotating closures to allow recovery (fallow). However more research is needed to understand the consequences on associated fauna and overall resilience, but also on the practicalities of enforcing or communicating such closures.

2.39 In many U.S. marine sanctuaries, federal regulations penalize even minor damage to coral and seagrass (van Breda & Gjerde, 1996). Although this “polluter pays” type approach requires adequate funding for enforcement, the penalties alone are an effective deterrent for many boaters, just as parking fines discourage motorists from parking illegally. Providing eco-friendly moorings as an alternative to anchoring would be recommended if a penalisation approach was taken, as would clear marking of the no anchoring area.

2.40 Boese *et al.* (1999) showed that recovery of experimentally created gaps within subtidal annual *Z. marina* beds may occur within two years. However, anchoring intensity shows annual peaks (i.e during the summer months), therefore, over time such an activity is likely to degradation of the seagrass. Managers should therefore consider fallow periods and biennial rotation of no anchoring areas, although there are practical issues regarding the enforcing and educating boat users.

Table 4 Examples of seagrass-friendly mooring types and previous trials/use

Type	Examples of locations used	Reason for use/ details of project	Outcome	Reference/ website
Mooring systems				
EzyRider - ground weights linked to the mooring buoy by means of a chain and elastic riser system	Moreton Bay, Australia	Federal Government's Caring for our Country Community Coastcare Grant, SEQ Catchments launched the Moreton Bay Environmentally-Friendly Mooring Trial, to test three designs over a two year period.	Preliminary results have shown a significant recovery of seagrass surrounding these moorings. Used the term "crop circle" to help public visualise the impact	(Anon 2010) http://ezyridermooring.com
Elasticated eco mooring rode and *Helix* - Helix is a corkscrew style anchor that is wound into the seabed creating minimal disturbance to the bed during deployment and service. Eco Mooring Rode is an elastic tether that elongates under load and accommodates the range of tidal heights. Can be used with a multitude of anchoring systems.	Studland Bay, UK Falmouth, UK Massachusettes, USA St Martin, USA Florida, USA Conneticut USA Also used for Salmon cage anchors in Canada Floating dock and fix pier anchors across the USA	Seagrass beds. rMCZ. Used 6 buoys to mark out the Voluntary no anchor zone	Copes with large tidal range. No damage to seagrass in five of the moorings, the 6th showed a small amount of damage. Trials have shown the enormous holding power of the Helix anchor in soft sediments and it is recommended by both state agencies and insurance companies in the US.	see MAIA Part 2 http://www.helixmooring.com
SEAFLEX - a robust flexible riser from anchoring system (concrete block) to mooring system. Used in conjunction with an eco friendly anchoring system	Mylor Yacht Harbour. Not trialled on seagrass.	Cycleau project, Trial project. Natural England.	When used with the HELIX anchor, the system requires less surface area for anchoring to seabed. According to the Cycleau project, problems were encountered in shallow waters with large tidal ranges.	http://www.cycleau.com (Kendall *et al.* 2006)

Type	Examples of locations used	Reason for use/ details of project	Outcome	Reference/ website
	Lundy MCZ	Marine Reserve, No Anchor Zone	SEAFLEX systems require an amount of swinging space. The amount of space required must be considered to prevent boat collision. This trial has highlighted that problems occur when eco moorings are placed amongst standard moorings. If a marina/location was to install SEAFLEX systems (or similar elastic moorings), collections of eco moorings should be installed together, *isolated* from standard moorings. There were reports of failing SEAFLEX moorings at the point where elastic rope is crimped to connect to the anchor point. This creates a weakness in the system, causing the rope to snap.	
Hazelett – designed to withstand bad weather	Isle of Man, Stellwagon Bank National Marine Sanctuary (NOAA) Marathon Florida	Individual using Hazelett mooring system on own boat in Isle of Mann (East Coast). Previously used standard chain and riser system. Chose Hazelett due to his mooring position in an extremely exposed bay, chose this system for strength and ability to cope in those conditions. Used to reduce damage to seagrass beds in British Columbia (used by NOAA) Used over traditional moorings to withstand bad weather.	Advantages of the Hazelett system, the elasticated rope runs through the eye in which it is attached to the anchor system (deadweight, helix anchor or sand screw). This seems to be a significant improvement to the SEAFLEX system, where elastic rope is crimped. This produces a weakness in the system, causing the mooring to fail as reported in the Mylor Harbour trial. No insurance problems. Withstood storm force gales in Florida.	www.hazelettmarine.com

Type	Examples of locations used	Reason for use/ details of project	Outcome	Reference/ website
Anchoring system				
Sand screw - shaft with one or several disks in a helix or spire of an Archimedes screw adapted to all sorts of sedimentary seabeds.	Cycleau project, Mylor Yacht Harbour. Natural England. Trial project.		According to Francour *et al.*, (2006), a sand screw is not suitable for a seagrass bed (*Posidonia* in this case) due to the potential destructive impact of the screw when inserted into the substrate. Carry out soil stability tests to calculate the appropriate coil size and anchor set up, in order for minimal damage to the surrounding bed. Conduct a trial of the different suitable systems alongside a voluntary no anchoring zone, in a small area of the bed.	http://www.cycleau.com
Harmony - steel coil is screwed into the substrate completely, resulting in a strong anchoring point. Either single anchor or multiple connected via a metal bar	Used widely throughout the Mediterranean. Port Cros National park. Zakynthos, Greece. Valencia, Spain.	The effect of the 'Harmony' mooring system has been tested on seagrass during a two year long project in the Mediterranean.	The conclusion after two years was that there was no impact on the surrounding seagrass bed from the 'Harmony' mooring system. The coil is less damaging to the seagrass roots than the sand screw. Trials showed that a single anchor can withstand a force of 3.36 tons (A 16m yacht in 75mph winds exerts 1.43 tons of force)	(Francour *et al.* 2006); Centre d'Etudes Techniques de l'Equipment, Provence

2.41 In the Isles of Scilly, damage to the seagrass bed due to mooring chain scarring was visible in St Mary's Harbour from 2008 aerial images (Jackson *et al.* 2011), however comparisons with historical images indicated that the meadow was accreting and that mooring scars were more numerous but smaller. This change was attributed to the installation of grid chain mooring system by the Duchy of Cornwall in 1996 to allow a greater number of boats to moor in the harbour. Whilst the observations indicate that this mooring system may have been advantageous in terms of increased coverage of seagrass, and limiting the size of mooring scar, fragmentation of the bed in terms of the number of scars may be greater.

2.42 In addition to limiting banning or replacing moorings and anchoring areas, managers should address the drivers of the pressure (Langmead *et al.* 2009). For example, why are fishermen trawling in the area, or why do boat owners prefer to anchor in the seagrass areas versus un-vegetated areas close by. Putting additional traditional chain moorings in adjacent non-seagrass areas may not be effective if this is a greater distance for a place on interest on shore. More novel approaches may be required, for example providing additional facilities closer to the new mooring areas.

Managing water quality

2.43 Water quality, in terms of turbidity, nutrient concentrations and chemical pollutants, often requires management at a larger scale than the bay or estuary where the seagrass occurs. For example, seagrass beds are sensitive to changes in nutrient levels. The main sources of nutrients are from agricultural runoff and sewage (with the exception of discharge from tertiary treatment plants).

2.44 Diffuse pollution from agricultural runoff, can result in an increase in nutrients, but also increases in water turbidity, particularly during storms. Management responses involve reducing the inputs of fertilizers onto the land, but also using soft engineering features (temporary storage bonds, buffer strips, bunds and even moving positions of gates) to intercept, store, slow and filter runoff (Wilkinson 2008). In the UK reducing inputs onto the land has been driven by the Nitrates Directive, the Common Agricultural Policy reform (rewards for agri-environment schemes) and the Catchment Sensitive Farming Initiative (a joint project between the Environment Agency and Natural England, funded by Defra).

2.45 Increased turbidity and sedimentation may also be a result of dredging activities and spoil disposal, up current from a seagrass bed. Seagrass beds are only likely to be impacted where the levels significantly larger than the natural variation in turbidity or sedimentation in the area (Erftemeijer and Robin Lewis III 2006). Seagrass beds are often able to cope with short durations of increased turbidity or sedimentation. Therefore if dredging or spoil disposal close to a seagrass bed cannot be avoid, appropriate management approaches may be to limit the duration and time the activity to coincide with specific hydrological conditions (for example, neap tides) or lower growth periods of the seagrass (for example, winter). Other mitigation methods and technical considerations are reviewed by Erftemeijer and Robin Lewis III (2006).

2.46 Discharge of boat sewage to coastal waters can represent a more direct pressure on seagrasses. Efforts to reduce mooring impact on *Posidonia* seagrass beds in the Cabrera National Park (Spain) by installing 50 fixed eco-moorings led to an increase in visitor boat sewage which resulted in degradation of the seagrass (Marba *et al.* 2002). Regulation under MARPOL Annex V only applies to recreational craft carrying fifteen or more passengers. Since 2006 the Recreational Craft Directive (Directive 2003/44/EC), implemented in the UK as Recreational Craft Regulations (SI 2004/1464), require that all newly built vessels have a holding tank fitted. The waste disposal from privately owned older boats and those carrying just a small number of passengers are not covered by these regulations, and so where densities of these boats occur in high numbers inputs can be significant. Management relies on non prescriptive approaches such as codes of practice.

2.47 Chemical pollutant pressures on seagrass are less common, however organic biocides such as Irgarol 1051 and Diuron, used commonly in antifouling paints since the banning of TBT, have been experimentally shown to reduce the growth of seagrass in concentrations above 0.5 µg/l (Chesworth *et al.* 2004). Management responses for pressures such as this need to be directed at the policy driver level, however more research will be needed to identify less toxic alternatives.

Restoration

2.48 Depending on the environmental conditions, even when a disturbance is removed from a seagrass bed, natural recovery may not occur, and restoration is becoming an increasingly popular management option. In the past the evidence supporting the contribution of seagrass to various ecosystem services is such that the taxation benefits of seagrass restoration have been assessed favourably by economists (Anderson 1989), and in some locations vast areas of seagrass have been restored (Erftemeijer and van Katwijk 2010, Giesen and van Katwijk 2011). Various methods for restoring seagrass exist from transplanting plugs and turf, to seeding areas (see Calumpong and Fonseca 2001).

2.49 Restoration of seagrass beds needs to be done with care, reflecting natural seagrass landscape configurations at each individual location (Bell *et al.* 2001, Campbell 2002, Van Katwijk *et al.* 2009). Landscape ecology studies should be used as an aid for restoration efforts, most importantly in suggesting appropriate spatial configurations of restored seagrass to facilitate recruitment of fauna and promote functional equivalency (Bell *et al.*, 1997). The selection of location and donor plants (or seeds) is also crucial as recent reviews have shown these factors to be the most crucial in terms of overall survival (Van Katwijk *et al.* 2009, Fonseca 2011, Cunha *et al.* 2012). The greatest failures in seagrass transplantation have been associated with transplanting seagrass to areas were historically it had never been recorded, as part of poorly thought through mitigation efforts (Fonseca 2011).

2.50 In October 2010 the first European Seagrass Restoration Workshop was held. Outputs of the workshop included decision trees, guidelines, and restoration models to aid seagrass restoration management, but the results of the workshop also identified a shift in priority to promoting natural restoration over using restoration as compensation for natural habitat loss during economic development (Cunha *et al.* 2012).

2.51 Outside of mitigation the cost of restoration can be restrictive; however some organisations have identified novel methods for paying for the work. For example a partnership between Columbia Sportswear and The Ocean Foundation financially supports a seagrass restoration project in Redfish Bay, Texas. Their propeller scar restoration project uses ‘sediment tubes’ which run along propeller scars, to encourage rhizome re-colonisation across the scar. In Virginia, Blue Crab fisherman using destructive methods have been taxed, and the money used in seagrass restoration projects (seagrass being an important nursery habitat for blue crab) (Anderson 1989). More recently projects have started to investigate the possibilities of setting up carbon off-setting schemes using seagrass beds, although currently the variability in carbon fluxes of many seagrass beds is limiting progress (Blue Ventures 2012, Fourqurean *et al.* 2012).

Non-prescriptive approaches

2.52 Non-prescriptive approaches are those where there is no legal framework for protection, instead they rely on public and stakeholders choosing to change their activities to help in protecting seagrass beds. These approaches include codes of practice, local agreements, planning processes and education.

Codes of practice

2.53 Codes of practices (CoPs) are available for many sea users who may cause damage to seagrass by their actions, and have been produced by industry, councils, recreational clubs and associations, conservation managers and conservation organisations. The Seagrass Outreach Partnership in Florida (www.flseagrass.org), where boat grounding and anchoring are a problem, have developed a number of codes of practice, particularly regarding responsible boating practice. Their particularly successful approach identified that conservationists and boat owners had similar goals (i.e. the boaters did not want to go aground, damage their propellers or become snagged on seagrass when anchoring). Similar CoPs exist in the UK, for example as part of a seagrass awareness campaign run by the South Devon AONB, (see seagrass information poster in Appendix 2), for seagrass beds in Torbay (Torbay Coast & Countryside Trust, see Appendix 3) and part of a series of CoPs produced by The Green Blue (TheGreenBlue 2010). The Green Blue is an environmental awareness programme set up by the British Marine Federation and the Royal Yachting Association with an aim to promote the sustainable use of coastal and inland waters by boating and watersports participants and the sustainable operation and development of the recreational boating industry.

2.54 The Dorset Wildlife Trust have set up a code of conduct for seagrass habitats, which people can sign up to on their web site to register support (Dorset Wildlife Trust 2011), see Appendix 4 for details. Taking this approach further an organisation in Florida, Eco-Mariner, runs a short online course to educate boaters about Florida Bay's geography, sensitive habitats (including seagrass beds) and threats to them, as well as Codes of Practice and regulations for protecting these habitats. On completion of the course individuals are awarded a reward card which gives them discounts in tackle shops, chandlers and restaurants (Eco-Mariner 2011).

Local agreements

2.55 Local voluntary agreements can be particularly successful in limiting a destructive activity over seagrass. For example, in the UK in Studland Bay a voluntary no-anchor zone (VNAZ) has been adhered to by the majority of boaters in the area (Axelsson *et al.* 2011), although this has now been removed. Compliance has also been very good in the no-anchor zone set up in the Fal and Helford SAC. Success in the Fal and Helford SAC was attributed to marker buoys identifying the zone, good support from the local community and a patrol by Truro Harbour Commission, but it should also be noted that boat use pressure was lower in this area compared to locations such as Studland Bay.

2.56 Egerton (2011) provides the following recommendations for setting up a no-anchor zone:

- Investigate and confirm poltical and administrative support.
- Consult as many stakeholders as possible, especially locals and involve them in any zoning plan.
- Let everyone know what is going on and why at the earliest opportunity.

- Be open about what is going on throughout any project.
- Explain clearly the importance of seagrass and why it is protected and the benefits a healthy bed could bring to the local economy. Produce flyers and posters explaining this.
- If a no anchoring zone is to be established a voluntary system would be recommended.
- If a voluntary no anchoring zone is established this should be clearly marked out with buoys that will not move. Further the buoys should have large lettering and a clear message so that they can be read from a distance.
- Voluntary no anchoring sites should be shown on maps (on the above mentioned posters) and possibly advertised online and with groups such as the RYA.

2.57 In June 2012, following frequent reports of dredging for shellfish in seagrass beds, the Southern Inshore Fisheries and Conservation Authority announced a voluntary code of conduct on dredging in seagrass beds. The move recognised the fact that seagrass beds are important nursery areas, but also the many other ecosystem services the beds provide. The code of conduct provides maps of seagrass protection areas in the Southern IFCA district where towed fishing gear should be avoided. The Southern IFCA have agreed that evidence of breaches of the code of conduct (i.e. new dredge scars in the seagrass) will lead to a warning being issued, after which further breaches will lead to the adoption of a regulatory approach (adistrict wide bye-law, with penalties of upto £50,000).

2.58 In the Laguna Madre, the US Nature Conservancy's *Save Our Seagrass* public awareness campaign developed a successful program to assist recreational boaters in protecting seagrass by identifying and marking voluntary boat lanes. Voluntary agreements are a particularly useful management tool for pressures such as anchoring, where International Safety at Sea Laws override other legislation to prevent anchoring.

2.59 Safety can also be another incentive for removing the pressure of landing boats at low tide which can cause significant damage to seagrass. In areas where people go ashore to utilize the beach and swim there is a considerable risk to public safety. Well located voluntary swimming areas can protect both vulnerable seagrass and bathers.

Education

2.60 Education is a powerful management tool for the protection of seagrass. Informing people about what seagrass is and why it is important can allow people to make a decision about whether they care about the habitat, but education should not stop there as it is important that people are also informed about how they can help alleviate a problem as an individual or group. On that basis education can be broadly split into two categories. First of all there is education targeting specific stakeholders who may directly utilize the area where seagrass is present. Secondly there is educating and promoting interest from the wider public. Without the latter, policies to help protect seagrass habitat are more difficult to justify to politicians.

Targeted stakeholder education

2.61 In addition to educating people about the types of activities which may cause damage to seagrass beds (and the likely repercussions of such damage), one of the most important bits of information that people need in order to avoid damaging seagrass is to know where the beds are. Many maps of seagrass now exist but very few are made available to boat users. Lessons could be learnt from offshore MPAs for deep-water coral reefs. Here, maps of known reefs shared with fishermen have helped them to avoid the reef, which damages their nets (Hall-Spencer *et al.* 2009). Similarly trawling or dredging through a seagrass bed can result in a large amount of seagrass material weighting down the catch and making it difficult to sort, or more difficult to haul.

2.62 In the past it was not practical to identify benthic habitats, and in particular sensitive habitats, on paper charts (although some showed MPAs or habitats which may cause a hazard to navigation), due to issues of space and chart clarity. However with the development and increased use of Electronic Chart Display and Information System (ECDIS) and electronic navigational charts (ENCs) opportunities now exist for creating habitat vulnerability layers (which can be turned on and off) to inform conscientious boat users. ENCs are produced by national hydrographic offices. In the UK ENCs are distributed by the United Kingdom Hydrographic Office who then distribute these to chart agents. In the United States, ENC manufacturers NOAA have been amongst the first to look into adding geographic information system (GIS) based coral reef shape files and MPAs as supplementary layers to existing ENCs. A recent successful inshore VMS trial to allow fishermen access to a candidate SAC, was heavily reliant on detailed maps of inshore reef habitat provided by Natural England (Devon and Severn Inshore Fisheries and Conservation Authority *et al.* 2012).

2.63 In addition to marking out seagrass on ENCs and making these available to boat users (including fishermen), seagrass can also be identified by a boat's digital echosounder. Seagrass blades have air filled lacunae which create noise above the seabed on the digital echosounder displays (see Figure 15). Information on ways of identifying vulnerable seabed habitats should be exchanged with boat owners through targeted articles in, for example, boating magazines or association newsletters, or in advertisements for digital echo-sounders.

2.64 Clubs and training centres also play an important role in educating new boat users. The Green Blue identified that lessons learnt by boaters during their first RYA course were likely to become good habits throughout their boating life. Including information about avoiding vulnerable habitats and correctly managing waste (boating sewage) could have long term benefits.

Wider public education

2.65 Seagrasses are an excellent teaching resource for all ages and stages of the school curriculum and for a wide range of different subject areas (including ecology, geography, policy, chemistry, and physics). At the same time, using seagrass as a teaching resource will help to educate the public as to the importance and vulnerability of this habitat, and provide greater public support for policy development and implementation. Given the global interest in this habitat many teaching resources are already available (examples in Appendix 5) (see also McKenzie 2008, McKenzie *et al.* 2008a, 2008b).

2.66 In the last few years there has been a growing success in promoting seagrass (and at the same time collecting valuable monitoring information) through the development of global networks of community based seagrass monitoring programs (for example SeagrassNet and SeagrassWatch). The overarching aims of both SeagrassNet and SeagrassWatch are to preserve valuable seagrass ecosystems by increasing scientific knowledge and public awareness. Initiatives such as this could help to build understanding of the importance of seagrass, and encourage ownership of the environment locally. In conjunction with statutory monitoring requirements, these volunteer networks could also be a way of increasing monitoring efforts to fill in research gaps (see Section 3).

2.67 In 2009 the first UK SeagrassNet site was established in the Fal and Helford Estuary. Unfortunately a lack of financial and public support means that monitoring is no longer carried out at the site. This attempt highlighted the importance of building up community and administrative support prior to setting up monitoring. Future attempts should aim to embed the monitoring into well-established groups or frameworks. For example monitoring an intertidal seagrass bed site could be included on a school's syllabus, or the monitoring could become part of regular natural history group events. Of course intertidal seagrass is more accessible for this type of monitoring.

2.68 Surveying subtidal beds requires trained divers and so it is more difficult to involve members of the community who cannot dive. One project which has attempted to bridge this is the The Blue Sound Action Group (BSAG) based in Plymouth Sound and Estuaries SAC. BSAGs aim is to introduce local people to the marine environment through innovative active engagement and runs many marine environment awareness projects. In 2011 they launched a project to train nine young people to dive and survey seagrass beds within the SAC. In the Isles of Scilly, monitoring using volunteer divers sponsored by Natural England has ran successfully for almost 10 years (Cook 2002, Cook 2004a, b, Cook and Foden 2005, Cook 2006, Cook and Paver 2007) and represents one of the longest term data series available for seagrass in the UK, and was useful in helping to identify indicators of change for the Water Framework Directive (Foden and Brazier 2007). SeaSearch, a volunteer underwater survey project for recreational divers to actively contribute to the conservation of the marine environment, has been highly successful in promoting awareness of seagrass beds and collecting data on seagrass habitats across the UK (for example, SeaSearch 2008). Finally, with good quality waterproof drop video cameras becoming more affordable, the potential to involve local boating clubs in seagrass surveying is a realistic option for managers to pursue.

2.69 In a study addressing the charisma gap between different marine habitats (Figure 14), Duarte et al (2008) identified that increasing public awareness of seagrasses can be aided by highlighting charismatic species which utilize the habitat, novel aspects of the habitat or ways in which seagrasses benefits society as a whole. Seagrass has recently appeared in the national news, as an important habitat for seahorses, as an important carbon store and as one of the most ancient living organisms on the planet. These news stories highlight the growing interest in the habitat but also in the ability of researchers to identify relevance aspects of their work which will capture public interest. Academics and research scientists are increasingly being encouraged (through sections of grant proposals) to exchange the knowledge gained during their research with a wider audience through not only static websites, but also blogs, Facebook pages, Youtube videos, articles in newsletters (RYA, Wildlife Trust, Dive magazines), television and radio news items, and harbor information packs for boaters.

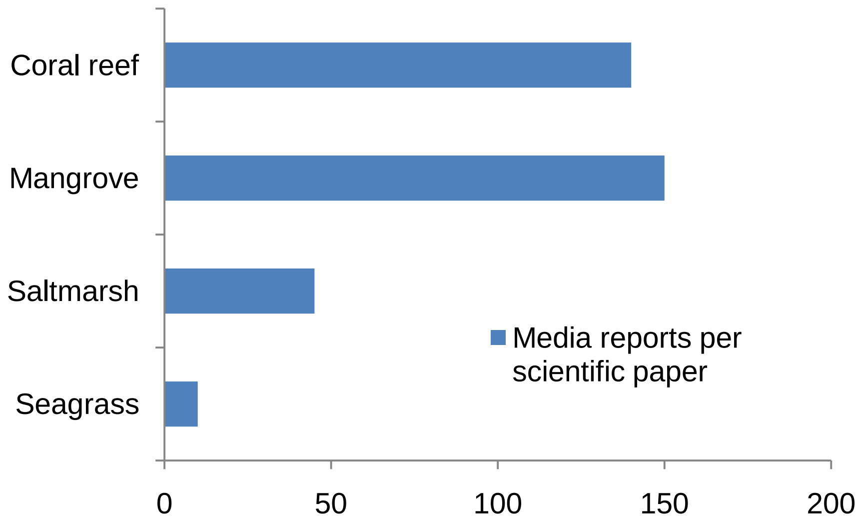

Figure 14 A global assessment of the number of media reports resulting from scientific papers regarding four marine habitats (Source: Duarte *et al*. 2008)

Management to enhance resilience

2.70 Section 1 illustrates that seagrasses are vulnerable to a multitude of anthropogenic and natural stressors. Strategies to mitigate the rate and extent of climate change impacts fall on the margins of being exogenic and unmanageable, however resilience-building adaptation strategies are a management option (Björk *et al.* 2008). Management strategies that enhance the resilience of seagrasses must be developed and implemented to ensure the survival of these valuable habitats (see Björk *et al.* 2008). Primarily this will involve reducing pressures on seagrass where possible (even if they appear to be “coping” with those pressures) to increase their ability to cope with greater environmental extremes. It is also important to make sure that current monitoring regimes can be built on to improve our knowledge of the surrounding environmental conditions and keep a better track of the changing trends in seagrass and, in particular, identify those at risk (see Section 3).

2.71 Seagrass beds in the UK are largely monospecific, which may make them vulnerable to global warming, because they lack species redundancy. However genotypic diversity (an important component of biodiversity) of *Zostera marina* can vary significantly by location (Reusch *et al.* 2005) and may provide critical response diversity for maintaining seagrass ecosystem functioning and for adaptation to environmental change. More research is required to assess genotypic diversity within and between seagrass populations.

2.72 Seagrass landscapes are very dynamic, showing natural cycles of accretion and erosion which shape the landscape configuration. Although such dynamism should buffer the effects of perturbations many seagrass loss events have often been catastrophic, suggesting that there is a critical threshold in fragmentation whereby the negative effects that seagrass loss initiates (for example, sediment resuspension and reduction) further accelerate losses at rates greater than the seagrass can recover. By reducing human pressures which fragment seagrass beds (even where natural recoverability occurs) the natural buffering capacity of the seagrass beds will be improved.

Recommendations

2.73 The following recommendations build on previous studies and reviews. Some of the recommendations represent actions which are already carried out in the UK (but not at all sites), whilst others are recommendations for the future management of seagrass beds in the UK

2.74 The current report proposes that at a site level managers should consider the following steps to build an appropriate knowledge base for protecting seagrass habitats:

- In order to complete the following recommendations, it is necessary initially to map out all the stakeholders and relevant legislation/policy and agreements (for example, using a tool such as Rapid Policy Network Mapping), to initiate discussions and progress work, and seek support. The community may be able to help with several aspects of work, such as voluntary projects and education programs.
- Collate all available data on state and pressures for the site from past surveys.
- Carryout a gap analysis to ascertain missing information or critical research requirements.
- Carry out a full character assessment map of the seagrass bed at the site (environmental conditions such as depth, sediment, wave exposure, but also human pressures).
- Using the character assessment assess sensitive and vulnerable parts of the beds, natural geographic and biological limits (to help inform on thresholds) and identify potential indicators of functional aspects of the meadow (in terms of ecosystem service delivery).
- Identify the potential natural limits of the seagrass beds and ensure protective boundaries allow possible recovery of outer limits.

2.75 Based on the review of the ecology, pressures and management options, and building on previous recommendations from the OSPAR seagrass case report, the current sudy recommends the following for the future management of seagrass beds in the UK:

Legislative:

- Protect seagrass beds.
- Include *Zostera marina* and *Z. noltii* in the list of priority species in the *Natura 2000* list of species.
- Control and treatment of urban and industrial sewage to reduce the loading with nutrients, organic matter and chemicals.
- Regulation of land use in catchment areas to reduce nutrient runoff and siltation due to soil erosion.
- Regulation of aquaculture, fisheries and clam digging in or adjacent to seagrass beds.

Monitoring:

- Develop baseline maps of seagrass meadows to allow for monitoring of changes in distribution and abundance.
- Long-term monitoring including abiotic factors.

- Implement monitoring programmes that provide feedback on the results of coastal management. If management strategies are not meeting their objectives, they need to be adapted to achieve their goals.
- In addition to common standard monitoring, monitoring at an individual site should target specific pressure responses and environmental variation (for example, spatial variability).

Education/Research:

- Raising awareness of the importance of seagrasses.
- Implement codes of conduct to reduce small-scale disturbances.
- Improve the links between local, national and international seagrass research.
- Research gaps in knowledge (in particular research in order to determine appropriate levels of quality for maintenance of the habitats functions).

Enforcement:

- Examine cost effective methods for enforcement, such as iVMS and self regulating options.

2.76 Management strategies that enhance the resilience of seagrasses should be developed and implemented to ensure the survival of these valuable habitats. While there is little that managers can do to control large-scale stressors at their sources, there are other actions they can take to help seagrasses survive catastrophic climate-related events. The following recommendations for management to promote resilience in seagrass were adapted from Bjork *et al.* (2008):

- Identify and fully protect or restore seagrass communities that are at low risk of succumbing to climate change from anthropogenic impacts because these seagrass communities will serve as refugia to help seed the recovery of damaged areas.
- Protect potential seagrass areas. Studies on the year to year dynamics of the seagrass populations highlight the need to protect potential areas and not only the present seagrass beds in order to promote resilience.
- Reduce the risk of any seagrass communities being lost as a consequence of climate change impacts by protecting the full range of seagrass communities (for example, across environmental gradients and spreading them out.
- Identify patterns of connectivity between seagrass beds and adjacent habitats, for example,, juvenile and adult habitat, to improve the design of marine protected area networks and allow for ecological linkages and shifts in species distribution.

3. Monitoring

3.1 The natural dynamics of seagrasses and environmental variability make it difficult to predict, with certainty, anthropogenic impacts. The spatial heterogeneity and dynamics of seagrass landscapes are driven by internal regulatory mechanisms, external demographic events (for example, disease or die back) and environmental factors (Frederiksen *et al.* 2004a). Sudden changes in seagrass cover as a result of events such as storms are set against longer-term changes due to climatic variation, which may be both negative and positive in terms of the overall distribution of the seagrass. The resilience of a seagrass bed (both in terms of the plant and the functions of the meadow) to anthropogenic pressures can be related to its environmental setting. For example, seagrass beds in relatively high wave exposure or currents, once damaged, may not recover to the same extent or as quickly as more sheltered beds. Location is also important in the delivery of many different ecosystem services. Deeper beds, or those in more current swept conditions, may not have the same carbon burial rates as those in shallow sheltered location where the primary production is greater and erosion levels lower. Similarly the value in terms of fish habitat can vary with location, exposure to wind and currents, depth and configuration of the meadow (Jackson *et al.* 2001b, Boström *et al.* 2006c). To manage seagrass beds it is important to understand the variability of the environment in which they occur and the population dynamics of both the seagrass and the species associated with them.

3.2 Monitoring seagrass habitats and understanding the causes of changes observed is an important component of adaptive management, and this section seeks to provide specific monitoring advice on necessary approaches required to identify anthropogenic impacts on seagrass beds. This advice builds on existing monitoring, guidance and reporting mechanisms currently used for a variety of statutory monitoring requirements.

3.3 The first step in any monitoring program should be to understand the ecology of the habitat (see Section 1) and the specific environmental conditions and human pressures at the site being monitored. The latter will involve collating as much information for the site as possible (see an example of this for Studland Bay in Dorset in MAIA Part 2).

3.4 Trends in seagrass health and the extent of beds can act as alarm indicators of trends in the environment, since health of seagrass meadows is closely linked to the health of the wider marine environment (Borum *et al.* 2004). In the past, seagrass monitoring focused on the state of the seagrass and did not consecutively monitor potential pressures or ecosystem services (benefits, see Figure 9). This approach makes it difficult to ascertain the causal pathway or repercussions of such changes (i.e. provision of ecosystem services and benefits to society). More recently efforts have been made to identify pressures. Indicators of ecosystem services (see Section 1) are still in development but will be essential for an ecosystem based approach to managing seagrass habitats. The following section describes common seagrass monitoring parameters, methods used for collecting the data and a short discussion on monitoring requirements.

Legislative monitoring requirements

3.5 Under many of the measures described below seagrass is protected as a habitat not a species or an assemblage of species. This leads to the question *what constitutes a seagrass bed under these regulations*? It has been argued that to qualify as a *Zostera* ‘bed’, plant densities should provide at least 5% cover (Tullrot 2009), but there is no minimum patch size.

Under the Water Framework Directive, extent is only measured where seagrass cover is greater than 5% (WFD-UKTAG 2009)[18]. In the Ecological Network Guidance produced by Natural England and the Joint Nature Conservation Committee (JNCC) for the identification of MCZ sites, the guidance suggests that an adequate minimum size for a seagrass bed should be 500m in diameter. These thresholds are not based on ecologically thresholds relating to functioning of the meadows, but to the practicalities of monitoring or average levels.

Habitats Directive

3.6 The principle source of information used by Natural England to assess the interest features of European Marine Sites, including component habitats such as seagrass, under the Habitats Directive is given in favorable condition tables provided in the Regulation 35 (formerly Regulation 33) advice for each site (see example for Plymouth Sound in Table 5). Attributes are monitored according to Common Standards Monitoring Guidance (JNCC 2004). Attributes common to all sites are extent, spatial configuration/ patchiness and density.

Table 5 Attributes of the eelgrass bed communities' sub-feature in the Plymouth Sound and Estuaries EMS Regulation 33 (now 35) advice package

Attribute	Measure
Extent	Extent in ha during peak growth season measured twice during the 6 yearly reporting cycle.
Water clarity	Average light attenuation measured periodically throughout the reporting cycle (frequency to be determined).
Characteristic species – density of *Zostera marina**	Average density, during peak growth season measured twice during the 6 yearly reporting cycle.
Patchiness/Spatial configuration*	Analysis of spatial configuration of beds [possibly using statistics package (for example, FragStats)], measured during peak growth season twice in the 6 yearly reporting cycle
Characteristic species – epiphytic community	Presence and abundance of epiphytic community measured once during the 6 yearly reporting cycle during peak growth season.
Wasting disease (*Labyrinthula* sp. / leaf infection scores).	Presence and abundance of *Labyrinthula* sp measured once during the 6 yearly reporting cycle during peak growth season
Litter or man-made debris	Quantitative measure of presence and type of litter or man-made debris. Measured once within the 6 year reporting cycle.
Number of moorings or anchors covering extent of *Zostera* bed	Measured once within the 6 year reporting cycle.

3.7 Table 5 illustrates that for Plymouth Sound, pressure monitoring is also advised in terms of water clarity, anchoring and mooring density and man-made litter. Epiphytic community measures are also proposed as an indicator of nutrient stress.

OSPAR

3.8 OSPAR-proposed monitoring for seagrass beds (Tullrot 2009) includes high-level monitoring of seagrass distribution using remote sensing data and fine-scale diver assessments of depth limits, degree of cover, biomass or shoot density along depth gradients and health. In addition, OSPAR recommends that the upper and lower depth limits of seagrass beds should be monitored to give a robust indication of overall status. Similarly to the CSM OSPAR recommend that monitoring should be carried out at the peak time of vegetation growth, and also advise on the advantages of including variables relating to habitat quality (for example, occurrence of epiphytes, macroalgal blooms and associated fauna) (Tullrot

[18] Neither the WFD-UKTAG (2009) or Tullrot (2009) provide details on what field of view/quadrat size the 5% refers to

2009). Monitoring associated fauna may provide important information in relation to the functioning and ecosystem service delivery of the habitat.

Water Framework Directive

3.9 Marine angiosperms (i.e. seagrasses) are a biological quality element required for assessment of Good Ecological Status under the Water Framework Directive (WFD)(2000/60/EC). The Netherlands, Ireland and the UK have agreed a common matrix for allocating intertidal seagrass a status using taxonomic composition, the presence of disturbance-sensitive species and abundance (Foden and Brazier 2007).

3.10 Under this Directive reference conditions for angiosperms (including seagrasses) are, in transitional waters, where 'the angiosperm taxonomic composition corresponds totally or nearly totally with undisturbed conditions and there are no detectable changes in angiosperm abundance due to anthropogenic activities'. For coastal waters reference conditions are where 'all disturbance-sensitive angiosperm taxa associated with undisturbed conditions are present' and 'the levels of angiosperm abundance are consistent with undisturbed conditions' (WFD, 2000/60/EC, Annex V) (Foden and Brazier 2006).

3.11 In the UK quantitative measurements of these attributes were used to develop a set of metrics for monitoring (Foden and Brazier 2007), these are: the presence of disturbance sensitive taxa (Taxonomic composition of seagrass species), shoot density and bed extent (as measures of abundance). Taxonomic composition also refers to a comparison between historically recorded species of seagrass and current species of seagrass, although it is unclear how this metric handles the fact that *Zostera angustifolia* is now recognised as a variety of *Z. marina*[19].

Marine Strategy Framework Directive

3.12 Under the Marine Strategy Framework Directive (2008/56/EC) EU Member States are obliged to assess good environmental status of their seas under a set of 11 descriptors, of which seagrass relates to Descriptor 1 Biological Diversity and Descriptor 6 Seafloor Integrity. Art. 10 of the Marine Strategy Framework Directive stipulates that member states have to set out a comprehensive set of environmental targets which "take into account the continuing application of relevant existing environmental targets laid down at national, community or international level in respect of the same waters…". This suggests that at least for those indicators/ quality elements that are common with WFD classification (like seagrass), the MSFD targets should be compatible with the 'good ecological status' set as a part of the WFD implementation.

3.13 As the practical mechanism for implementing the *Ecosystem Approach* to Europe's seas, within the MSFD, healthy marine ecosystems will be a condition to realise the potential benefits resulting from the ecosystem services they provide. Indicators must be appropriately linked to ecosystem services and the drivers of change (both natural and anthropogenic, see Section 1). Without this managers will lack the necessary evidence-based feedback to learn from, and improve upon previous management approaches (adaptive management). Fit-for-purpose ecological and social indicators need to be able to track the levels of biodiversity or flows in terms of ecosystem services, detect change before it becomes irrevocable damage and identify the causes of change. It is relevant to consider that:

- Loss of seagrass can occur at different spatial scales;

[19] The full scope of the UK monitoring programme is available on the Environment Agency website. http://www.wfduk.org/tagged/angiosperms

- Loss can occur without root removal – so root functions are retained but above ground plant functions is lost;
- Replacement by invasive algae may allow some habitat function to persist; and
- Degradation without loss may reduce function without structural change.

3.14 For each ecosystem service, an understanding of the influence of different pressures on state change and a sound knowledge of how these state changes influence the provision of different services is a basic need for an ecosystem based approach to management. To illustrate this, Table 6 provides an example of common state changes to seagrass resulting from the pressures discussed in Section 1, and illustrates the likely consequences in terms of the ecosystem service of carbon sequestration.

Table 6 Common seagrass state change, likely consequences in terms of carbon sequestration and state indicators which capture these changes

State change (negative changes shown but positive change possible)	Influence on C-sequestration (↑ rate increases significantly, ↗ slight increases in rate, → rate maintained, ↘ slight reduction in rate, ↓ significant reduction in rate; 🔓 carbon source, 🔒 carbon remains locked up)	
Loss of area of seagrass, rhizomes left intact	↘ 🔓	Primary production severely reduced. Carbon sequestration halted. Erosion of rhizomes increased as seagrass leaves no longer attenuate currents. Area becomes a source of carbon (rate depends on the rate of breakdown of the rhizomes)
Loss of area of seagrass, rhizomes eroded/ perturbed habitat shift to soft sediment.	↓ 🔓	Primary production severely reduced. Carbon sequestration halted, although some carbon may still be locked up in sediments the area will become a source of carbon (rate depends on the rate of breakdown of the rhizomes)
Replacement of seagrass with macroalgae (including invasive species)	↓ 🔓	Rates of primary production reduced or maintained (dependent on algal productivity). However, loss of the root rhizome rhizomes will result in sever reduction in carbon sequestration
Change in depth limit	↘ 🔒	Rates of primary production reduced or maintained (dependent on cause of change in depth limit). The area of seagrass lost will release carbon however remaining bed will still lock up carbon if limit is progressive or stable, but not if regressive, so an indication of limit type important.
Fragmentation	↘ 🔓	Rates of primary production reduced or maintained (depending on overall loss in extent of seagrass). The area of seagrass lost will release carbon. Remaining bed will still lock up carbon, but erosion may be increased (depending on wave energy on configuration of fragmentation), so may become a source of carbon.
Increased epiphytal load	↗ 🔒	Rates of overall primary production will increase to a threshold where epiphyte growth compromises seagrass health and productivity. Enhanced wave baffling due to filamentous epiphytes may increase sedimentation and reduce erosion. Carbon sequestration increases unless combined with loss/degradation in seagrass.
Decrease in density	↘ 🔒	Rates of primary production reduced. Wave baffling and erosion increased, however remaining bed will still lock up carbon (unless seagrass growing in a high energy environment)

(Source Jackson & Beaumont, 2012)

Monitoring condition

3.15 In addition to monitoring the seagrass attributes, understanding the ecology of the habitat (Section 1) and the specific environmental conditions and human pressures at the site being monitored should be a priority. Monitoring or collating data on environmental conditions (for example relative wave exposure, storm events, temperature and rainfall) will help to distinguish natural versus anthropogenic causes of state change (Borum *et al.* 2004). Understanding the environment for the seagrass bed to be monitored (see Section 1) and collation of all previous data should be a first step in any monitoring program. This approach will allow for a full site character assessment, followed by analysis of the sensitivity and therefore vulnerability of different parts of the seagrass bed allowing a more targeted management approach. This approach was trialled in Studland Bay in Dorset, and the steps in the process are discussed fully in this report (See Part 2). In this trial, data is collected from previous studies and combined with new analyses of wave exposure and aerial imagery (full coverage maps of the seagrass, wave exposure models and configuration maps) to create seagrass character maps and grid maps of pressures and sensitivity, which are then used to create seagrass vulnerability maps of the area.

Extent and landscape configuration

3.16 Extent provides information on the overall size of the seagrass bed, but also the limits of the seagrass bed, therefore picking up changes in, for example, the lower depth (which may change due to water clarity or human disturbance for example, dedging). The area extent of any habitat, including seagrass, is a commonly reported parameter which is understandable to scientists, managers and other stakeholders. Extent can also be used for calculating rough estimates of the value of the seagrass in an area (where this can be linked to an ecosystem service, for example, known density of juveniles or carbon sequestration rates per m^2 of seagrass).

3.17 Seagrass configuration relates to the spatial patterning or juxtaposition of different landscape elements, and measures of habitat fragmentation (irrespective of habitat extent) (McGarigal and McComb 1995). Measure of configuration such as habitat connectivity, fragmentation, amount of edge and core areas, and habitat diversity all have important influence on various ecological processes. For example, core area is the area of each patch deemed to be unaffected by the edges of the patch, where predation success and environmental disturbance may be greater (see Section1). Changes in configuration can be due to natural environmental conditions but also a result of human disturbance (see Section 1). Software for analyzing spatial configuration is available, for example Fragstats (McGarigal *et al.* 2002), which can provide measures of the various configuration properties of a seagrass meadow (landscape metrics, for example, amount of core area, core area to edge ratio, connectivity etc.) .

3.18 The most appropriate techniques for measuring each of the seagrass metrics differs (see summary in Table 7). Measuring extent and configuration of seagrass requires full coverage data such as aerial RGB or multispectral imagery (or, arguably, side scan sonar) (Borum *et al.* 2004). Optical images, whether satellite digital or aerial photographs, have the advantage of being direct observations and give continuous detailed coverage. However, use is limited by certain environmental conditions, in particular depth for example turbidity. Most authors agree that the images should be taken at low tide with a sun angle of greater than 35 degrees, without wind or clouds obscuring the view, at the peak of the seagrass growing season and after a period of low wind and rainfall (Orth & Moore, 1983; Green *et al.*, 2000). Procurement of aerial photographs often takes into account, and avoids, significant cloud cover or sun glare, however because seabed habitat mapping is often not the primary reason for the acquisition, many photographs are not taken at low tide or with a consideration of factors which may have resulted in a temporary increase in turbidity.

3.19 The cost of aerial photography is still high, but the amount of information which can be gained if taken under the right conditions (see Part 2) is much greater than from methods with a narrow field of view. The recent increase in commercial high resolution satellite imagery (for example, GeoEye) may bring costs down in the future. The biggest problems when analysing aerial images is the differentiation between green algae and seagrass, and differentiation of any habitat at depth. For perennial beds, the first problem can be addressed by carrying out photography in the summer and the winter (when algal blooms are not present) and comparing the result. Problems of classifying habitats in deeper water can be alleviated using water correction techniques (Green *et al.* 2005), whereby the spectral data for a bare substrate (for example, sand) at known depths are used to create an algorithm which can be used to “remove” the water coloumn from the image, greatly improving classification accuracy.

3.20 An alternative method is using digital echosounders. Envision Ltd also utilised video towing approaches (concurrently) to act as an appropriate comparison with which to assess echo-sounder technology (Envision 2010, Egerton & Southeran 2011). Acoustic surveys of the seabed offer particular benefits where environmental conditions, such as water depth or clarity, limit the use of optical techniques, or logistical considerations rule out physical surveys (Lee Long *et al.*, 1998; Munro & Nunny, 1998). (See MAIA Part 1, for full discussion of its use).

3.21 Seagrass blades contain air filled lacunae to aid flotation and these create back scatter in the echo signal that is greater than the background water noise (at round 200kHz), a property which has been used frequently to acoustically map these habitats (Sabol 1997, Jackson 2003a, b, Envision 2010, Egerton and Southeran 2011), (see Figure 15 Screen capture from a digital echosounder display illustrating visibility of seabed covered by seagrass). This capability has the potential to provide greater detail regarding the architectural structures of the seagrass (for example leaf height, density, standing crop). Bare patches, for example scars can also be ground truthed using this method. Acoustic surveys of the seabed offer particular benefits where environmental conditions, such as water depth or clarity, limit the use of optical techniques, or logistical considerations rule out physical surveys (Lee Long *et al.,* 1998; Munro & Nunny, 1998). Disadvantages are that digital echosounders are not able to identify sparse seagrass and some studies have shown acoustic methods to overestimate the coverage of seagrass (see Part 2). Also unless the resolution of transect data (for example, digital echo-sounderor towed video) is high enough (for example, transects <1m apart), which is not cost effective, assessments of spatial configuration and patchiness are not possible, especially if utilising software such as Fragstats as this requires continuous data. Video survey is an appropriate method for ground truthing aerial imagery or to measure extent.

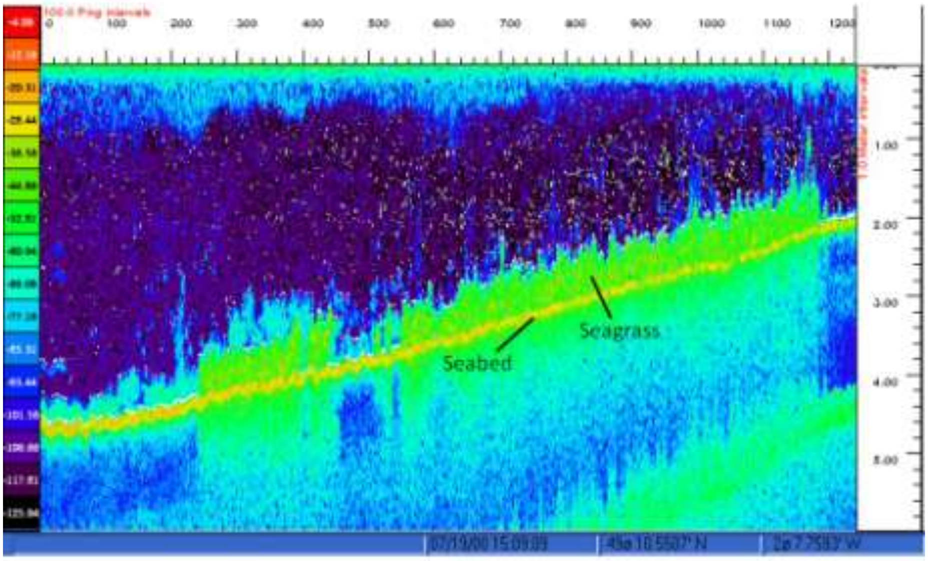

Figure 15 Screen capture from a digital echosounder display illustrating visibility of seabed covered by seagrass

3.22 Side-scan-sonar (SSS) also emits a beam of acoustical waves but can differentially analyse the returning waves reflected by underwater structures and produce two-dimensional images, called sonographs. This method has been use widely to map seagrass beds (Siljeström *et al.* 1996, Kendrick *et al.* 2000, Montefalcone *et al.* 2011). However, the precision and accuracy of SSS depends on a number of factors. In particular, the horizontal extent of the image is a direct result of the frequency of the acoustic signal and the angle of the signal to the bed (determined by the height of the transducer above the sea floor) (Kenny *et al.* 2003). In shallow habitats such as seagrass this means that transects must be run close together if the images are to overlap and give full coverage, which will significantly increase acquisition and processing costs. For more localised studies, for example, the measurement of mooring scars (see Part 2) SSS offers a quick method for monitoring change, and like other acoustic methods it has advantages in turbid and deep waters where visual methods are restricted.

3.23 Measuring spatial configuration objectively is an important aspect of assessing the fragmentation of seagrass. Spatial statistics software do exist, for example FRAGSTATS version 3.4 (McGarigal *et al.* 2002). This software is integrated with GIS and measures numerous metrics at the landscape (i.e. the whole seagrass bed location, across habitat types), class (habitat specific, for example, for seagrass) and patch scales (an individual separated patch of seagrass). Although Fragstats cannot be used to analyse configuration using transect data, there are alternative methods. Drop down video could be used, and the fractal dimension of each video transect used as an indicator of seagrass heterogeneity (see Jackson *et al.* 2006). This involves measuring the area of seagrass along the whole transect at a number of different resolutions. The slope of the line obtained by regressing log(seagrass area) on log(resolution) gives the fractal dimension (Burrough 1986). Using this method, a dimension of zero implies homogeneity (the seagrass in the transect area is all one patch of seagrass) and an increase in the value towards one reflects an increase in heterogeneity (increase in the number of patches covered by the video transect). Using fixed position transects this information can be used to monitor the fragmentation or accretion of the bed. Towed video data is also an appropriate method for providing information on the distribution of the seagrass meadow at the site, for example depth limits (upper and lower) and spread.

3.24 There are other natural factors which control the growth, spread and configuration of seagrasses (for example, depth, sediment type, topography) and remote video techniques can be used to collate this information and provide a context map to assess natural coverage of the seagrass against anthropogenic disturbances. Seagrasses are very dynamic habitats and without this contextual information monitoring data on “extent” cannot be interpreted. Both acoustic and towed video methods are unsuitable for mapping very shallow seagrass due to restricted boat access.

Water quality

3.25 Nutrient concentrations and light attenuation in the water column are key water quality parameters which affect seagrass growth and should be measured in seagrass monitoring programmes. However they can show large annual and seasonal variation and therefore require regular monitoring were possible. Although light attenuation has traditionally been measured using a Secchi disc, the use of light meters (for example, Hobo®LI light loggers) allows greater temporal and spatial coverage for less cost. Nutrient concentrations are often low and difficult to detect in summer so it may be a better choice to measure inorganic nutrient concentrations in winter and/or total nutrient concentrations in summer. Light for photosynthesis is a main requirement of seagrasses and therefore both water column transmissivity and depth will control the lower depth limit of seagrass. Thus the lower depth limit is a useful bioindicator of water clarity and system health. The upper depth limit is controlled by exposure to waves and air, but is also a result of anthropogenic activities (trampling, landing boats) and grazing by geese.

3.26 Other water quality parameters such as pollutants may be more difficult to monitor (due to the large numbers of different pollutants which may exist). However at specific sites where it is suspected that pollution may be having an adverse effect on the seagrass responsive regular sampling of the water and seagrass tissues may be needed (for example where high densities of boats occur near to seagrass it may be worth monitoring biocide concentrations which may leach from anti-fouled hulls (see methods in Chesworth *et al.* 2004).

3.27 Due to large temporal variability in water quality parameters, they must be measured frequently. It is not sufficient to measure them once a year along with an annual seagrass sampling. In a routine monitoring programme, water quality could be measured at a few sites placed in areas representative of the the general water quality of the area. In a more detailed monitoring programme aiming at identifying spatial gradients in water quality and seagrass indicators within a given bay, more sampling sites are obviously needed.

Climatic variables

3.28 Several climatic variables may also affect seagrass growth and may therefore provide useful information in the interpretation of monitoring results. The most relevant climatic variables to include are water temperature, rainfall or freshwater run-off and wave exposure (REI). Where the seagrass bed occurs close to a Met office station all of the relevant data needed can usually be acquired, although caution should be made for wind data if the bay/ estuary being assessed has a different wind regime (e.g funnelling of winds) from the station. To estimate the amount of wind exposure experienced by different parts of a seagrass bed being monitored (which can not only identify areas where recovery may be impeded, but also natural limits to the seagrass extent), a relative wave exposure can be calculated (see Part 2). This should be done across the maximum number of years for which wind data is available for the site but also for the three years preceding sampling, to ascertain whether any wave exposure anomalies (for example prolonged storm events).

3.29 Although higher temperatures are thought to induce flowering and there are optimal temperatures for flowering in seagrass, this has not been examined for UK populations. Seed production occurs in most if not all seagrass beds around the UK (pers. observations) even where temperatures are below 15°C, however seedling development and survival is considered to be much rarer and may be linked to temperature. Acclimation to changes in seasonal temperature is an important mechanism allowing seagrass to grow faster and penetrate to deeper water, so seawater temperature is a useful variable to measure as part of a seagrass monitoring program.

3.30 Water temperature requires regular measurements due to the high seasonal variation. Cefas collect data on sea-surface temperature (and sometimes salinity) at a few coastal sites around England and Wales[20]. Where the site is not close to one of these stations, or is but has very different hydrodynamics, alternative methods are needed. Satellite data (for example, Advanced Along-Track Scanning Radiometer (AATSR)) is unlikely to provide an appropriate resolution of data (temporally or spatially) but a number of loggers are now

[20] http://www.cefas.defra.gov.uk/our-science/observing-and-modelling/monitoring-programmes/sea-temperature-and-salinity-trends/station-positions-and-data-index.aspx

available that may provide a cost effective option and give data directly relevant to the site being monitored.

In the UK, a vast amount of environmental data is available from ongoing monitoring work (for example, Environment Agency and Cefas online databases) and research and there are an increasing number of environmental data repositories which can be queried by location or environemental variable[21].

Wasting disease

3.31 Recent advances in high definition video technology make the measurement of other variables such as the wasting disease and epiphytic community composition a possibility. Currently in situ diver measurement and photography of these attributes is required, which is time consuming and expensive.

3.32 The quantity of wasting disease lesions has been used as an indicator (Figure) of the stress induced in a seagrass bed by environmental conditions (Burdick *et al.* 1993). Adverse conditions such as increased turbidity, low levels of insolation (light reaching a surface) and raised temperatures during the growing season cause weakening of the plants and make them susceptible to pathogens and secondary decomposers. Levels of wasting disease infection in a *Zostera* population are indicative of the suitability of the local environmental conditions for health and growth (Burdick *et al*. 1993).

Amount of infection	**Infection**	**Diagrammatic representation of Wasting Index**
Uninfected	0%	
Minimal infection	1%	
Some infection apparent	10%	
As much as half the leaf infected	20%	
Over half the leaf infected	40%	
Almost all the leaf infected	80%	

Figure 16 Wasting Index (WI) (Burdick *et al*., 1993)

Epiphytic community composition

3.33 Epiphyte communities play an important role in the functioning of seagrass ecosystems (see Section 1). Floral epiphytes contribute to primary productivity and are the major source of food for grazers and detritivores (Larkum *et al.* 2006). Epiphytes have been shown to be effected by deterioration of water quality and increased amounts of dissolved nutrients, in terms of shifts in species composition (Frankovich and Fourqurean 1997). One of the main advantages of looking at the epiphytic community on seagrass is that they tend to be more sensitive and react more rapidly than the host plant (seagrass) to changes in the environment allowing prompt management reactions and avoid impacts at the scale of the meadow which may not be recoverable (Giovannetti *et al.* 2010).

Genetic diversity and age structure

3.34 Genotypic diversity (an important component of biodiversity) of *Zostera marina* can vary significantly by location (Reusch *et al.* 2005) and may provide critical response diversity for maintaining seagrass ecosystem functioning and for adaptation to environmental change. Previous studies have shown a correlation between genetic diversity and resilience to extrinsic factors such as disturbance (Hughes & Stachowicz 2004a, Reusch *et al.* 2005,

[21] http://www.dassh.ac.uk/links.html

Hughes & Stachowicz 2011). Resilience of seagrass meadows to disturbance is also dependent on dispersal and gene flow. More research is required to assess genotypic diversity within and between seagrass populations in the UK. Currently costs make genetic methods beyond the scope of regular monitoing.

3.35 Seagrass are rhizomatous plants that grow by reiteration of a limited set of modules, so their past growth history can be reconstructed from the scars left by abscised leaves on the long-lived rhizomes (Duarte *et al.* 1994). Sampling different parts of the existing meadow to assess the age structure of the seagrass and can be used to allow predictions of extinction risk to be made using stochastic population dynamics.

3.36 In the 1980s methods were developed for using snapshots of spatial extent to estimate resilience in the face of environmental perturbations (Sugihara & May 1990). This method is currently being developed in relation to seagrass populations by researchers at the University of Warwick (Bull pers. comm.), and may provide a more cost effective method for the future.

Spatial and temporal considerations

3.37 Common standards across all sites mean that larger scale patterns can be monitored and also that results can feed into national monitoring schemes and record cards. However, each site will have specific environmental conditions and pressures which will require more targeted or detailed monitoring. For example in a coastal or estuarine area subject to fluctuating levels of nutrient input, more regular seasonal monitoring of factors such as phytoplankton, water clarity and epiphyte community composition may be required alongside other monitoring.

3.38 The timing of monitoring is important. Due to the cost of monitoring there is often a trade-off between the available budget and the minimum requirements to make the monitoring useful. Under Common Standards Monitoring many seagrass attributes are measured against the six year reporting cycle (i.e. once every six years). Surveys are carried out at the height of the seagrass growing season to avoid temporal variation. Whilst a potentially appropriate time scale for attributes such as extent, greater variation in factors such as density may mean that sampling every six years will mean that significant changes will not be detected for some time after they have occurred and hence changes cannot be attributed to a specific cause. In such circumstances there is no point in collecting some of the data, particularly non-biological variables. Annual monitoring of seagrass density, epiphyte cover and wasting disease would be more appropriate and provide an early warning of potential problems, however the costs associated with this may be too high.

3.39 One option may be to seek support from volunteer monitoring schemes (for example, SeagrassNet sites), and guide work to complement and inform the statutory monitoring programme. SeagrassNet (www.seagrasnet.org) started in 2001 in the Western Pacific but now includes 126 sites in 33 countries with a global monitoring protocol and web-based data reporting system. With the slogan “Local eyes, global wise”, the SeagrassWatch programme investigates and documents the status of seagrass resources and the threats to this important and imperilled marine ecosystem. The overarching aims of both are to preserve valuable seagrass ecosystems by increasing scientific knowledge and public awareness.

Table 7 A summary of suggested methods for measuring seagrass attributes and environmental parameters

Attribute	Methods	Potential existing sources of information in the UK
Seagrass variables		
Extent	Aerial photography or CASI, backed up with ground truthing using drop camera, video survey or SCUBA. Image analysis to create a broad class thematic image. Particular attention should be directed at upper and lower depth limits Alternative: depth limit could be assessed using a digital echo-sounder system.	Environment Agency Coastal Monitoring Programme.
Patchiness/ Spatial configuration	Landscape metrics determined from set areas of the thematic images. (FRAGSTATS version 3) or, if using drop down video transect data, fractal dimension could be calculated. Side scan sonar can be a useful rapid assessment tool for determining the extent of patches in the seagrass meadow, but less effective in very shallow water.	Environmental Impact Assessments
Density and leaf length	Diver sampling using a quadrat to count shoot density and measure the longest leaf of 3 shoots. Alternative: canopy height could be assessed using a digital echo-sounder system. Ground truthing with divers. If using towed video then cover could be used as a proxy for density – but it is important that this is done at slack high tide when the leaves are not flattened by water currents.	SNCB Statutory Monitoring programmes, and volunteer diver survey groups Environment Agency, Water Framework Directive monitoring
Epiphyte community	SCUBA Diver sampling. Identification of functional groups in laboratory for area up to 10cm from leaf apex. A non destructive alternative would be to take in situ photographs for later analysis in the laboratory. HD video zoom could also be used to reduce cost (this requires further trials).	SNCB Statutory Monitoring programmes, and volunteer diver survey groups
Wasting disease (*Labyrinthula* sp, Leaf infection scores).	SCUBA diver sampling. Identification of functional groups in laboratory for area up to 10cm from leaf apex. A non destructive alternative would be to take *in situ* photographs for later analysis of leaf infection scores in the laboratory. HD video zoom could also be used to reduce cost (this requires further trials).	SNCB Statutory Monitoring programmes, and volunteer diver survey groups
Ephemeral algal community	Drop camera, towed video or in situ diver observations to estimate percentage cover. Sample collection is often necessary to carry out accurate identification, particularly for smaller less common species.	SNCB Statutory Monitoring programmes, and volunteer diver survey groups
Birds supported by habitat	Seasonal monitoring. Needs to be carried out at different states of the tide and times of day. As a minimal, monitoring at low spring tides during the day.	SNCB Statutory Monitoring RSPB Monitoring BTO
Mobile fauna	Seasonal monitoring. Needs to be carried out at different states of the tide and times of day. As a minimal, monitoring at low spring tides during the day.	Academic research, SeaSeach

Table continued…

Attribute	Methods	Potential existing sources of information in the UK
Environmental variables		
Relative wave exposure	RWE: based on fetch depth and monthly maximum wind speed directions. This will Identify those areas less likely to recover from losses but also measure wave exposure for previous three years leading up to monitoring of the sea grass. Comparing to RWE across a larger number of years will help to identify potential natural causes of change. This requires local wind data (for example, occurrence of a MET office station close to the location)	Environmental Impact Assessment, Defra FutureCoast Project SCOPAC Met Office
Surrounding sediment particle grain size analysis, and sediment dynamics	Diver core sampling. Granulometric analysis of cores (as a minimum the proportion of sands to fines).	Defra **FutureCoast Project** SCOPAC British Geological Survey Shoreline Management Plans
Turbidity	Regular sampling, especially during the growing season. Ideally the use of continuous light loggers (for example, Hobo®LI light loggers), alternatively monthly sampling using a secchi disc. Sampling should be repeated across the gradients of depth and wave exposure where the seagrass grows. Remote sampling methods (for example, satellite imagery) is an option for larger sites due to the resolution of the data.	Environment Agency WFD Monitoring (not all sites and not regularly) BADC
Temperature	Regular sampling, especially during the growing season. Ideally the use of continuous temperature loggers. Remote sampling methods (for example, satellite imagery) is an option for larger sites due to the resolution of the data.	WFD, Cefas, Harbour commissioners, BADC
Salinity	Monthly sampling repeated throughout the extent of the seagrass.	
Depth	Annual survey of bathymetry across the extent of the seagrass (including a buffer). Using echosounder transects parallel to the shore.	Environmental Impact Assessments MCA Bathymetric surveys Seazone
Human pressures		
Nutrient concentrations	Regular (minimum of monthly) water sampling in the vicinity of the seagrass bed for concentrations of nitrate and phosphate, as well as existing WFD work	Environment Agency Monitoring for WFD , MSFD, - what about Bathing Directive?
Anchoring/ mooring density	Aerial image analysis, regular onshore observations	MMO aerial surveys
Mobile fishing gear	In situ observations of the use of mobile gear or tracks in the seagrass.	Inshore VMS, IFCA observation data, MMO aerial surveys

4. Glossary

Abscised	A biological process where a plant sheds one of its parts (for example, leaves, shoots, flowers or seeds).
Acclimation	To adapt or become accustomed to a new climate or environment.
Accretion	Growth or increase in size by gradual external addition, fusion, or inclusion of other patches of seagrass.
Aerobic metabolism	The creation of energy through the combustion of carbohydrates and fats in the presence of oxygen, resulting in the by products carbon dioxide and water.
Anaerobic fermentative	The breakdown or composting of organic material without oxygen.
Anatomically	Concerned with anatomy (a branch of biology which considers the structure of living things).
Annual populations	Populations which only live for one year.
Attenuate	To weaken or reduce the force, intensity, effect, quantity, or value of an effect – in this context the ability to weaken water velocity caused by waves and currents.
Bed shear stress	An index of fluid force per unit area on the sea bed, which influences sediment mobilization and transport.
Binding	The joining of separate elements together.
Biomass	Weight of biological material.
Bioturbation	The disruption of marine sediment structure by the activities of benthic organisms.
Burial rates	The amount and speed at which material is buried under newly deposited material.
Carbohydrate metabolism	Descriptive term for the various biochemical processes responsible for the formation and breakdown of carbohydrates in living organisms.
Carbon sequestration	The capture and storage of carbon dioxide from the atmosphere or other inorganic carbon from the water column.
Centrifugal	Proceeding or acting in a direction away from a central point.
Cryosections	A procedure (often performed in histological analyses) whereby a specimen is frozen prior to thin sections being sectioned.
Crypsis	The ability of an organism to avoid observation or detection by other organisms either through camouflage, lifestyle, transparency or mimicry.
Deposition	Process by which material is added to a formation, for example, the seabed.
Desiccation	The process of drying out of a living organism.
Detritivores	Species that feed primarily on detritus (see below).
Detritus	Non-living particulate organic material (for example, the bodies or fragments of dead organisms as well as faecal material.
Diffusion boundary layers	A thin layer of liquid in contact with a surface across which gases diffuse and is subjected to shear forces.
Dispersal	The movement of a species away from an existing population or away

	from the parent organism.
Dissolution	The processes of dissolving a solid substance into a solvent to make a solution.
Diurnal	*A* pattern that recurs daily or the behaviour of animals and plants that are active in the daytime.
Duplex retina	A retina which has both cone and rod photoreceptor cells.
Endemic	The ecological state of being unique to a defined geographic location.
Endogenic	A pressure coming from within a system.
Entrainment	The movement (pulling or pushing) of one fluid by another.
Epiphyte	Plant or animal living attached to a plant.
Erosion	The process by which sediment is removed from the seabed by by water flow, and then transported and deposited in other locations.
Euryhaline	The ability to tolerate a wide range of salinities.
Eutrophication	The process by which a body of water acquires a high concentration of nutrients, especially phosphates and nitrates.
Exogenic	A pressure coming from outside a system.
Extrinsic	Something originating or acting from outside a system.
Fecundity	The potential reproductive capacity of an individual or population.
Fovea	Central part of the retina where cone photoreceptors are more concentrated and is responsible for the highest visual acuity (sharpest vision).
Fractal dimension	A ratio providing a statistical index of complexity comparing how detail in a pattern changes with the scale at which it is measured.
Fragmentation	The emergence of discontinuities in a habitat patch. Components include a reduction in the total area of the habitat; a decrease of the interior : edge ratio; the isolation of one habitat fragment from other areas of habitat and the decrease in the size of each patch of habitat.
Gene flow	The transfer of alleles or genes from one population to another.
Geodatabase	A database designed to store, query, and manipulate geographic information and spatial data.
Gonad somatic index	A measure of reproductive health calculated as the ratio of the gonad weight versus total body weight.
Granulometric	The measurement of grain sizes in sediment.
Herbivores	Organisms that are anatomically and physiologically adapted to eat plant-based foods.
Histological	The study of the microscopic anatomy of cells and tissues of plants and animals.
Hydrodynamics	The study of liquids in motion.
Hydrophilous pollination	Form of *pollination* whereby pollen is distributed by water flow.
Inorganic carbon	Carbon not of biological origin.
Insolation	A measure of solar radiation energy for a given area and duration.
Irradiance	The power of electromagnetic radiation per unit area.
Lacunae	An air space in the cellular tissue of *plants.*

Landscape configuration	The juxtaposition of different landscape elements (i.e. habitat types) and measures of habitat fragmentation.
Leaf area index	The one sided green leaf area per unit ground are, used as a proxy measure for primary production.
Lesions	Any abnormality in (damage to) the tissue of an organism.
Littoral	Zone of the shore extending from the high water mark to the permanently submerged.
Longevity	Length or duration of individual life.
Macrofauna	Benthic organisms which are retained on a 0.5mm sieve.
Mechanical disturbance	A negative disruption resulting from human operated machine or tool.
Meristems	Undifferentiated tissue at the tip of a stem or root where new cells are formed.
Mesocosms	A smaller (man-made) system which is representative of or analogous to a larger (natural) one.
Micro-spectrophotometry	The technique of measuring the light absorbed, reflected, or emitted by a microscopic specimen at different wavelengths.
Microtidal	Maximum tidal range of <2m.
Monomorphic	Something that has only one form, in this context roots that only have a horizontal growth form.
Mounding	Sediment which has stacked up into an elevated pile.
Ocular	Of or relating to the eye.
Oligotrophic	A water column that is poor in nutrients and plant life and rich in oxygen.
Ontogenetic	The origin and development of an individual organism from embryo to adult.
Optic nerve	Nerve which transmits visual information from the retina to the brain.
Pathogens/ Pathogenic	Any disease-producing agent, in particular this term is used to describe infectious virus, bacterium, or other microorganisms.
Perennial	A perennial plant or simply perennial is a plant that lives for more than two years.
Perturbations	A negative change in a physical system.
Phenotypic plasticity	The ability of an organism to change its phenotype (physical or biochemical characteristics of an organism) in response to changes in the environment.
Photon flux density (PFD)	The photometric light intensity illuminating a surface. It is the photons per unit area per unit time typically in candelas or lumens.
Photoreceptor	A cell or nerve ending specialised in sensing or receiving light.
Phylogeny	The evolutionary development and history of a species or higher taxonomic grouping of organisms.
Pore water advection	The transfer of matter by the flow of a fluid through the interstitial spaces in between grains of sediment.
Predation	A biological interaction where a *predator* (an organism that is hunting) feeds on its prey (the organism that is attacked).
Pseudo faeces	Mucus wrapped inedible particles rejected by filter-feeding molluscs prior to digestion (and therefore not true faeces).

Pulsed	A series of intermittent occurrences characterised by a brief sudden change in a quantity.
Regression	A directional reduction in area.
Relative exposure index (REI)	An index developed by NOAA (National Oceanographic and Atmospheric Association) showing the relative amount of wave energy a site is exposed to.
Resorption	The act or the process of resorbing – assimilation of a substance.
Retina	Is the light-sensitive layer of tissue at the back of the inner eye, where the photoreceptor cells are located.
Retinaculae	An often hooked or sticky appendage used to hold parts (for example, seeds) together or in place.
Retinal pigment epithelium	The pigmented cell layer just outside the retina that shields and nourishes the retinal visual cells.
Retinomotor	Motility of photoreceptor cells usually in response to diurnal changes in lighting conditions.
Rhizomatous	Producing, possessing or resembling rhizomes.
Rhizome	Horizontal, usually underground stem that often sends out roots and shoots from its nodes.
Rhizome elongation rates	Speed at which rhizomes extend in length.
Rhodopsin	The pigment sensitive to red light in the retinal rods of the eyes.
Rode	A cable, chain, or rope linking an anchor weight to a boat.
SCOPAC	Standing Conference on Problems Associated with the Coastline’.
Secondary decomposers	Organisms which feed off partially-decomposed substrates.
Sediment resuspension	Sediment that has previously settled to the seabed is redistributed through the water column.
Shoot density	The number of shoots (section of the plant which protrudes from the sediment, which splits into separate leaves) per specified area (usually per m^2).
Skewness	The degree of asymmetry of the distribution of, in this context, sediment grain sizes.
Spadix	A fleshy spike of tiny flowers, usually enclosed within a spathe.
Spathe	Leaf like bract that encloses a flower cluster or spadix.
Stochastic population dynamics	Random events which influence population parameters.
Striations	Series of ridges, furrows or linear marks.
Substratum	A base or a solid surface which living things attach to while they grow.
Surface irradiance	The density of solar radiation incident on a surface usually expressed in watts per square centimetre or square metre.
Sympatric speciation	The process through which new species evolve from a single ancestral species while inhabiting the same geographic region.
Temporal variability	Changes which occur over time.
Toxic metabolites	Potentially harmful substances formed as the result of normal biological functions (metabolism).

Transmissivity	The rate of loss at which the emitted radiation of an object is received by a camera lens or eye.
Tungsten	A setting for colour temperature on digital cameras.
Turbidity	The cloudiness of seawater caused by individual particles (suspended solids) that may be invisible to the naked eye.
Vegetative spreading	Process by which a plant can grow/ extend its areal coverage by elongating roots or rhizomes.
Visual acuity	Acuteness or clearness of vision.
Wave mixing depth	The maximum depth to which the water column is mix by a wave.

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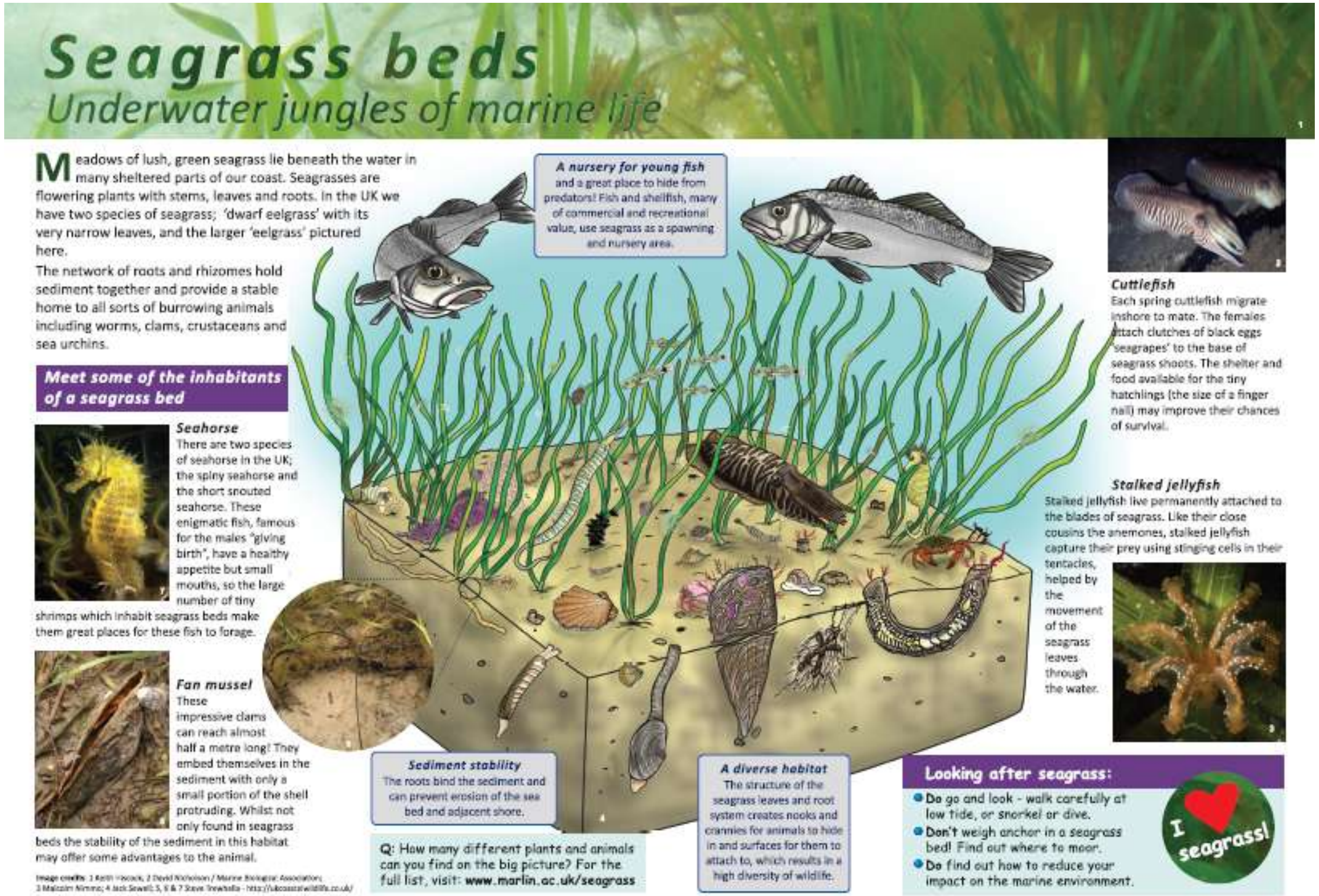
Appendix 1 Marine Life Information Network sensitivity matrix for *Zostera marina*

For full details of each factor and underlying references see the MarLIN website http://www.marlin.ac.uk/speciessensitivity.php?speciesID=4600 (Tyler-Walters 2008)

Table A Marine Life Information Network sensitivity matrix for *Zostera marina*

	Intolerance	Recoverability	Sensitivity	Evidence / Confidence
Physical Factors				
Substratum Loss	High		Very High	Moderate
Smothering	High		Very High	Moderate
Increase in suspended sediment	Intermediate	Moderate	Moderate	Moderate
Desiccation	Intermediate	High	Low	Moderate
Increase in emergence regime	Intermediate	High	Low	Low
Increase in water flow rate	Intermediate	Moderate	Moderate	Low
Increase in temperature	Tolerant	Not relevant	Not sensitive	Moderate
Increase in turbidity	High		Very High	Very low
Increase in wave exposure	High		Very High	Low
Noise	Tolerant	Not relevant	Not sensitive	Very low
Visual Presence	Tolerant	Not relevant	Not sensitive	Very low
Abrasion & physical disturbance	Intermediate	Moderate	Moderate	Moderate
Displacement	High	Low	High	Low
Chemical Factors				
Synthetic compound contamination	Intermediate	Moderate	Moderate	High
Heavy metal contamination	Low	Very high	Very low	Moderate
Hydrocarbon contamination	Low	Very high	Very low	Moderate
Radionuclide contamination	Insufficient information	Insufficient information	Insufficient information	Not relevant
Changes in nutrient levels	High		Very High	Moderate
Increase in salinity	Low	Very high	Very low	Low
Changes in oxygenation	Low	Very high	Very low	Very low
Biological Factors				
Introduction of microbial pathogens/parasites	High		Very High	High
Introduction of non-native species	Intermediate	Low	High	Moderate
Extraction of this species	Intermediate	Moderate	Moderate	Low
Extraction of other species	Intermediate	Moderate	Moderate	Moderate

Appendix 2 South Devon Area of Outstanding Natural Beauty seagrass awareness leaflet



Appendix 3 Code of practice for Torbay seagrass beds

SEAGRASS BEDS ARE EASILY DAMAGED SO PLEASE

DON'T	DO
Anchor over the seagrass beds as anchors pull up roots, allowing storms and currents to wash away large areas	**Anchor away from seagrass**
Travel at high speed over shallow seagrass areas at low tide as boat propellers, keels and jet ski jets can cut through the leaves and roots, scarring and killing the seagrass	**Watch out for seagrass and observe Torbay Harbour speed restrictions**
Discharge waste or rubbish into the sea as this kills it, directly or cuts out light and allows algae to smother the seagrass	**Use proper disposal sites**
Use scallop dredges or other mobile fishing gear in seagrass areas as these cut through the leaves and roots breaking up the seagrass beds	**Observe voluntary 'no scalloping' areas and keep mobile gear out of the seagrass**
Use gill nets in the seagrass areas as footropes, weights and anchors can damage the seagrass	**Set nets outside the seagrass areas, this also avoids areas with over-wintering diving birds**
Walk on the seagrass or dig for bait in it	**Walk or dig outside the seagrass areas**

Source: Torbay Coast & Countryside Trust

Appendix 4 Dorset Wildlife Trust code of conduct

- Put all litter in bins provided.
- Respect the voluntary no-anchor zone.
- Use fixed moorings to avoid anchoring.
- If you have to anchor, avoid seagrass - anchor on bare sand.
- Avoid using boat (sea) toilets in the bay.
- Keep speed to a minimum when travelling over seagrass.
- Avoid grounding on seagrass - but if this happens, allow the tide to refloat you.
- Do not chase, disturb or touch seahorses. Seahorses are a protected species and it is an offence to disturb them. It is best for you and the seahorse to keep your distance and calmly observe. If the seahorse swims away, do not pursue it.
- Divers - keep diving gear tidy to avoid trailing yourself and your gear along the bottom and reduce disturbance to the soft sediments and the seagrass.
- Divers' and snorkelers' fins can stir up the sediment and potentially damage the seagrass. To avoid this, kick gently and move with care.
- Do not pull at or hold onto the seagrass.
- Tell others how they can help.

(Source: Dorset Wildlife Trust 2011)

Appendix 5 Web based educational seagrass resources

Public awareness raising resources:

http://www.thegreenblue.org.uk/pdf/TGB%20Factsheet%2015%20Seagrass.pdf

http://www.marlin.ac.uk/habitatsbasicinfo.php?habitatid=318&code=2004

http://www.marlin.ac.uk/habitatsbasicinfo.php?habitatid=257&code=2004

http://www.seagrasswatch.org/education.html

http://www.ioseaturtles.org/Education/seagrassbooklet.pdf

http://www.marine-conservation.org.uk/seagrass.html

http://www.helfordmarineconservation.co.uk/downloads/eelgrass-leaflet.pdf

Teaching resources (various ages):

http://www.teachoceanscience.net/teaching_resources/education_modules/seagrass/access_classroom_resources/

http://www1.coseecoastaltrends.net/modules/seagrass/access_classroom_activities/

http://flseagrass.org/fun_activities.php

http://www.reef.crc.org.au/seagrass/index.html

http://www.seagrasswatch.org/education.html

http://www.naturefoundationsxm.org/education/seagrass/importance_of_seagrass.htm

http://www.webrangers.us/activities/seagrasses/

MAIA

Marine protected areas in the Atlantic arc

Towards an Atlantic network of Marine Protected Areas

The purpose of the European Marine Protected Areas in the Atlantic arc (MAIA) project is to create a **network of MPA managers and stakeholders**, who will take initiatives on an international level in terms of designation, governance and management. This will be to enhance the **development of a consistent, efficient and accepted MPAs network** in the Atlantic arc.

MAIA is structured in four main technical lines of work:

- Establishing a status report on the existing MPAs
- Setting up common monitoring strategies
- Implementing management plans
- Involving stakeholders

MAIA gathers 9 partners from 4 countries: United Kingdom, France, Spain and Portugal, involved in MPAs designation and management.

As lead partner, the French Marine Protected Areas Agency, coordinates the project implementation.

The 2010 – 2012 Action Plan

Organisation of technical workshops on common MPA management issues in the Atlantic arc.

Site visits in each partner country to enhance the sharing of information, knowledge and know-how.

Overview reports to compare MPAs' situation in the Atlantic arc.

Field studies to be carried out by MAIA partners, promoting the exchanges within the network.

Creation of a dedicated website, including a private collaborative space, a document database and a GIS database used to establish a baseline on the status of MPAs in the Atlantic arc.

Production and dissemination of document resources.

www.maia-network.org

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