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SENSITIVITY AND VULNERABILITY TO MAN INDUCED CHANGE OF SELECTED COMMUNITIES:

Intertidal Brown Algal Shrubs, *Zostera* Beds and *Sabellaria spinulosa* Reefs

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Summary

This study has confirmed the general conclusions of Holt *et al* (1995) regarding the high sensitivity and vulnerability of *Zostera* in many respects, though, despite a great deal of research which has been carried out world-wide, there is still much that is not understood. Recommendations for future work include: acquisition of basic biological knowledge including longevity of *Zostera* spp and recruitment rates and processes; investigation of methods for artificial establishment of *Zostera* beds; the consolidation of present expertise and knowledge via a workshop; determination of the taxonomic status of *Z. marina/angustifolia;* determination of the present status of *Zostera* in the UK as a whole via collation of regional studies plus additional survey work; and investigation of the effects of a range of potentially damaging impacts including eutrophication, increased turbidity and physical damage by recreational or dredging activities. Outline costings are presented for a number of these options.

This study has also confirmed the general conclusions of Holt *et al* (1995) regarding the generally low sensitivity of brown algal shrubs, with the exception of the longlived and slow recruiting *Ascophyllum nodosum.* Nevertheless there are undoubtedly potentially damaging impacts to all of them. Gaps in knowledge for open rock dwelling fucoids are fewer, or at least less serious, than for *Zostera.* Pool dwelling fucoids, with their more restricted habitat, vulnerability to competition from alien species, and possible sensitivity to eutrophication and hydrocarbons in the case of *Cystoseira tamariscifolia,* are less well studied than those inhabiting open rock and might be considered to be more sensitive.

Sabellaria spinulosa seems to be a generally robust and tolerant species which is nevertheless sensitive to extensive damage caused by bottom fishing from which it may not recover over long time scales.

Improvements have been made to the numerical sensitivity scores of previous work, and inherent problems of such broadly based sensitivity scores discussed. It is emphasised that these scores can give only very general indications of sensitivity to which there will undoubtedly be exceptions in relation to some, and possibly many, impacts or situations. Despite this, there may well be some value to the scoring system in very broad sensitivity mapping but it should not be used in place of a combination of expert opinion, survey work and consultation for important management or conservation decisions.

The concept of Critical Natural Capital (CNC) has been considered and arguments are presented as to why *Zostera* spp and *Ascophyllum nodosum* would probably constitute CNC, but not other fucoids and probably not *Sabellaria spinosum,* though the latter is a less clear cut case. Assessment of CNC in practice will presently be hampered by important gaps in our basic knowledge, especially in relation to the ability of *Sabellaria* and more particularly *Zostera* to recover, or be reinstated, after loss.

Contents

1 General introduction

1.1 Background

Holt *et al* (1995) undertook an initial analysis of sensitivities of various marine life forms (as defined using the BIOMAR classification) to man induced change on behalf of the Countryside Council for Wales. The brief for that work was to examine different types of marine communities and organisms and catalogue and evaluate their sensitivities both in a very general sense (longevity, stability, fragility, 'intolerance' to changes in environmental parameters, particularly water quality, and recoverability of the communities / organisms) and also with due regard to various impacts. The following definitions of sensitivity and vulnerability, produced by JNCC during the course of the work, were adopted:

Sensitivity	*"The innate capacity of an organism to suffer damage, or death, from an external factor beyond the range of environmental parameters normally experienced";*
Vulnerability	*"The exposure of an organism to an external factor to which it is sensitive".*

This approach was different from the more usual way of considering an impact (eg an oil spill) and examining the severity of its impact on marine organisms at the individual, population and community level. There are considerable benefits to this "organisms-eye" view of sensitivity to impact. Firstly, if sufficient information is available, the variety of impacts affecting the particular life forms can be compared. This information can be essential in conservation management decisions such as local management plans, granting of consents to discharge or licenses for extractive industries. Most importantly this approach highlights lack of knowledge in a number of life forms, some of which are subject to frequently occurring impacts. Conversely, the disadvantages of the life form sensitivity approach include difficulty of fitting individual species to a particular category of life form, differences in sensitivity within categories (i.e. some species within a life form class are more sensitive than others), and the problems with classifying the life form categories themselves. Holt *et al* (1995) also acknowledged the need to assess the conservation importance of a community and its vulnerability in terms of likelihood of being impacted as separate issues.

The current report aims to take the work of Holt *et al* (1995) further, using the three specific features; "seagrass communities", particularly *Zostera marina*; "brown algal shrubs", particularly intertidal species such as fucoids; and "subtidal reefs", concentrating on *Sabellaria spinulosa*.

Holt *et al* concluded that "many aspects of fucoid biology and ecology pertinent to sensitivity are well studied. With the exception of *Ascophyllum*, fucoids are short lived perennials, stable on sheltered shores but relatively unstable on more exposed shores which is in part due to biotic interactions, and of varying tolerance to pollutants dependant on pollution type and developmental stage of the plant. Recolonization rates are generally moderately good, though it takes a long time before normal cycles of stability are reached. *Ascophyllum* communities are very long lived, stable with similarly varying tolerance of pollutants, but often with very slow recolonization. There is a lack of information within algae in general, including fucoids, on the effects of long term low level exposure to chemical pollutants, particularly on the young stages, and also on recovery of associated flora and fauna". With the exception of *Ascophyllum nodosum*, they considered fucoids to be generally a robust group, without extreme sensitivity to most environmental or, so far as is known, chemical parameters; nevertheless they gave examples of damage caused by anthropogenic impacts, including published evidence of extreme sensitivity to chlorate. However, Holt *et al* (1995) did not consider pool dwelling fucoids such as *Cystoseira* spp, *Bifurcaria bifurcata* or *Halidrys siliquosa*.

Holt *et al* (1995) concluded that seagrass communities, and *Zostera marina* in particular, have also been very well studied, though less so in Britain than in North America and northern Europe, particularly the Southern North Sea area. Nevertheless, they suggested that "a full understanding of the causes of massive declines has still not been achieved. *Z. marina* is undoubtedly extremely sensitive to man induced changes, particularly in relation to eutrophication, sedimentation, and turbidity, and its poor ability to recover naturally exacerbates this. Further work on the interaction and relative importance of the various factors known to affect it, on conditions changes / conditions required for recovery and on possible mitigative or preventative measures is required". They also gave examples of effects caused by physical disturbance and introduced species (*Sargassum muticum*). They did not consider *Z. angustifolia* or *Z. noltii.*

In contrast to the above two groups, relatively little information was found on *Sabellaria* (under the life form category of faunal accretion). Much of what Holt *et al* presented related only to *Sabellaria alveolata*, but they did suggest that *S. spinulosa* might be relatively sensitive to impacts from fishing and other physical disturbance and tolerant of sedimentation caused by sewage effluents.

One of the outputs of the previous study was a tentative systems for 'scoring' sensitivity which is given here in Appendix 1. This involved the assignation of scores on a scale of 1 (not sensitive) to 5 (sensitive) under the headings of longevity, stability, fragility, 'intolerance' to environmental stresses or changes, and recoverability. The first four were also averaged in an attempt to obtain an 'overall damage' score but this was thought to be unsatisfactory, as it can effectively hide the fact that one particular type of impact might be extremely damaging to an otherwise insensitive species or community.

1.2 Aims

The brief specified for the present work by English Nature, referring to intertidal brown algal shrubs, *Zostera* beds and *Sabellaria spinulosa* reefs as defined above, was *"for those features which are known to be degraded by human activities, we need to identify the environmental factors responsible and environmental conditions and remedial work which may be necessary to prevent further degradation and to enhance recovery or restoration"*. This approach was to be in accord with the concept of Critical Natural Capital (CNC) being developed and tested by English Nature (Gilliespie & Shepherd 1995; Masters & Gee 1995). CNC is formally defined as *"those elements of the natural environment whose loss would be serious, or which would be irreplaceable, or which would be too difficult or expensive to replace in human timescales"*. In this context we were asked to refine and add to the previous work, investigate whether it was possible to quantify acceptable tolerance levels of change for the specific features listed, drawing attention to gaps in knowledge and questions of interspecific variability where appropriate, and to outline research programmes to investigate the most important or immediate problems. One difference from the previous work is that this report includes some consideration of the vulnerability of the communities as well as their sensitivity.

An update on the numerical scoring system for sensitivity, together with consideration of its usefulness, was also envisaged but at a relatively low priority.

1.3 Methods

The majority of the work carried out took the form of a major literature search using much grey literature provided by JNCC and the country agencies (English Nature; Countryside Council for Wales; Scottish Natural heritage and Department of the Environment for Northern Ireland), as well as published sources of information and informed opinion.

In a general sense, less sensitive organisms tend to occupy wider ecological ranges, but nevertheless there are range limits near which any organism or community must be sensitive to change. For a study of this sort to be meaningful, it is necessary to ignore extremes of the ecological ranges occupied, and concentrate on 'mid-range' or 'typical' habitats or niches. An exception to this would be geographical ranges, since the study concerns the sensitivity of communities *within British waters*. The common shore crab *Carcinus maenas*, for example, is found in a great variety of habitats ranging from fully marine to somewhat brackish. There nevertheless comes a point on any estuary beyond which it cannot penetrate because of lowered salinity. This does not mean that we would have to regard *Carcinus maenas* as being particularly sensitive to salinity changes, becauses throughout the majority of its distribution it clearly is not. On the other hand, many southern species which reach their northerly limits (or, vice versa) in Britain are clearly sensitive to relatively small temperature changes throughout much of the British waters which they normally inhabit, e.g. *Sabellaria alveolata* which can suffer high mortalities in cold British winters (but note that if this study was being carried out in the south of France *S. alveolata* would probably not be regarded as being particularly sensitive to temperature).

Outline proposals for further work are given where these are considered necessary. They have been prepared using approximate direct research costs to which overhead components need to be added in all cases. In a few cases it was felt that insufficient information presently exists to give even approximate costs, for example because there may be similar work under way presently for which we have few details.

CNC was taken into account in accord with the suggestions of Masters & Gee (1995) who worked specifically on marine communities. They actually used the synonymous term Critical Environmental Capital (CEC); the term CNC will usually be used throughout the remainder of this report to mean the same thing. They proposed a series of flow charts containing a number of questions, the answers to which determine whether a site or community fits the definition of CNC. These flow charts are given in Appendix 2. In this report, the present ability to answer is summarised alongside the relevant questions in tabular form, although in many cases the CNC questions are very site specific and so not relevant to this study.

Attempts were made to improve the assignation of numerical scores to sensitivity, but, in view of the doubts and concerns raised by Holt *et al* (1995) over this issue, were given a relatively low priority here. The methods used followed those of Holt *et al* (1995) except that the 'damage scores' of longevity, fragility, stability and intolerance were not averaged to give an 'overall damage score' as this was felt to be of little value.

1.4 Report structure

Brown algal shrubs, *Sabellaria* reefs and *Zostera* beds are considered in three separate sections (2-4). Each of these sections contains the following:

an introduction with background information;

a main body of text summarising the present state of knowledge and concerns;

a sub-section containing costed outline proposals for further work;

a sub-section containing a tabular assessment of our present ability to decide whether a site/community constitutes CNC

relevant references

There are some inevitable differences between the three main sections - for example, only *Ascophyllum* is exploited, or likely to be exploited, on any scale, so only section 3 contains a sub-section on exploitation; only *Zostera* presents important taxonomic problems (section

4.2), and only with regard to *Sabellaria* reefs is the nature of the physical structure formed by the animals important enough to warrant detailed discussion (section 3.2).

A further attempt to enumerate sensitivities is given in section 5 and a general discussion in section 6. A table summarising present knowledge of the three features in relation to impacts classified according to the Marine Conservation Handbook (Eno 1991) is presented as Appendix 3.

1.5 References

ENO, N.C. 1991. Marine Conservation Handbook. Peterborough. English Nature.

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2 Brown algal shrubs (intertidal)

2.1 Introduction

On the basis of the initial analysis (Holt *et al* 1995) brown algal shrubs (BAS) are in general classified as being reasonably resistant to impact, but somewhat slow to recover from severe damage. It is also fair to say that as a life form intertidal brown algal shrubs are exceedingly widespread around Britain, being almost ubiquitous upon rocky shores except where limited by strong wave action on exposed coasts, or by problems of turbidity and low salinity in estuaries. In a conservation context they do not include any species which are generally considered threatened either locally or nationally, nor are they thought of as harbouring species which are particularly at risk, though some of the pool species (eg *Bifurcaria, Cystoseira*) are at their northern limits.

It is useful to relate the BIOMAR life forms (eg Brown Algal Shrubs), as used in this study, to the MNCR biotopes (Connor *et al* 1996) (Table 1).

Brown algal shrubs in the intertidal form two habitat types. Most abundant are the 'typical' species which inhabit drying rock surfaces - *Pelvetia canaliculata* (a rather marginal 'shrub', which is close to being a 'turf'), *Fucus spiralis, F. vesiculosus, F. serratus* and *Ascophyllum nodosum.* There is also *Fucus ceranoides,* which occurs only in reduced salinities (Boney 1966). Then there are those which inhabit intertidal pools: the widespread *Halidrys siliquosa* (Cabioch *et al* 1992), and the southern forms *Bifurcaria bifurcata* and *Cystoseira* spp (Norton 1985).

Thus in terms of conservation strategy brown algal shrubs will generally demand low priority, and will not come high on any list of monitoring programmes, though they may frequently be included within protected areas selected on the basis of other communities present or under the criterion of 'representativity'. Against this background this analysis should not aim to further analyse brown algal shrubs as a group, but should rather concentrate on specifics. It should address in greater detail the following questions:

1) What are the differences between algal shrub species in terms of their sensitivity and recoverability?

2) How stable are brown algal shrub habitats and communities?

3) What exceptions are there to the general conclusion that they are resistant to impacts?

4) What levels of the various impacts are acceptable?

5) What serious gaps are there in our current knowledge of the group which limit our ability to draft appropriate conservation strategies?

An analysis of these questions should enable the identification of those limited situations in which brown algal shrubs become more of a conservation concern, and should provide some guidance to appropriate management strategies under those circumstances. This section of the report is structured around the various 'criteria of sensitivity' identified and tentatively quantified in Holt *et al* (1995).

Table 1 The following MNCR biotopes (codes listed on left) are dominated by, or contain substantial amounts of, species which could be considered as intertidal brown algal shrubs (from Connor *et al* 1996).

ELR.BPat.fvesl	Barnacles, *Patella* and *Fucus vesiculosus* f. *linearis* on exposed eulittoral rock.
ELR.Fdis	*Fucus distichus* subsp *anceps* and *Fucus spiralis* f. *nana* on extremely exposed upper eulittoral rock.
MLR.PelB	*Pelvetia canaliculata* and barnacles on moderately exposed upper shore rock.
MLR.vesB	*Fucus vesiculosus* and barnacle mosaic on moderately exposed mid eulittoral rock.
MLR.Fser	*Fucus serratus* on moderately exposed lower eulittoral rock
MLR.Fser.R	*Fucus serratus* and red seaweeds on moderately exposed lower eulittoral rock.
MLR.Fser.Fser	Dense *Fucus serratus* on moderately exposed to sheltered lower eulittoral rock.
MLR.Fser.Bo	*Fucus serratus* and under-boulder fauna on lower eulittoral boulders
MLR.Fser.Pid	*Fucus serratus* and piddocks on lower eulittoral rock
MLR.Myt.fves	*Mytilus edulis* beds and scattered *Fucus vesiculosus* on moderately exposed mid eulittoral rock
MLR.Myt.R	*Mytilus edulis* beds, red seaweeds and *Fucus serratus* on moderately exposed lower eulittoral rock.
SLR.Pel	*Pelvetia canaliculata* on moderately exposed to sheltered upper eulittoral rock.
SLR.Fspi	*Fucus spiralis* on moderately exposed to sheltered upper eulittoral rock.
SLR.Fves	*Fucus vesiculosus* on sheltered mid eulittoral rock.
SLR.Asc	*Ascophyllum nodosum* on very sheltered mid eulittoral rock.
SLR.Asc.Asc	*Ascophyllum nodosum* on full salinity mid eulittoral rock.
SLR.Asc.T	*Ascophyllum nodosum*, sponges and ascidians on tide-swept mid eulittoral rock.
SLR.Asc.VS	*Ascophyllum nodosum* and *Fucus vesiculosus* on variable salinity mid eulittoral rock.
SLR.Fser	*Fucus serratus* on sheltered lower eulittoral rock.
SLR.Fser.T	*Fucus serratus*, sponges and ascidians on tide-swept lower eulittoral rock.
SLR.Fcer	*Fucus ceranoides* on low salinity eulittoral rock.
SLR.FvesX	*Fucus vesiculosus* on low salinity eulittoral rock.
SLR.AscX	*Ascophyllum nodosum* on mid eulittoral mixed substrata.
SLR.AscX.mac	*Ascophyllum nodosum* ecad *mackaii* beds on extremely sheltered mid eulittoral mixed substrata.
SLR.FserX	*Fucus serratus* on lower eulittoral mixed substrata.
SLR.FserX.Myt	*Fucus serratus* with *Mytilus edulis* on lower eulittoral mixed substrata.
SLR.serXT	*Fucus serratus* with sponges, ascidians and red seaweeds on tide-swept lower eulittoral mixed substrata.
SLR.FcerX	*Fucus ceranoides* on reduced salinity eulittoral mixed substrata.
RKP.FK	Fucoids and kelp in deep eulittoral pools.
RKP.FK.Bed	*Fucus serratus* and *Laminaria digitata* in deep bedrock-floored eulittoral rockpools.
RKP.FK.Bo	*Fucus serratus*, *Laminaria digitata* and under-boulder fauna in deep boulder-floored eulittoral rockpools.
RKP.FK.Snd	*Fucus serratus*, *Laminaria digitata* and sand tolerant seaweeds in sediment-floored eulittoral rockpools.

2.2 Longevity

There is a basic difference in longevity between *Ascophyllum* and the other BAS species. *Ascophyllum nodosum* has a long life span. Individual fronds can survive for 10-15 years (David 1943), and assemblages originating from a common holdfast are thought capable of living for decades (Baardseth 1970) or even longer (P. Aberg pers comm). In contrast *Fucus* spp have life spans of the order of 3-4 years (eg Knight & Parke 1950; Hawkins 1979; Southward & Southward 1978). The various pool dwellers, *Halidrys siliquosa, Cystoseira* spp and *Bifurcaria bifurcata.*, are reportedly perennial (eg Boney 1966; Moss & Sheader 1973; Cabioch *et al* 1992) though little detailed information on longevity is available. *Himanthalia elongata*, though it is a fucoid, is not included here as it does not take the form of a shrub.

2.3 Fragility

Recreational activity can impact BAS communities by the effects of boating, and by the effects of trampling. These are the only anthropogenic physical impacts to which BAS are regularly exposed.

The effects of boating on BAS are minimal. Rocky shores are unsuited for launching boats, and are seldom chosen for that purpose. Intertidal rocky areas provide poor holding for anchors, and are dangerously close to the shore, so damage from anchors is rare. Boat users will try to avoid water with BAS floating near the surface since there is a risk of fouling the propeller, so damage to the algae by propeller action is limited. Recreational boating can be ignored as an impact factor on this community (though not on several others).

Trampling has a more significant impact. People will walk on rocky shores for recreation, collecting animals for souvenirs, for shore angling, and for access to the water by divers. Marine biologists, particularly student classes, are major tramplers in some areas. A number of detailed studies abroad have recorded the harmful effect of trampling on brown algae. In S.E. Australia heavy experimental trampling reduced the mass of the brown alga *Hormosira* by 75%, and it had made only a 60% recovery after 400 days (Povey & Keough 1991). In Southern California the alga *Pelvetiopsis* was found to be absent at the most trampled sites (Beauchamp & Gowing 1982). In the same area Thom & Widdowson (1978) resurveyed a number of areas examined fifteen years earlier, and in the most accessible sites found a decline in large algae and their replacement by crustose and turf forms. On the Oregon coast experimental trampling had severe effects on the canopy cover of foliose algae, including fucoids (Brosnan & Crumrine 1994). The foliose algae became replaced by turf forms. Species resistant to wave action did not display any improved resistance to trampling.

Until recently very few detailed studies had been conducted in Britain. Boalch *et al* (1974) resurveyed Coleman's transects at Wembury in Devon after 40 years. The amount of access had been increased by construction of car parks, and a decline in *Ascophyllum* was noted, together with an increase in *Fucus vesiculosus*. This was tentatively attributed to trampling, being especially serious for the long-lived but slowly recruiting *Ascophyllum*. Recent provisional work in the Isle of Man (Flavell 1995 unpublished) reinforced the view that *Ascophyllum* was particularly susceptible to trampling damage. However, recent detailed studies in northeast England (Fletcher & Frid 1996 in press) have looked at the effect of controlled experimental trampling on fucoid communities. They found that trampling decreased fucoid cover, increased bare space, and increased cover of *Enteromorpha*. These changes were evident at the lowest level of trampling tested - 20 footsteps per m^2 per spring tide cycle. They concluded that this level exceeded the 'recreational carrying capacity' (see Goldsmith 1974) of the shore, and point out that it is equivalent to only five people following the same route once on each spring cycle.

It is certain that trampling does damage BAS communities, and if persistent it is likely to change the balance of the community. *Ascophyllum*, because of its slow recruitment, appears particularly sensitive. Possible control measures include the reduction of visitors, or the controlled routing of visitors.

2.4 Stability of brown algal shrub habitats and communities

2.4.1 Stability of habitat

2.4.1.1 Effect of erosion/deposition Since brown algal shrubs are in general associated with hard rocky shores erosion is not normally a problem within the scale of the life span of these algae. Nevertheless there are situations in which the durability of the attachment surface can become a problem. Very soft or friable rocks such as some chalks, shales and sandstones support reduced populations of fucoids (Lewis 1964), and this effect becomes particularly noticeable in wave exposed conditions (Anand 1937). However rocks of this type are in a very small minority. The other situation which affects permanency of attachment is where the fucoids have become affixed to other epilithic biota rather than directly to the rock surface. Barnacles inhibit limpet grazing and facilitate fucoid 'escapes', so that patches of fucoids grow up on a matrix of barnacles. As the fucoids grow, and the barnacles die and disintegrate, the attachment weakens and the fucoids become detached (Hartnoll & Hawkins 1985). The other common attachment is to the shells of limpets. As the fucoids grow the pull upon the limpet increases, with a greater risk of detachment during rough weather. These effects will only influence the fucoid populations on a very local scale, and will not compromise their general stability.

Deposition is a problem only where the rock substrate abuts onto a sandy beach. Very considerable changes (>1 metre) can occur in sand level due to variations in wave action, and raised sand levels can kill all of the epilithic biota if the coverage persists for any time (R G Hartnoll, personal observation).

2.4.1.2 Effect of rock size When the algae are attached to bedrock the permanency of the substrate is assured (except in the limited circumstances described in 2.4.1.1). However, once the attachment is to boulders or stones stability is no longer guaranteed, and will become a function of both boulder / stone size and severity of wave action. As the boulders become smaller and the wave action stronger there is less capability for the establishment of long-lived species such as fucoids, and ephemerals will replace them (Lewis 1964; Sousa 1979).

2.4.2 Stability of community

2.4.2.1 Influence of survey scale The impression gained regarding the stability of brown algal shrub communities can depend upon the scale of the survey carried out. A broad-scale survey (hundreds of metres or more) covering an entire shore, or several shores, may demonstrate apparent stability. It will detect some seasonal patterns of change (Hawkins & Hartnoll 1983b), and may also detect broad-scale stochastic effects due to unusual weather patterns or unusually good (or bad) recruitment. These changes are responses to extrinsic factors. A survey conducted on a smaller scale (less than 10 metres) can, on the other hand, demonstrate a highly dynamic community structure due to intrinsic biological interactions (see 2.4.2.2).

2.4.2.2 Effect of biological interaction and stochastic recruitment There have been a series of studies describing naturally occurring cycles on rocky shores of moderate exposure to wave action (Burrows & Lodge 1950; Southward 1956; Southward & Southward 1978; Hartnoll & Hawkins 1985). The details of the cycle are fully described in Hartnoll & Hawkins (1985), and only a brief outline is appropriate here. Basically, small patches of substrate cycle between phases dominated by barnacles, fucoids and bare rock, a process driven largely by variations in grazing pressure of limpets. The cycle has a period of about five years, but is subject to perturbation by extrinsic stochastic factors. Patches in different phases of the cycle form a mosaic pattern on the shore. Detailed analysis has shown that the predominant patch size is of the order of a square metre (Johnson *et al* in submission). Such cycling is only likely on smooth surfaces - increasing complexity of substrate tends to stablize the spatial dynamics of the community.

2.4.2.3 Effect of wave action The effect of difference in wave action on BAS community stability is predominantly through its influence on the balance of the biological interactions described in 2.4.2.2. If the physical conditions are such as to greatly favour one component of the interaction, then the putative cycle will become locked in one phase, and a dynamic system becomes stabilised. Thus in strong wave action the grazers and barnacles are favoured at the expense of the fucoids, and a stable situation with minimal fucoid cover prevails. Conversely, in shelter the fucoids are favoured and maintain a more or less total and permanent canopy (Southward & Southward 1978; Hartnoll & Hawkins 1985). Only under intermediate wave action is a fully dynamic system developed.

2.5 Intolerance to changes in environmental parameters, especially water quality

There are virtually no experimental studies where the responses to impacts of more than one BAS species have been investigated in a manner which allows them to be compared, though in long term studies of diesel oil exposure *Ascophyllum*, *Fucus serratus* and *F. vesiculosus* responded similarly to each other (Bokn *et al* 1993). One of the main proposals in section 2.9 is for comparative experimental studies to remedy this major deficiency in our knowledge. Some anecdotal comparisons will appear, such as the suggestion that *Cystoseira tamariscifolia* is specially sensitive to eutrophication. However, these must be treated with caution, and in any case do not usually discriminate between the influences of sensitivity and recoverability.

Some conclusions regarding BAS's likely tolerance of impacts may be drawn from their natural distribution, both geographical and in response to salinity. Most of the species involved are distributed throughout the British Isles and beyond - *Pelvetia, Ascophyllum, Fucus* spp and *Halidrys* (Norton 1985). This indicates that they are well within their natural tolerance ranges, and are not highly stressed by climatic factors. In contrast *Bifurcaria*, and the four British species of *Cystoseira* (*C. baccata, C. foeniculacea, C. nodicaulis* and *C. tamariscifolia*) are all southern species, predominantly limited to south western Britain between the Isle of Wight and south Wales and in western Ireland (see Lewis 1964; Norton 1985). This means they are at their northern limit, presumably making them more susceptible to stress. Only C. *nodicaulis* and C. *tamariscifolia* are found as far north as Western Scotland.

Most of the species do not penetrate far into estuaries. *Fucus ceranoides*, however, is strictly estuarine, though apparently only because it is outcompeted on fully marine shores by other species of fucoids, in the absence of which it can survive. It does grow better in reduced salinities, however (Boney 1966), so possibly may show greater tolerance of other variables. *Fucus vesiculosus* penetrates into the Baltic, where it is common subtidally, suggestive of stronger tolerance to altered environmental parameters than other species.

The following activities (see 2.5.1 - 2.5.4) were identified in Holt *et al* (1995) as having impacts on brown algal shrub communities. In several instances - salmonid farming, sewage and industrial waste - any effects on BAS communities are likely to be trivial in comparison to the other adverse effects of these activities. Because of this levels of these activities will be set in response to their impacts elsewhere on the local environment.

2.5.1 Salmonid farming

Intensive salmonid farming leads to eutrophication, and like eutrophication arising from any source this can promote the growth of ephemeral algae. Salmon farming can cause the overgrowth by green algae of adjacent BAS communities. As well as eutrophication salmon farming produces a general deterioration in water quality, particularly near-bottom water, and can produce anoxic conditions at the sea bed (Hansen 1994; Gillibrand *et al* 1996). These latter effects are far more damaging than any influence on BAS communities, and will require remedial action.

2.5.2 Oil/gas

Fucoids show limited sensitivity to oils in the short term (O'Brien & Dixon 1976; Bokn *et al* 1993), and appear unlikely to be seriously harmed by chronic levels in the water which would be acceptable on aesthetic grounds, or which did not harm more sensitive or commercially valuable organisms. However, there is only limited evidence concerning the long-term effects of low level exposure to oil, which do indicate some adverse influences. Long-term exposure to low levels of diesel reduce the growth rate in *Ascophyllum* (Bokn 1987; Gray 1987), though this recovered within a season after two years exposure (Bokn 1987). It is considered that the early stages are more sensitive (Scanlon & Wilson 1987; Rueness 1973), and that this could account for the disappearance of *Ascophyllum* from polluted sites in the Oslofjord (Rueness 1973). Further studies of the effects of long-term exposure to low-levels of oil and other pollutants, especially on juveniles, are required. Cabioch *et al* (1992) grouped C. *tamariscifolia* with two other (non British) *Cystoseira* species as being very sensitive to surface pollutants such as detergents and hydrocarbons, and noted that their disappearance is always a sign of a deterioration in environmental conditions.

The impacts of oil on BAS communities are more likely to arise in the context of acute pollution resulting from major oil spills. Under these circumstances factors other than the well-being of BAS will determine the clear-up measures of choice. Furthermore effects of oil and/or emulsifiers on the populations of *Patella* will generate effects far greater than the direct effects on the BAS, producing imbalances which can persist for 10-15 years as demonstrated following the Torrey Canyon oil spill (Southward & Southward 1978; Hawkins & Southward 1992). Nevertheless, very heavy oil fouling clearly impacts the fucoids and their associated fauna. In Norway heavy oil fouling following a ship grounding reduced both fucoid cover and the number of associated species. In moderate exposure species number had recovered after 2 years, but not after 4 years in shelter (Hjohlman & Lein 1994).

2.5.3 Sewage

Sewage can affect BAS communities by fostering eutrophication and encouraging the growth of epiphytes, by reducing levels of dissolved oxygen in the water, and by increasing turbidity and cutting out the light. However, fucoids appear to be reasonably resistant to the input of sewage, and grow apparently healthily to within 20 metres of an outfall discharging untreated sewage from 13 000 people in the Isle of Man (Holt *et al* 1993). It is likely that before the concentration of sewage becomes such as to harm BAS to any great extent aesthetic and public health considerations are going to force action.

Boney (1966) stated that *Cystoseira* plants bear dense growths of epiphytes in the summer. This suggests that they have little inherent defence against epiphyte settlement and growth, so that eutrophication leading to faster growth rates of epiphytes could be potentially damaging - though this is purely speculation at present.

2.5.4 Industrial wastes

As reported by Holt *et al* (1995), mature fucoids at least are generally quite robust in the face of chemical pollutants. In the case of heavy metals they are able to concentrate them highly in their tissues, and for this reason have been used as bioindicators of heavy metal pollution (eg Soenko *et al* 1976; Luoma & Bryan 1982; Carison 1990; Burt *et al* 1992). The alginate within the fucoids is believed to have a role both in the uptake of the metals, and in storing the heavy metals in fairly inert forms, so that the plants do not appear to be harmed.

In contrast to this general tolerance is the report by Rosemarin *et al* (1994) that "brown algae (Phaeophyta) exhibit an extraordinarily high sensitivity to chlorate and pulp mill effluents containing chlorate", even though Cyanophyta, Chlorophyta, Rhodophyta, diatoms, freshwater and brackish phytoplankton, and *Zostera* were all unaffected. In the same connection pulp mill effluents in the Baltic reduce *Fucus vesiculosus* biomass "at both intermediate and remote distances" (Kautsky 1992).

The above observations are based solely on the work of Swedish workers, who studied populations from the Baltic. Rosemarin *et al* (1994) studied several Phaeophyta, including *Fucus vesiculosus*, and found that they all displayed major toxic reactions to chlorate down to the lowest concentrations used (21 µg ClO_3^- $litre^{-1}$). In one case *F. vesiculosus* disappeared over an area of 12 km^2 around a pulp mill (Lindvall 1984), and short term uptake tests and field transplant experiments confirmed that chlorate was primarily responsible (Rosemarin *et al* 1986; Lehtinen *et al* 1988; Rosemarin *et al* 1990 cited by Rosemarin *et al* 1994). In field observations, Lehtinen *et al* (1988) reported 60% decline in total algal biomass after several months exposure to 1.2µM and almost complete disappearance of *Fucus vesiculosus* after several months exposure to 6µM. Removal of chlorate from these effluents has in fact allowed *Fucus* to begin to recolonise this area (Notini 1991 cited by Rosemarin *et al* 1994). There are no other references to the effects of chlorate on brown algae in the literature, and further study is indicated (see 2.9.4). No other reports were found of unusual sensitivity by brown algae to any other substances.

According to a number of works cited by Rosemarin *et al* (1994) the chlorate itself is likely to be non-toxic - it is more likely that plants use it as an analogue of nitrate, whereby it is converted to chlorite (toxic) via reduction by nitrate reductase. It may therefore be that chlorate is more problematical when nitrate levels are low as in the summer. The chlorate is actually present in the effluents because it is a by-product from the use of ClO_2 as a bleaching agent. Use of ClO_2 rather than molecular chlorine is a recent trend within the pulp industry invoked to avoid the formation of organochlorine compounds in the effluents (Perrin & Bothwell 1992).

Admittedly the likelihood of exposure to pulp mill effluent in Britain is remote, but chlorate may be present in other effluents. The following information is pers comm from Andrew Wither (AW), Environment Agency (North West Region). The paper industry within Britain does not use chlorine dioxide as an oxidising agent, and there is probably no longer any significant production of chlorate for herbicide use as it is explosive. Chlorate is produced in reasonably high concentrations (perhaps in the order 10 - 100 mg per litre) in the effluent from brine electrolysis (for industrial production of chlorine). The only plant AW was aware of is at Ellesmere Port where it discharges into the Manchester Ship Canal (but there may be others nationally). A few years ago there was a proposal by ICI to build such a plant at Fleetwood with marine discharge, and chlorate discharge was one of the issues considered. The proposal appears not to have progressed very far.

Generally, though, other taxa are likely to be adversely affected by industrial wastes before they seriously impact BAS.

2.6 Exploitation

Currently in Britain the exploitation of fucoids is restricted almost entirely to *Ascophyllum*, which can be used in animal feeds, fertilisers, kelp tablets and powders, but is used principally by the Nutrasweet Kelco alginate factory in south west Scotland as a source of alginate. Exploitation is not widespread, nor does the scale seem to be increasing at present. Most harvesting is concentrated in the western isles and to a lesser extent the Orkneys. Viewed overall harvesting appears to be well within sustainable limits (Kain & Holt in prep), though it is always possible that some easily accessible shores might be overharvested. Traditionally it has been harvested by hand cutting, but recently mechanical methods have become available in Europe. These include suction pumps with rotating cutters which can be used from small boats (Sharp 1987), but they tend not to be used in Britain because the shores are too rugged.

The recolonisation of cleared *Ascophyllum* areas by propagules is a slow and poorly understood process (Knight & Parke 1950; Hawkins 1979; Boaden & Dring 1980). If the plants are removed completely recovery times are variously reported as >8 years in Britain (Knight & Parke 1950), 3-8 years in Norway (Seip 1980), and 16 months to gain a cover of 3-4 cm long juveniles in Maine (Keser *et al* 1981). It is clear that total clearance of *Ascophyllum* represents an unacceptable impact.

However, provided that the plants are not removed completely *Ascophyllum* can regenerate from the basal portions which remain. The effectiveness of this regeneration is in proportion to the length which remains. In Norway, Prinz (1956) found that plants cut 5 cm above the holdfast may not regenerate, whilst those cut at 15 cm recovered fully in 4-5 years. In Maine, Keser *et al* (1981) found that plants cut at 15-25 cm sometimes regained their original biomass within a year. Incidentally, mechanical harvesting methods leave longer portions of the plants than hand cutting (Sharp 1987). If harvesting is to be practised on a sustainable basis then a rotational system leaving at least 15 cm (and preferably more) is indicated. Even then the environmental impact will be extreme, and could not be countenanced in a sensitive area. Regular harvesting changes the size distribution of the population, and changes the growth form of plants to a short bushy pattern (Ang *et al* 1993).

The collection of fauna of the BAS community for food does not occur in Britain, but in other parts of the world the collection of large gastropods has major environmental impacts. Thus in Chile the removal of virtually all large intertidal grazing gastropods (predominantly *Fissurella* species) has totally skewed the intertidal community towards algal dominance (Moreno & Jaramillo 1983; Moreno *et al* 1984; Moreno 1986). The removal of the large carnivorous gastropod *Concholepas* has had gross effects on the other epilithic fauna (Moreno *et al* 1986). Any initiative to harvest *Patella* in Britain would have major consequences. Though this may sound unlikely, *Patella aspera* is harvested commercially in Portugal (including the Azores) for both domestic and export markets.

2.7 Alien introductions - *Sargassum, Undaria*

There are precedents in Britain for the introduction of alien intertidal species to have substantial impacts on the native communities. The introduction of the Australian barnacle *Elminius modestus* in the 1940s, probably to Chichester Harbour, was followed by a rapid spread around much of the British coast (Crisp 1958). It competed with the native *Semibalanus balanoides* in the more sheltered parts of its range, and has effectively replaced it on some shores (Bassindale 1958; Lewis 1964).

The major alien invader among the brown algae is the Japanese *Sargassum muticum*, which appeared in the Isle of Wight in 1973 (Farnham *et al* 1973), and has subsequently spread in both directions along the Channel (Farnham *et al* 1981). It occurs only subtidally and in pools, so it is not a competitor with the intertidal BAS. Subtidally it competes with, and can replace, *Laminaria saccharina* and the eel grass *Zostera marina* (Givernaud *et al* 1991). In pools it competes with other pool dwelling browns, *Cystoseira* and *Bifurcaria*, and may outcompete or dominate them (Posford Duvivier 1997; S J Hawkins, personal observations) but there are no detailed studies of the magnitude or overall effects of this competition.

A more recent invader is the Pacific laminarian *Undaria pinnatifida*, first found in the Solent in 1994 (Fletcher & Manfredi 1995). Its arrival was not unexpected, since it has been found in Brittany since 1983 where it was deliberately introduced for cultivation purposes (Castric-Fey *et al* 1993). It is a low shore/subtidal species, and is unlikely to pose a threat to the majority of intertidal fucoid populations; however, it might pose a threat in pools (and it might compete with the native kelps subtidally), though in Brittany its behaviour is claimed to be non-aggressive to native species (Castric-Fey *et al* 1993).

2.8 Recoverability

2.8.1 Recruitment strategy

Clearly recovery must initially depend upon adequate recruitment, without which superiority in growth rate is irrelevant.

Pelvetia, Fucus spiralis, F. vesiculosus and *F. serratus* all recruit readily to cleared areas, especially in the absence of grazers (Hartnoll & Hawkins 1985; Hawkins & Hartnoll 1985). In major grazer-clearance experiments these species will recruit abundantly outside their customary zones (Jones 1948; Lodge 1948; Burrows & Lodge 1950, 1951; Hawkins & Hartnoll 1983a) until competitive interactions eventually restore normal zonation. So although recruitment is rapid, recovery of the original community structure may require some years. However, fucoid propagules do show a marked tendency to settle near the parent plant (Deysher & Norton 1982; Norton 1992, for review). This is partly due to turbulent water flow throwing the propagules down onto the rock (Norton & Fetter 1981). So a small-scale disruption within a monospecific stand will tend to be recolonised by conspecifics, with a more rapid community re-establishment.

On the other hand *Ascophyllum* has been widely recognised as demonstrating very poor recruitment (eg Knight & Parke 1950; Hawkins 1979; Boaden & Dring 1980; Seip 1980; Jenkins 1995). It could be argued that because of its unusual longevity (see 2.2) there is no need for prolific reproduction, but in fact *Ascophyllum* makes the same high level of reproductive investment as the other intertidal fucoids (Josselyn & Mathieson 1978; Cousens 1986). Furthermore, experimental studies have shown the ability of *Ascophyllum* zygotes to germinate and grow under a wide range of temperature and light regimes (Sheader & Moss 1975). The reason for the poor recruitment of *Ascophyllum* under natural conditions is still not understood. This lack of recruitment clearly compromises the recoverability of *Ascophyllum*.

2.8.2 Growth rate

Given their ubiquitous abundance, their accessibility, and their ecological significance, there is a remarkable lack of information on the growth rates of intertidal fucoids. This is partly due to practical problems. Their branching habit, and their seasonal loss of reproductive regions, both make meaningful measures of size change difficult to determine in the field, at least over long time periods.

The short-term growth rates of intertidal fucoids show a consistent pattern of increasing growth rate for algae zoned lower on the shore. Specific growth rates (percentage increase per day) for the five main intertidal species are given in Table 2.

Table 2 Specific growth rates for five intertidal brown algal shrub species, based on Fortes & Lüning (1980) and Norton (unpublished).

1.12 % day^{-1}	*Pelvetia canaliculata*
2.37 % day^{-1}	*Fucus spiralis*
2.45 % day^{-1}	*Ascophyllum nodosum*
2.95 % day^{-1}	*Fucus vesiculosus*
3.40 % day^{-1}	*Fucus serratus*

It is this difference in growth rate which is partly responsible for the pattern of zonation of BAS, being the mechanism whereby low-shore algae can restrict the slow growing but hardier species to higher levels. A faster growth rate will obviously be an aid to recovery, but since the low-shore fucoids have a larger adult size, there may not be much difference in the time taken to reach that size. Opportunistic algae such as *Enteromorpha, Porphyra* and *Ulva* grow considerably faster than fucoids, and are usually the initial colonisers of bare space. However, the longer life span of fucoids means that they outlast and supersede the ephemerals (Littler 1980; Littler & Littler 1984; Hawkins 1981a).

It is probable that the speed of growth is particularly critical in the earliest stages as it accelerates the escape from limpet grazing. Fucoids are not usually damaged by grazing molluscs once they exceed 30-50 mm in height (Knight & Parke 1950; Menge 1975; Hawkins 1981b; Lubchenco 1983; Hawkins & Hartnoll 1983a), and the critical size in relation to limpets may well be smaller than this. Lower shore fucoids can reach 10 mm within 2 months, whereas *Fucus spiralis* requires 6 months, and *Pelvetia canaliculata* may take 18 months (Knight & Parke 1950; Schonbeck & Norton 1980). Consequently low-shore fucoids are more likely to escape grazing. Working in Norway, Sundene (1973) found that *Ascophyllum nodosum* zygotes settled on stone and brick substrata and transferred to the sea after 10 days reached only 2-10 mm after one year and 5-15 mm after the second year. Maximum growth rates for young (10-80 mm) A. *nodosum* in Scotland were 7mm (Sept-Nov), 5mm (Nov-Feb) and 10mm (Feb-May) (Schonbeck & Norton 1980).

2.9 Proposals for further work

The analysis above has highlighted a number of topics regarding brown algal shrub species or communities where there are major gaps in our knowledge, gaps which preclude effective or comprehensive risk assessment and drafting of appropriate strategies. These are considered below, with outline proposals for research projects to plug these gaps. The costings proposed are *very* provisional - a more detailed costing would involve some preliminary work in most cases. The costs are presented using a standard breakdown into headings.

2.9.1 Effects of long-term exposure to low-level pollutants, especially on propagules and juveniles

There are few experimental studies on the effects of pollutants on fucoids, and those carried out are nearly all relatively short term. Sjoeten & Lein (1993) examined the effect of oil on *Ascophyllum nodosum,* but the experimental duration was only three weeks. Scanlon & Wilkinson (1987) investigated the effects of several biocides on both early and adult stages of *Fucus serratus,* over much shorter durations. They found that earlier stages were more sensitive. Bokn *et al* (1993) found no significant effect of diesel fraction on fucoids in 2-year mesocosm exposures.

There is a strong need for detailed investigations of the sensitivity of the common intertidal BAS species - *Ascophyllum nodosum, Fucus serratus, F. vesiculosus* and *F. spiralis*, and also the pool species *Cystoseira, Bifurcaria* and *Halidrys* - to a range of putative pollutants. These should include oil, dispersants, pesticides, sewage, and relevant industrial chemicals. It will also be necessary to study propagules, juveniles and adult plants. Short-term experiments would be relatively uninformative, and long-term exposure to low concentrations is required. As discussed above, there is an absence of established protocols for such work, and the initial component of this study would be a series of trials to try and develop satisfactory methodologies. Until these have been done it is difficult to present any detailed proposals for a programme, but the 2-year tidal-simulated mesocosm experiments of Bokn *et al* (1993) point the way forward. A minimum 3-year research programme is needed here.

Estimated direct project costs (normally overheads to be added)

Labour	
Principle scientist(s) (0.75 years)	£30,000
Research assistants (3 years)	£70,000
Technicians (3 years)	£43,000
Travel and subsistence	£ 6,000
Consumables	£ 9,000
Equipment	£15,000
Total direct costs	£173,000

2.9.2 Rates of recovery/recolonisation of associated fauna/flora

It is very clear from both experimental studies (Hartnoll & Hawkins 1985), and from the observations of major environmental events such as oil spills (Southward & Southward 1978; Hawkins & Southward 1992), that the knock-on effects of the loss or development of a BAS canopy are very substantial. There are major effects on all other elements of the community. The encrusting and turf-forming algae can benefit from the shade of BAS, but be inhibited by the removal of light. The various animal species are affected by changes in food supply, shade, sweeping, and availability of rock surface. The population cycles set up can take years to return to a stable situation.

The only effective way to study these processes is by experimental manipulation in the field. BAS canopies can be cleared, and the changes monitored. Alternatively, canopies can be generated by the exclusion of grazers. Experiments of this type are in progress as part of the EU funded *Eurorock* programme, and should substantially improve our understanding of these processes on a Europe-wide scale. If a further programme were to be started the field sites would need to be monitored for three years.

Estimated direct project costs (normally overheads to be added)

Labour	
Principle scientist(s) (0.25 years)	£10,000
Research assistants (3 years)	£70,000
Technicians (1 year)	£14,000
Travel and subsistence	£10,000
Consumables	£ 6,000
Equipment	£ 5,000
Total direct costs	£115,000

2.9.3 Early growth rate of species, escape from grazing

It is assumed that the rate of growth of very small fucoids is a major factor in their escape from grazing, since the major grazer is the limpet *Patella*, and beyond a certain size fucoid sporelings are not eaten. Neither of these assumptions are based on detailed studies, and both need further investigation.

It is very difficult to identify very small fucoid sporelings to species in the field, so the investigation of early growth rates must be based upon laboratory culture to produce settlements of single-species stands. These settlements would need to be induced on settlement plates suitable for deployment on the shore - only growth in the natural environment would be relevant. The plates would initially be deployed in grazer-exclusion areas, and growth rates would be monitored in the absence of grazers. At appropriate germling-size increments a proportion of plates would be opened to grazer access to determine whether grazer immunity had been reached.

The programme would ideally include the major BAS species - *Ascophyllum nodosum, Fucus serratus, F. vesiculosus* and perhaps *F. spiralis.* It would need to be conducted at two shore levels (three if *F. spiralis* included) in a fully factorial format. The combined demands of laboratory culture and fieldwork would require two workers for a two-year period.

Estimated direct project costs (normally overheads to be added)	
Labour	
Principle scientist(s) (0.5 years)	£20,000
Research assistants (4 years)	£93,000
Technicians (2 years)	£29,000
Travel and subsistence	£ 6,000
Consumables	£ 8,000
Equipment	£10,000
Total direct costs	£166,000

2.9.4 Generality of sensitivity to chlorate

Desk study Prior to carrying out any experimental work, it would make sense to carry out a further desk study to find out the likelihood of significant quantities of chlorate being generated in any coastal areas of Britain. This could take the form of further literature search combined with enquiries to likely sources of knowledge; the latter could include the Department of the Environment (UK, NI), Environment Agency personnel, and industrial chemists. It is suggested that this should take up to ten man days at an estimated cost (ex overheads) of £1,500 - 2,500 depending on the level of experience.

Experimental work Rosemarin *et al* (1994), who worked with populations from the Baltic, studied several Phaeophyta including *Fucus vesiculosus*. All species examined displayed major toxic reactions to chlorate down to the lowest concentrations used (21 $\mu g\ ClO_3\ litre^{-1}$). This sensitivity needs to be confirmed using British populations, which will certainly be genetically different from the rather specialised Baltic ones, and covering the main BAS species - *Ascophyllum nodosum, Fucus serratus, F. vesiculosus* and *F. spiralis.*

The basic experimental protocol would involve all species and a range of chlorate concentrations in a fully factorial design. The range of chlorate concentrations would need to extend below that used by Rosemarin *et al* (1994). Both growth rate and photosynthetic performance could be used as measures of damage. A problem arises with the experimental format which did not arise in relation to the subtidal Baltic populations. Are the experiments going to involve continuous submersion, which is an un-natural situation for British fucoids, or will a more or less natural regime of immersion be provided for each species? The literature is not helpful in providing guidance for long-term experiments on fucoids. Sjoeten & Lein (1993), working with *Ascophyllum*, employed short term exposure (3 days) and a maximum observation period of 3 weeks, but they did incorporate periods of air exposure to simulate low tides. Scanlon & Wilkinson (1987), with *Fucus serratus*, carried out only short-term experiments. Developing relevant and appropriate protocols will be a major element in this programme - the tidal-simulated mesocosm experiments of Bokn *et al* (1993) offer a starting point. A two-year programme is suggested.

Estimated direct project costs (normally overheads to be added)

Labour	
Principle scientist(s) (0.5 years)	£20,000
Research assistants (2 years)	£47,000
Technicians (2 years)	£29,000
Travel and subsistence	£ 2,000
Consumables	£ 8,000
Equipment	£10,000
Total direct costs	£116,000

2.9.5 Impact of alien introductions on rock pool algae (*Cystoseira, Bifurcaria*) in SW England

The Japanese seaweed *Sargassum muticum* appeared in the Isle of Wight in 1973 (Farnham *et al* 1973), and has subsequently spread in both directions along the Channel (Farnham *et al* 1981). It occurs subtidally and in pools, and in pools it competes with other pool dwelling browns, such as *Cystoseira* and *Bifurcaria*, and may outcompete them (Eno 1995; Hawkins, personal observations) and possibly other specis such as the red alga *Furcellaria lumbricoides* (Gilliland pers comm). Since *Sargassum* is still spreading its ecological effects in the intertidal should be examined, even though these are restricted to the pool microhabitat. Recently *Sargassum* has rounded Lands End and is advancing up the west coast. It has been found in pools at Polzeath (August 1995) and drift is common as far north as Saunton (S.J. Hawkins, unpublished). *Undaria* is also likely to spread rapidly and to pose a threat to rock pool species.

The most straightforward approach to the investigation would be a comparison of areas where *Sargassum* is present with those where it is absent. The abundance of *Cystoseira* and *Bifurcaria* in suitable pools in the two areas could then be compared. It would be essential to include several shores in each category, they should not be geographically discrete, and the shores would have to be shores suited to the native species. Even so, objections could be made to the protocol.

A better approach would be an experimental one, utilising only shores where *Sargassum* is already established in pools with *Cystoseira* and *Bifurcaria*. At least three shores should be selected, and a series of pools selected on each shore containing *Sargassum* and at least one of the native species. The pools should be randomly allocated to control and experimental categories, and in the latter all *Sargassum* removed. Any *Sargassum* appearing during the experimental period should be removed. The abundance of *Cystoseira* and *Bifurcaria* in both pool categories would be monitored for one year at three monthly intervals. A programme using both approaches would extend over two years.

Competitive effects of *Undaria* should also be studied. The present more limited distribution of *Undaria* means it is probably impractical to use the same areas for study of both, but this possibility should be considered. In the event that combined work of this fashion is not possible, separate funding of similar work on *Undaria* should be undertaken.

<u>Estimated direct project costs</u> (normally overheads to be added)

Labour	
Principle scientist(s) (0.5 years)	£20,000
Research assistants (2 years)	£47,000
Technicians (1 years)	£14,000
Travel and subsistence	£ 8,000
Consumables	£ 6,000
Equipment	£ 5,000
Total direct costs	£100,000

2.10 Assessing the extent to which present knowledge of sensitivity allows assessment of criteria for identifying Critical Natural Capital (CNC).

The following questions are those which need to be asked in order to identify CNC in the maritime zone, according to Masters and Gee (1995, Appendix 2) who used the term Critical Environmental Capital (CEC). Comments on the present state of knowledge regarding sensitivity are made where relevant. Some of the questions can only be effectively answered in relation to specific sites.

a) **Species Reproduction** These questions test the ability of key species to regenerate and reproduce themselves.

What key species are present on site?	All brown algal shrubs can be regarded as key species. Limpets - *Patella spp* - will also be present.
Are any key species longlived (25+ years)?	*Ascophyllum* is the only one with a lifespan greater than 25 years.
Do these [long lived] species have reproductional rates such that generational turnover is 25+ years?	Limited data, but turnover rate probably greater than 25 years.
Is the populational trend of any key species declining?	No indication that this is the case nationally.
Can this decline be halted and reversed by human intervention?	

b) **Species Physical Sensitivity** This section addresses the sensitivity of key species to physical disturbance, and the effect this may have on their fitness.

Are these species habitat specific?	Yes. Extensive data on distribution in relation to shore height and wave exposure.
Are any of key species particularly sensitive to physical damage, disturbance or pollution?	*Ascophyllum* is possibly more sensitive to trampling. Inadequate data on comparative sensitivity of BAS species to pollution, though in general they are not thought to be particularly sensitive. Known exceptions include extreme sensitivity to chlorate, and *Cystoseira tamariscifolia* is thought to be sensitive to pollutants such as detergents and hydrocarbons.
If the site is threatened by these impacts, could human intervention make good the resulting damage?	Insufficient experience or knowledge to answer this properly, though generally seems unlikely.

c) **Island Biogeography** These criteria relate to the ability of key species to (re)colonise a site.

Are any key species at the site isolated by physical space or barriers from the nearest neighbouring colony?	Not relevant to this study.
Are these barriers impenetrable? **or** Is the nearest neighbouring source of recolonisation beyond the normal dispersal range of these key species?	Not relevant to this study. Dispersal range may be surprisingly small - see text.
Could recolonisation of key species be achieved by human intervention (technically and financially)?	Technically possible by transplant of suitable colonised substrate. Unlikely to be financially attractive.

d) **Natural Processes** These criteria relate to the role a site may play in coastal processes, in earth science interest, or coastal defence.

Does the site contain features that potentially make a significant contribution to coast protection / sea defence?	Yes. The rocky substrate and the algal shrub community will both dissipate wave action.
Would it be technically and financially feasible to replace these natural features with engineered coastal protection/sea defence?	Not directly relevant to this study, but unlikely. Sea defences will create artificial rocky shores.
Does the site play a significant role in natural coastal processes?	Not relevant to this study, but probably.
Would it be technically and financially feasible to maintain these processes at the site artificially?	Not relevant to this study, but unlikely.

e) **Technological Factors: Ecological Restoration** These criteria consider whether it is technically and financially possible to restore a natural habitat/community artificially.

Should the site be destroyed, could the conditions that existed previously be reinstated/recreated at the same site and or another available location within the natural area?	Cannot comment without knowledge of site and detail of mode of 'destruction'.
Would key species be able to recolonise site naturally? (refer to biogeography criteria).	Yes in many cases, depending upon distance. All have planktonic propagules.
Would it be technically and financially feasible to restore these key species to the site artificially?	Technically possible, though never tried. Financial feasibility would depend on site, but unlikely to be attractive.

2.11 References - intertidal brown algal shrubs

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3 Subtidal faunal reef communities - *Sabellaria spinulosa*

3.1 Introduction

Sabellaria spinulosa was originally included under the category of faunal accretion in Holt *et al* (1995) based on the BIOMAR life form classification. For the purpose of this study we were asked to consider it as a subtidal reef. In practice we have considered 'accretion' and 'reef' to be synonymous, although it could be argued that 'reef' has the connotations of a rather more substantial structure than 'accretion'. The initial work of Holt *et al* (1995) covered *Sabellaria alveolata* in more detail than *Sabellaria spinulosa*, simply because there was more readily available information on the former.

This work attempts to cover the following important characteristics of *Sabellaria spinulosa* with reference to sensitivity as outlined in the initial scoping report:

Physical form of *Sabellaria spinulosa*
Longevity and stability of *Sabellaria spinulosa* individuals and colonies
Fragility of *Sabellaria spinulosa* colonies
Intolerance of *Sabellaria spinulosa* individuals / colonies
Recoverability of *Sabellaria spinulosa* colonies

Equivalent MNCR biotopes

Table 3 shows MNCR marine biotopes dominated by *Sabellaria spinulosa* (from Connor *et al* 1996). These are apparently under revision at present and further definition of biotopes involving *S. spinulosa* seem likely.

Table 3 MNCR biotopes dominated by *Sabellaria spinulosa*, with descriptions (from Connor et al 1996).

MIR.Sab.R *Sabellaria spinulosa* with kelp and red seaweeds on sand-influenced infralittoral. Occurs in exposed/moderately exposed tide-swept and sand-scoured bedrock and boulders. Sometimes with a rich fauna of ascidians, sponges, hydroids and bryozoans. Known distribution given as North East England/South east Scotland and Luce Bay, North Irish Sea.
MCR.Sab.C *Sabellaria spinulosa* crusts on silty turbid circalittoral rocks. Occurs in moderately exposed, slightly tide swept conditions with high turbidity with an almost entire crust (of *Sabellaria spinulosa* Superabundant) with few other species. Known distribution given as NE England and Gower.
MCR.Sab.SAs *Sabellaria spinulosa* reef with sponges, ascidians and brozoans on tide swept circalittoral rock. Occurs in areas with very high level of suspended sand and supports a wide variety of other species. Known distribution given as Seven Sisters, Lleyn, Burrow Head, and off Foyle.

3.2 Physical form and distribution

The physical form in which *Sabellaria spinulosa* occurs is crucial because it is only when it occurs in dense aggregations or "reefs" that it is likely to act as a host for a wide diversity of associated organisms. Its potential classification within the Critical Environmental Capital concept depends on its forming such reefs. Many authors indicate, either directly or by inference, that *S. spinulosa* is most commonly found in solitary form, eg George & Warwick (1985) and Hayward & Ryland (1990). Hayward & Ryland (1990) describe it as "on rocks; sublittoral (occasionally LWS Menai Straits); boreal and warm temperate species; all coasts; locally abundant." A number of editions of local marine fauna refer only to presence of individuals, or at least fail to mention dense aggregations, reefs or accretions.

The Plymouth Marine Fauna (Marine Biological Association 1957) refers to "occasional specimens" and "small numbers" over wide sublittoral areas (while referring to "extensive colonies" of *Sabellaria alveolata* intertidally near Bude). Wilson (1971) found it surprising that in the Plymouth area *S. spinulosa* is "almost entirely solitary", occuring commonly on stones and shells, while in the North Sea it is "frequently colonial"; he carried out settlement experiments which "lead one to expect them [colonies]".

Bruce *et al* (1963) (Marine Fauna of the Isle of Man) reported *S. spinulosa* around the south of the Isle of Man both circalittorally and at 25 fms (c 50m) the latter on shell and shell gravel in *Modiolus* beds and elsewhere, but gave no indication that it was ever abundant.

Garwood (1982) mentioned that *S. spinulosa* was found both intertidally and subtidally off the North East coast of England but did not mention substantial deposits or reefs. However, thick crusts, sometimes extensive, were found off Northumberland and North Yorkshire by MNCR surveys (R. Holt pers comm).

Eales (1967) mentions that *Sabellaria alveolata* and *S. spinulosa* can be found together. This is most likely in the sublittoral fringe area of western coasts. Hiscock (pers comm), however, suggests that many east coast records may confuse *Sabellaria alveolata* (mainly intertidal, definitely a more reef forming perennial species) with *Sabellaria spinulosa* (definitely mainly subtidal, arguably annual or at least less perennial). According to Cunningham *et al* (1984) and Garwood (1982) there are no confirmed reports of *S. alveolata* on the east coast.

Areas where it has been reported to form dense aggregations include the Thames Estuary (Attrill 1996), the Bristol Channel (George & Warwick 1985), EN, EA pers comm), the Solent (Environment Agency South West pers comm), Dublin Bay (Walker & Rees 1980), Burrow Head, North Irish Sea (Earll 1992; Covey in prep in Connor *et al* 1996), Morecambe Bay (Irving *et al* 1996) St Andrews, Scotland and Hilbre Island, Dee Estuary (McIntosh 1922 cited in George & Warwick 1985), Northumberland and North Yorkshire (Connor *et al* 1996 and R Holt, pers comm), Gower (Hiscock 1979 in Connor *et al* 1996), North and West Wales (R holt pers comm; Hiscock 1984 in Connor *et al* 1996) off Foyle, Ireland (Erwin *et al* 1990 in Connor *et al* 1996) the Wash (Warren 1973; NRA 1994; Foster-Smith *et al* 1997), Seven Sisters, Sussex (Wood & Jones in Connor *et al* 1996) and several locations in the southern North Sea (eg Riesen & Riese 1982,; Linke 1951; Dorje 1992).

With the exception of Linke (1951), none of the above references describe very massive reefs of the sort created intertidally by *Sabellaria alveoloata*, but 'crusts' or 'sheets' of variable thickness but rarely more than a few cm thick. There are also few details of density of animals; however, in the Bristol Channel George & Warwick (1985) reported a mean of over 4000 individuals m^{-2}; off Lundy an average of 6800 m^{-2} was found on the wreck of the MV Robert (Hiscock & Rostron unpubl.); and in the south east of England up to 1600 in individual grab sample has been found (Attrill pers comm), thought the crusts reported for the Thames estuary contained only up to 228 m^{-2} (Attrill pers comm). Linke's observations were on intertidal areas in the southern North Sea where he described massive but transient reefs of *Sabellaria spinulosa*. These observations, together with commentary by Wilson (1971)

S. spinulosa > Frequent

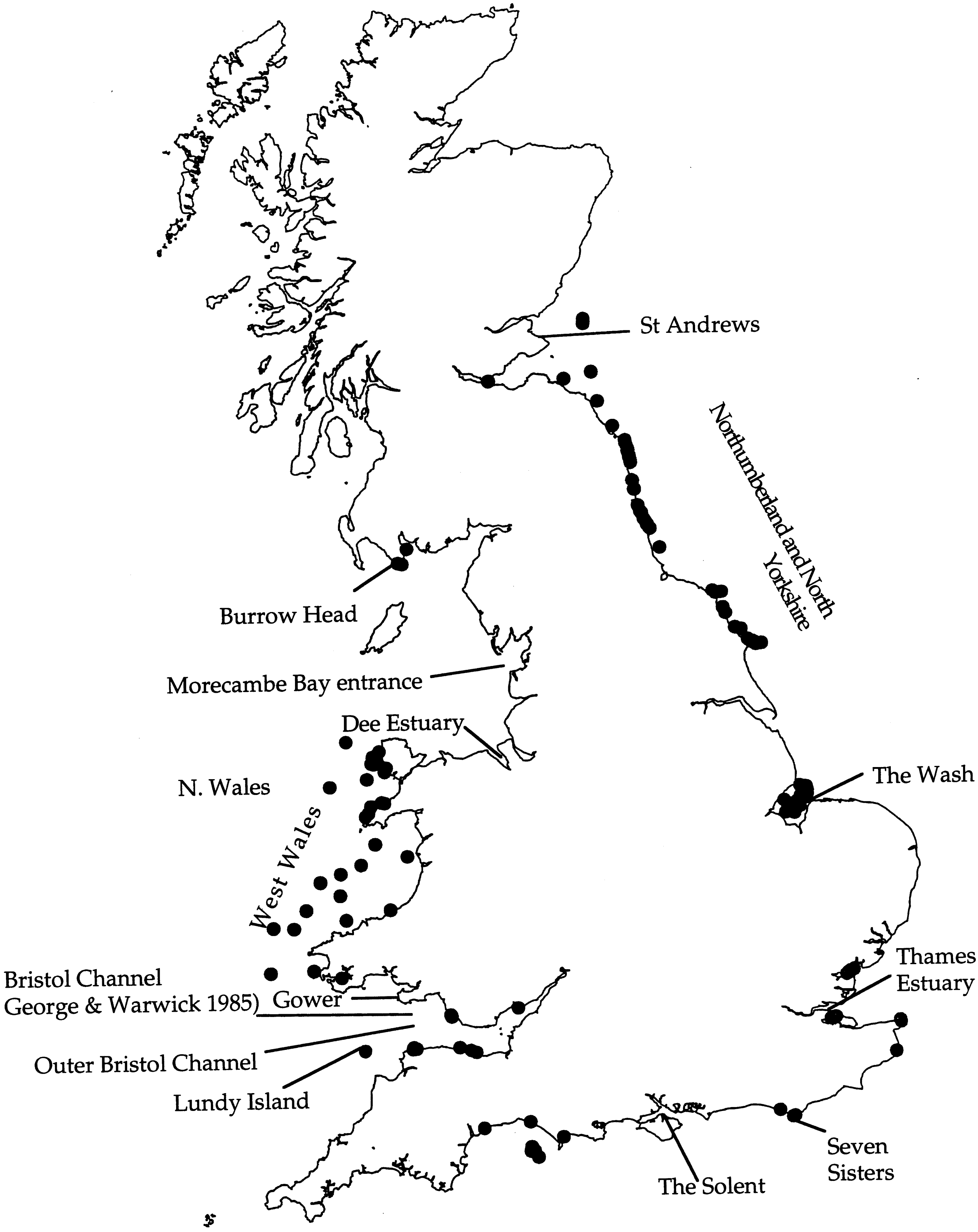

Figure 1 Records for *Sabellaria spinulosa* (records of at least 10% cover only) from the JNCCs MNCR database. Placenames for areas with dense aggregations of *S. spinulosa* mentioned in the text are superimposed (excluding Dublin bay, Ireland, Foyle, N Ireland, and the Dutch and German coasts of the Southern North Sea).

are given in more detail in 3.3. Neither of these authors appears to have considered the possibility that these reefs could have been formed by *Sabellaria alveolata*.

The following is pers comm information from Rohan Holt (MNCR): *Sabellaria spinulosa* appears to be almost ubiquitous on much of the Welsh coast, at least in the north which tends to be more silted or sediment influenced. It is found from the sublittoral fringe to the circalittoral, with many records being from 15-30 m, and seems to be capable of growing on a variety of substrata, including kelp holdfasts, rock and less consolidated sediments such as stony sand or gravel. In some parts of West Wales it grew almost to the exclusion of everything else, and frequently formed sheets up to 2 or 3 cm thick. More often, north west of Anglesey and in other tide swept sites near sediment plains, it forms an underlying thin crust often covered by ascidians and the erect bryozoan *Flustra foliacea*.

Attrill (pers comm) found large aggregations of *S. spinulosa*, up to approximately 20 cm in diameter, while beam trawling on sand in the outer Thames estuary. In other parts of the Thames estuary it formed the more usual sheets or crusts, though these appeared to be thin and not particularly extensive.

The thicker, and probably more permanent, crusts or reefs seem to have a considerable influence on the benthic community structure, eg Connor *et al* (1996) (see Table 3). George & Warwick (1985) mentioned that *Sabellaria* reefs contained a more diverse fauna than nearby areas, and NRA (1984) found sites in the Wash associated with *S. spinulosa* to have more than twice as many species and almost three times as many individuals (excluding the *Sabellaria* themselves) as sites with low, or no, *S. spinulosa*. In the NRA survey sites the distinction between '*S. spinulosa* sites' and 'low or no *S. spinulosa*' was made at only 100 individuals per 3 grab samples (covering 0.3 m^2), raising the possibility that even relatively sparse *S. spinulosa* can strongly influence community structure.

Figure 1 gives an indication of the known distribution of *S. spinulosa* according to the MNCR database (using only records where its abundance was recorded as "frequent" or higher) with any other known areas of dense occurences superimposed.

3.3 Longevity and stability

From survey work on the Northumberland and North Yorkshire coasts, R Holt (pers comm) suggests that *Sabellaria spinulosa* is a fast growing annual as sheets up to 1" (2.4 cm) thick appeared to develop within one growing season. These were definitely seasonal in abundance. Areas where *S. spinulosa* had been lost due to winter storms appeared to recolonize quickly up to the maximum observed 1" (2.4 cm) thick sheet during the following summer.

Attrill *et al* (1996) working with NRA samples found up to 230 / m^2 in one location in the outer Thames estuary, where they resembled the more familiar "sheets", though these were quite thin and not extensive. The samples were collected quarterly for two and a half years; the raw data was made available to us (Attrill pers comm) to look for seasonal variation in abundance, but each sample consisted of only 4 day Grabs so that within-sample and annual variations masked any seasonal variation. No useful seasonal data was therefore found. The melon sized aggregations found in sandy areas by Attrill (pers comm) appeared to be of too great a diameter to be created in one year. However, it is also possible that they are seasonal features which are added to each year, whether or not individual worms are perennial.

George & Warwick (1985) also made seasonal observations in the Bristol Channel. They concluded that in the year of study the settlement of juveniles was low and that the density of adults could not be maintained by that degree of recruitment. They found that the majority of the reef was composed of *S. spinulosa* over one year old but gave no further indication of potential ages. However, they mentioned that most of the species found within the reef matrix are slow growing and long lived with very low turnover rate, suggesting that the reef itself must be relatively old and stable. They also pointed out that, since *Sabellaria alveolata* can live for nine years (Wilson 1971), it is quite possible that *S. spinulosa* could also be long lived.

Reproductive seasonality is unclear, but spawning probably occurs largely over winter and settlement in early spring. George & Warwick (1985) found major settlement in the Bristol Channel to occur in March, which is in agreement with the observations of Wilson (1970, 1971) working in the Plymouth area, who generally found a spawning period from January - March and a settlement period from March to April. Bhaud (1972) reported larvae of *Sabellaria spinulosa* in the plankton from December - March in Mediterranean populations. However, according to Garwood (1982) on the north-east coast of England larvae were found in the plankton from August to November. This would appear to conflict with the seasonal nature of at least some of the reefs in this area as mentioned elsewhere in this report. The MBA (MBA 1957) reported the breeding season according to three separate authorities as "May", "September", and "Jan-Sept, fertilizations made and larvae reared" in the Plymouth area. D. P. Wilson (see Wilson 1970, 1971 above) worked extensively on both *S. alveolata* and *S. spinulosa* for many years (eg "The larvae of the British sabellarians, published in J. mar. biol. Ass. U.K. 1929) and his observations seem to be founded on extensive and careful laboratory and field observations.

Wilson (1971) also discusses the observations of Linke (1951, original reference not seen by present authors) on *Sabellaria spinulosa* in the southern North Sea. Linke apparently described the sudden appearance of massive colonies on stone-work of protective groynes uncovered at low water on the island of Norderney, Fresian islands. In 1943 no colonies were present (time of year of this observation is unknown) but by September 1944 there were reefs 6-8 m wide and 40-60 cm high stretching for 60 m along both sides of three groynes and for 10 m around their broad ends. Linke assumed that settlement took place in 1944. In the summer of 1945 many colonies were dead and those remaining ceased growth in the autumn. Spawning took place in both their first and second years. Small scattered clumps were alive in 1946 but it is not known if they were from the 1944 settlement. Local fishermen confirmed that such reefs do occur annually here and there in other localities, though Linke (1951) observed that in this particular locality there had been only scattered individuals for decades. Wilson (1971) attributed the mass settlement to a swarm of larvae which were induced into settling after having been washed into the area of the scattered individuals. This suggests that perhaps the ability of newly settled young to stimulate settlement of larvae (discussed in 3.3.1) can "accelerate" the settlement process once it has started.

Michaelis (1978) reports that during the 1950s such intertidal populations became rare in this area but gives no explanation. He mentions that *S. spinulosa* was still present subtidally in the area, however.

Neither of these authors appears to have considered the possibility that these reefs could have been *Sabellaria alveolata* misidentified as *S. spinulosa*.

George & Warwick (1985) have suggested that growth and recruitment of *S. spinulosa* could be inhibited or even prevented by dense populations of the brittle star *Ophiothrix fragilis*, which can occur at very high densities thus preventing adequate food particles from reaching the worms. This is thought to have been the reason behind very low recruitment and growth of *S. spinulosa* in an area of the Bristol Channel in 1976. Fecundity of the adults in the colony was also severely reduced, possibly for the same reason. The possibility that the larvae themselves could be filtered out by very dense *O. fragilis* was not mentioned but should be considered.

3.3.1 Substrate requirements

In Holt *et al* (1995), Hiscock (1991) was quoted as saying that *Sabellaria* spp require bedrock to establish a community, but this is not the case; the reference was meant to imply that *S. spinulosa* reefs will form on hard substrata but this does not preclude their formation on other substrata (Hiscock pers comm). (The same is true of *Sabellaria alveolata,* eg Larsonneur 1994).

Other sources also suggest that bedrock is not necessary for formation of *Sabellaria spinulosa* reefs, though a somewhat firm substrate is presumably required. Rees (1993) describes habitat/ distribution as being typically on shell (especially oyster valves), sandy gravel or rocky substrates with moderate to strong tidal flow. Larsonneur (1994) reported the presence of *Sabellaria spinulosa* dominated communities on rock/pebble bottoms in the Bay of Mont St Michel. Incidentally, he also reported that sand stabilised by sand masons *Lanice conchilega* is sufficiently stable to allow colonisation by *S. alveolata.* The same process seems possible with *Sabellaria spinulosa* too, since *Lanice* and *S. spinulosa* are sometimes found together (eg Foster-Smith *et al* 1997) and extensive *S. spinulosa* colonies can occur in essentially sandy areas (see below); this has not been demonstrated, however. Numerous studies have reported high densities of *S. spinulosa* in Day grab or other grab samples which would be unlikely from hard bottoms unless the reefs were extremely thick and very brittle; (Attrill 1996; George & Warwick 1985; Hagmeier & Kandler 1927). Hoare & Hiscock (1974) reported the presence of *S. spinulosa* associated with kelp holdfasts (which themselves require a hard substrate, of course).

Experimental lab work by Wilson (1970) showed that *Sabellaria spinulosa* larvae are strongly stimulated to metamorphose and settle by cement secretions of other *Sabellaria spinulosa,* whether the latter are adult or newly settled young. Scallop shells, particularly *Pecten maximus,* appeared to have some slight settlement inducing properties; oyster shells, with which *Sabellaria spinulosa* are often associated in the southern North Sea, were not tested. While *S. alveolata* larvae were stimulated to metamorphose by cement secretions of *S. spinulosa,* the opposite was rare; *S. spinulosa* are clearly very choosy in this respect. It appeared that in the absence of suitable stimulation metamorphosis and settlement sometimes occurred but always more slowly.

There is some suggestion from field observations that once a colony has established it can increase in extent by addition to the existing colony without the need for hard substrate; Warren & Sheldon (1967), Schafer (1972) and Warren (1973) have reported extensive *Sabellaria spinulosa* colonies in essentially sandy areas.

It is likely that stability of the reefs is to some degree a function of stability of the substratum. The more transient reefs reported by R Holt (pers comm) and others probably occur principally on relatively unstable substrata, while longer lasting reefs could be limited to more stable substrata.

3.4 Fragility

Reefs in the form of widespread sheets are probably surprisingly fragile - George & Warwick (1985) mention that reefs are broken up sufficiently easily to be sampled by Day Grab, a grab not usually very satisfactory for obtaining samples on hard grounds or grounds containing a high proportion of stones (see 3.3). Attrill *et al* (1996) also obtained samples of *S. spinulosa* reefs which they considered to be quantitative using a Day grab, as did NRA (1994). R. Holt (pers comm) has observed that crusts of *S. spinulosa* on cobble and boulders off the Northumberland and North Yorkshire coasts often break up during winter storms. The 'balls' of *S. spinulosa* found by Attrill (pers comm) are probably considerably more robust but there is no hard evidence for this.

Subtidal *S. spinulosa* reefs are reported to have been lost due to physical damage in at least five areas. In the Waddensee, Riesen & Reise (1982) reported that extensive subtidal *S. spinulosa* reefs were lost from the Lister Ley, island of Sylt, between 1924 and 1982; they reported that local shrimp fishermen claimed to have deliberately destroyed them with "heavy gear" as they were in the way of the shrimp trawling. Reise & Schubert (1987) reported similar losses from the Norderau area, and attributed them to similar causes. Shrimp trawling still occurs in these areas and the *S. spinulosa* have not reappeared, but have effectively been replaced by mussel *Mytilus edulis* communities and assemblages of sand dwelling amphipods (Reise & Schubert 1987). The mussels are also exploited.

Dorjes (1992) reported complete loss by 1987 of almost two km^2 of *Sabellaria spinulosa* reef in Jade Bay, North Sea, the distribution of which had been described by Schuster (1952, ref not seen), and suggested that this was probably as a result of fisheries activities.

In Morecambe Bay prawn fisheries have been implicated in the loss of subtidal *Sabellaria spinulos* reefs in the approach channels to the Bay (Taylor 1993; Mistakidis 1956).

Warren & Sheldon (1967), discussing the pink shrimp fishery of the Thames Estuary and the Wash, reported that "it has been the accepted practice among commercial fishermen to search with a small hand dredge for the polychaete worm *Sabellaria spinulosa* and then trawl for shrimp in areas where this was found." Warren (1973) and Warren & Sheldon (1967) reported that *Sabellaria spinulosa*, probably along with other associated organisms, can be an important food source for pink shrimp *Pandalus montagui*. Warren (1973) reported "In recent years ross (*Sabellaria spinulosa*) has been found only in small clumps in the Wash where the bottom is predominantly sandy, particularly towards the offshore end of the fishery. No reefs of ross are known to exist."

Michaelis (1978) mentions that during the 1950s *S. spinulosa* "withdrew from the intertidal area of Niedersachsen" (the Waddensee), where "Formerly the 'reefs' of this worm were frequently found on the head of the groins around the East Friesian Islands", but unfortunately offers no explanation. (See 3.3 for a summary of Linke's observations in this area during the 1940s).

Graham (1955) assumed that trawling would damage *Sabellaria spinulosa* reefs but did not back this up with any direct evidence. He also assumed that recovery would be rapid as the worms were effectively annual.

Rees and Dare (1993), using a four point numerical scale of assessment of "risk of extinctions through natural and anthropogenic factors" for a number of benthic species, considered that the risk for *S. spinulosa* from trawl/dredge effects was high, scoring the maximum 4.

Clearly it is certain that at least in the short term *Sabellaria spinulosa* reefs would be severely damaged by extensive aggregate dredging activities, and that aggregate extraction is very likely to occur in areas where *S. spinulosa* is found, as expected from the distribution and habitat requirements of the species, and as has been noticed in practice by English Nature and others (eg Bristol Channel, Kindleysides pers comm; East Anglia, Attrill pers comm). The extent of important *Sabellaria* reef structures, and speed of recovery from this damage, are presently unknown, though at least one comprehensive study is underway in relation to gravel extraction in the outer Bristol Channel. Compared to fishing impacts, gravel extraction is likely to be more limited in extent, more controlled, and less likely to continue for very long time periods, so that recovery from adjacent undamaged areas seems more likely.

3.5 Intolerance to changes in environmental parameters, especially water quality

Its widespread distribution, which apparently encompasses the whole of the British Isles, including Shetland (MNCR database, Hayward & Ryland 1990) and the Mediterranean Sea (Bhaud 1972), together with its predominantly subtidal habit means that *S. spinulosa* is likely to be much less sensitive to temperature changes than the intertidal *S. alveolata*, which has been shown to be severely affected by low winter temperatures - for example, many *S. alveolata* mortalities were attributed to the cold winter of 1963 while *S. spinulosa* was not affected (Crisp 1964). However, it is worth noting the loss of the intertidal population mentioned by Michaelis (1978) which apparently "withdrew from the intertidal area of Niedersachsen" (in the Waddensee) during the 1950s, as this is one of the few references to sizeable intertidal populations of *S. spinulosa*. No explanations for this withdrawal have been offered, though it appears that these intertidal populations were always sporadic (see 3.3).

Sabellaria spinulosa appears to be generally tolerant of changes in water quality. Hoare & Hiscock (1974) investigated the distribution of marine organisms around the outfall from a bromide extraction plant in North Wales. The effluent had a pH of 4 and among other contaminants contained free halogens. Species richness and diversity was markedly reduced within 150 m of the outfall both intertidally and subtidally, with red algae, *Antedon bifida* and *Helcion pellicidum* being particularly sensitive. However, *S. spinulosa* was found closer to the outfall than any other organism, and was found in larger numbers at intermediate distances than further away. Hoare & Hiscock (1974) also reported that other workers had described *S. spinulosa* as a pollution indicator but unfortunately did not give relevant references.

Furthermore, in a report on surveys of Dublin Bay in relation to sewage discharge and dumping, Walker & Rees (1980) reported that "In the dumping area and in the southeast of the bay downtide of the dump site, where depths are greater, the faunas resembled the *Nucula/Sabellaria* [*spinulosa*] community of Caspers. As well as having pollution indicator species, this latter community generally had greater faunal densities and diversities than elsewhere in the bay (except low diversities at the dump sites in 1971). Apart from a possible effect of depth, this suggests that the dumping was having an enriching rather than a degrading effect, although the probable sediment change since 1874 may imply a change in community type".

The distribution of *S. spinulosa* in reef form appears to be restricted to areas subject to relatively high sediment loadings (Rohan Holt, pers comm; MNCR; Connor *et al* 1996; see also quoted distribution of reef forms in 3.3). Observations from Port Erin Marine Laboratory further support this as it was not found in 51 grab samples from the SE Douglas scallop ground (coarse sand, relatively clean, 30m depth) nor was it found in many hundreds of grab samples from west of Port Erin (similarly coarse and clean ground), though it occurs elsewhere in the Irish Sea. This distribution further supports the argument that it is best regarded as not likely to be very sensitive to changes in water quality induced by man's activities. The exception to this must, of course, be the situation where sediment loadings are reduced, perhaps by changes in water movement as a result of construction. Pollution in the form of increased sediment loading is probably more usual, however, for example due to dredging activities. It seems very unlikely that sediment plumes such as those which can occur in relation to aggregate dredging activities would be responsible for widespread damage to this species.

3.6 Recoverability

There are at least five reported instances of large scale losses of subtidal *S. spinulosa* reef which have been attributed to physical impacts (fishing or fishing gear related): three in the Waddensee, one in Morecambe Bay and one in the Wash (see 3.4). Intertidal populations were also apparently lost in the Waddensee for unknown reasons during the 1950s. No recovery has ever been reported from any of these areas, though trawling or dredging probably continues in the subtidal areas in each case. In Morecambe Bay, the commercial fishery for pink shrimp *Pandalus montagui* previously associated with the *S. spinulosa* reefs has not existed for some time (Sankey 1987 and Andrews, pers comm) though *Pandalus* is still found on rougher ground and brown shrimp *Crangon crangon* are still fished commercially in the general area (Sankey 1987).

In the periods concerned the Waddensee, and arguably the eastern Irish Sea Bay, have undergone some eutrophication.

Potential causes of lack of recovery can therefore be postulated as:

Lack of larval supply, which could conceivably occur when all the reefs in an area have been lost. However, given the apparent fecundity of the organisms this seems unlikely to be sole reason on a long term basis, though it cannot be ruled out, particularly in the short term. George & Warwick (1985) have demonstrated that fecundity and recruitment are likely to be highly variable (see earlier). The dispersal range of the larvae is not known; they do, however, spend between 6 weeks and 2 months in the plankton, and in experimental conditions are capable of spending much longer periods in the plankton before succesfully settling (Wilson 1970). Dispersal range is therefore likely to be considerable.

Continuation of physical impacts. This seems likely to be the most important factor in the Waddensee cases, at least. However, the fishery for pink shrimp no longer exists in Morecambe Bay, although it is not known if the lack of *S. spinulosa* reefs has resulted in more widespread bottom trawling for other species.

Lack of suitable substrate. It is possible that the majority of suitable substrate for initial establishment of *S. spinulosa* colonies has been removed by continuous fishing. There is insufficient knowledge of the true requirements to make an informed judgment. However, the stimulation of metamorphosis and settlement by previously existing *S. spinulosa*, and apparent lack of settlement without this stimulation, is potentially important in this regard (see above).

Competition by other filter feeders as reported by George & Warwick (1985) referring to *Ophiothrix fragilis*. In one area of the Waddensee the reefs were replaced by communities often dominated by *Mytilus edulis*, which is presumably less susceptible to physical damage. There is no knowledge of the likely competitive interactions between *Mytilus* and *S. spinulosa*. There is also no knowledge regarding the possibility of removal of the larvae by filter feeders such as *Ophiothrix* and *Mytilus*.

Deterioration in water quality. This seems very unlikely to be a significant factor in view of other information gathered (see 3.3.1).

Rees and Dare (1993), using a four point numerical scale of life-cycle traits for selected benthic species, considered that *Sabellaria spinulosa* had low recruitment (scoring 1 out of 4) and were moderately long-lived (scoring 2/4) with low annual mortality rate (2/4), but conceded that there was very little published information for these traits on which to base the scores.

3.7 Proposals for further work

Any future work would need to be carried out as part of, or in parallel with, proposed work under the EU LIFE II programme in support of the UK Marine Special Areas for Conservation. In this regard Countryside Council for Wales are the lead organisation for on-going studies of the dynamics and sensitivity of Annex I/II features* and for literature reviews and workshops to increase understanding on the biological characteristics of Annex I/II features*, which include reef biotopes such as *Sabellaria* and *Modiolus* reefs. *Refers to Annexes I (habitats) and II (Species) of the EU Habitats Directive.

There is presently a monitoring programme in operation on *Sabellaria spinulosa* beds in the outer Bristol Channel in connection with an aggregate dredging operation (D. Kindleysides pers comm). This appears to have little or no seasonal component to it, though the present authors have not had access to details of the programme. We also do not know whether it includes analysis of year classes of the *S. spinulosa* cf George & Warwick (1985). If not, inclusion of analysis of recruitment and population structure on a seasonal and interannual basis could substantially increase the knowledge gained from this work.

On a wider scale there is a need for information on recruitment, longevity and stability on a variety of *S. spinulosa* reefs from areas where they appear to be mainly annual and areas where they may be more stable and long lived. Settlement surfaces, bearing varying amounts of existing *Sabellaria spinulosa*, could be placed in a variety of suitable locations and subsequently monitored monthly. A minimum three year programme is suggested. This would be a relatively expensive programme, requiring considerable boat time, and probably diving studies, in more than one site. It should ideally be carried out in conjunction with an aggregate dredging montioring programme such as that outlined above, but we presently have insufficient details to determine what additional work would be required.

Clearly one of the most informative programmes which can be envisaged would be observations on recovery in an area where fishing activities have previously had effects but have ceased. Within Britain this would probably be limited to the Morecambe Bay area, about which we presently have very little information. Fishery exclusion areas are politically and practically difficult to obtain, and notoriously difficult to police even when close inshore and highly visible. The apparent cessation of the commercial pink shrimp fishery is therefore very promising in this regard, though of course if the reefs are no longer present then trawling for other species (*Crangon*, flatfish) may have become possible in the same area. Sankey (1987) implies that these areas may remain rough and as such may not be fished. The situation requires clarification, however. Furthermore, we presently have not been able to find sufficient detailed knowledge of the previous distribution of the *S. spinulosa* reefs to allow a full programme to be prepared. Given this information, a series of surveys of the area using a combination of sidescan sonar, video tows and RoxAnn, backed up by Day Grab sampling, can be envisaged. Based on recent experience in the Wash and Morecambe Bay, RoxAnn surveys alone are not thought to be very good at detecting *Sabellaria spinulosa* crusts (Foster-Smith *et al* 1997; P. Gilliland pers comm), but nevertheless probably provide additional information if carried out during other surveys. Sidescan surveys are of most value in providing topographical information on the seabed, but have been used to map communities including beds of *Ophiothrix fragilis* and reefs of *Modiolus modiolus* in the North Irish Sea (Holt *et al* 1996).

3.8 Assessing the extent to which present knowledge of sensitivity allows assessment of criteria for identifying Critical Natural Capital (CNC).

The following questions are those which need to be asked in order to identify CNC in the maritime zone, according to Masters and Gee (1995, Appendix 2) who used the term Critical Environmental Capital (CEC). Comments on the present state of knowledge regarding sensitivity are made where relevant. Some of the questions can only be effectively answered in relation to specific sites.

a) **Species Reproduction** These questions test the ability of key species to regenerate and reproduce themselves.

What key species are present on site?	*Sabellaria spinulosa* can be regarded as a key species when it forms long lasting reefs, but might not be regarded so if the population is strongly annual.
Are any key species longlived (25+ years)?	Not long lived as individual animals but possibly so as reefs. Insufficient information on longevity/stability of reefs.
Do these [long lived] species have reproductional rates such that generational turnover is 25+ years?	No.
Is the populational trend of any key species declining?	Some areas of reef have been lost in Morecambe Bay and the Wash, and in the southern North Sea.
Can this decline be halted and reversed by human intervention?	Insufficient knowledge for longer lived, more stable reefs, which are likely to be the ones most at risk.

b) **Species Physical Sensitivity** This section addresses the sensitivity of key species to physical disturbance, and the effect this may have on their fitness.

Are these species habitat specific?	Generally yes, though we do not know in detail how much hard bottom is needed. High sediment loadings are required in the water. Presence of other *Sabellaria spinulosa* is likely to be very important.
Are any of key species particularly sensitive to physical damage, disturbance or pollution?	Can be very sensitive to fishing and possibly other physical disturbance, probably not particularly sensitive to pollution in general.
If the site is threatened by these impacts, could human intervention make good the resulting damage?	Insufficient experience or knowledge to answer this properly, but seems unlikely.

c) **Island Biogeography** These criteria relate to the ability of key species to (re)colonise a site.

Are any key species at the site isolated by physical space or barriers from the nearest neighbouring colony?	Not relevant to this study.
Are these barriers impenetrable? **or** Is the nearest neighbouring source of recolonisation beyond the normal dispersal range of these key species?	Not relevant to this study. No direct knowledge of dispersal range though larvae reported to be in the water for 2-3 months before settling so likely to be considerable.
Could recolonisation of key species be achieved by human intervention (technically and financially)?	No knowledge therefore seems unlikely.

d) **Natural Processes** These criteria relate to the role a site may play in coastal processes, in earth science interest, or coastal defence.

Does the site contain features that potentially make a significant contribution to coast protection / sea defence?	Not relevant to this study. *S. spinulosa* reefs seem unlikely to perform this role alone.
Would it be technically and financially feasible to replace these natural features with engineered coastal protection/sea defence?	Not relevant to this study.
Does the site play a significant role in natural coastal processes?	Not known but seems unlikely.
Would it be technically and financially feasible to maintain these processes at the site artificially?	See above.

e) **Technological Factors: Ecological Restoration** These criteria consider whether it is technically and financially possible to restore a natural habitat/community artificially.

Should the site be destroyed, could the conditions that existed previously be reinstated/recreated at the same site and or another available location within the natural area?	Not relevant to this study.
Would key species be able to recolonise site naturally? (refer to biogeography criteria).	Where *S. spinulosa* acts as an annual we may often be able to answer yes quite confidently to this question. However, where there are apparently more long-lived stable reefs, we will not be able to answer the question confidently.
Would it be technically and financially feasible to restore these key species to the site artificially?	No knowledge therefore seems unlikely.

3.9 References - *Sabellaria spinulosa* reefs

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4 *Zostera* beds

4.1 Introduction

Three MNCR biotopes dominaed by *Zostera* are presently recognised (Table 4).

Table 4 The following MNCR biotopes are dominated by *Zostera* (from Connor *et al* 1996).

EMS.Pcer.Znol	*Zostera noltii* beds in upper to mid shore muddy sand. "PCer" refers to polychaetes and *Cerastoderma edulis*. Scarce, confined to estuaries where salinity varies from 8-30°/₀₀, and normally in sheltered to very sheltered areas. *Hydrobia ulvae* is a characterising species.
IGS.Zmar	*Zostera marina / angustifolia* beds in lower shore to infralittoral clean or muddy sand. Typically to about 5m depth, sheltered to very sheltered, full salinity. Associated flora and fauna can include *Laminaria saccharina, Chorda filum, Ensis* spp and *Echinocardium cordatum*. Known distribution given as including Shetland, Scilly Isles, South Wales, North/Northwest Ireland and widespread in the west of Scotland.
IMS.ZmarBv	*Zostera marina* and bivalves in sheltered infralittoral fine sand and mud. Differs from above in sometimes occuring in moderately exposed areas, being more muddy with a greater bivalve infauna eg *Mya truncata* and *Abra alba*. Examples of known distribution given as Shetland, Orkney, East Scottish lagoons, Devon, West of Scotland and Northwest Ireland.

Holt *et al* (1995) pointed out that the ecology of seagrass beds and the effects of disturbance, whether man induced or otherwise, have been well studied in America and Northern Europe, particularly the Wadden Sea area. This work was prompted by the huge losses of seagrass beds in Northern Europe, and North America during the early part of this century, caused by 'wasting disease' (Jermyn 1974; Rasmussen 1977; den Hartog 1987; den Hartog 1989; Giesen *et al* 1990b), general lack of recovery of those beds, and the importance of seagrass communities to other communities, particularly to certain bird populations. A great deal of research has been carried out on *Zostera marina* in particular, yet a full understanding of the causes of massive declines has still not been achieved. *Z. marina* is undoubtedly extremely sensitive to man induced changes, particularly in relation to eutrophication, sedimentation, and turbidity, and its poor ability to recover naturally exacerbates this. However, in view of the massive amounts of literature available on *Zostera marina*, and the preliminary nature of the report by Holt *et al* (1995) this report has attempted to update and add to the knowledge base under headings appropriate to the definitions of sensitivity used throughout this report (longevity, stability, fragility, 'intolerance' to changes in environmental conditions, particularly water quality, and recoverability). Proposals for future work are given in 4.10.1 - 4.10.5.

An important point omitted by Holt *et al* (1995) is that there is some doubt over the taxonomic status of *Zostera angustifolia*, since some workers regard it as a narrow leaved intertidal form of *Zostera marina*. The clarificiation of its true taxonomic status is of vital importance in sensible discussion of the sensitivity (and vulnerability) of *Zostera marina*, and for management decisions. This subject has therefore been discussed in section 4.1 and proposals detailed for initial taxonomic studies (section 4.10.2).

Within Britain there seems to be a relatively large amount of survey material (including reports of loss/appearance/spread/status of *Zostera*), though much of this is in grey literature (unpublished reports etc). Despite this there are certainly gaps even in this knowledge, which is widely spread and would benefit from being collated. In contrast, there is a lack of scientific research into factors which influence growth, reproduction, colonisation, recruitment, and mortality of *Zostera* under British conditions - unlike the Netherlands, Denmark, France and the USA, where there have been many more such studies (and also in Australia, though much of the work there has been on more tropical species).

As with more widespread work (particularly Australia and the USA), within Europe, eutrophication is often quoted in general terms as being the major cause of decline, or at least lack of recovery, of *Zostera* beds (excepting the case of wasting disease which remains an enigma). This encompasses a range of causes from blanketing by epiphytes, smothering by thick growths of algae eg *Enteromorpha*, or increased turbidity due to phytoplankton growth. Other causes which have been implicated in seagrass loss worldwide include:

Increased turbidity through eg dredging.
Loss of sediment through changes in water movement.
Increased sediment deposition due to changes in water movement.
Physical damage by anchors or dredging for bivalves or by trampling.
Natural changes in insolation
Changes in temperature and salinity
Invasive species
Changes to grazer regimes

These and other factors are discussed in more detail in the following sections, which are organised under headings appropriate to the definitions of sensitivity used throughout this report (see Holt *et al* 1995 for further details).

4.2 Taxonomic status of the genus *Zostera* in Britain

There is great debate about the specific status of *Z. marina* and *Z. angustifolia*, two of the three *Zostera* species recorded from the British Isles. *Z. angustifolia* is usually distinguished within Britain as a separate species (Tubbs 1996), but is rarely recorded elsewhere, although it has apparently been recorded from Denmark and Sweden (Cleator 1993). There is no such doubt about the status of *Z. noltii* which is clearly a separate species.

The issue of specific status is of great importance because of its potential ramifications for conservation and management issues. For example, decisions regarding the management of adjoining populations of *Z. angustifolia* (intertidal) and *Z. marina* (subtidal) would probably be very different if they were known to be separate species than if they were known to be the same species. In the former situation there are possibilities for recovery of one population from the other, at least in some circumstances, whereas in the latter this could never be the case. Taking a more general view, the relative rarity of *Z. angustifolia* nationally would be regarded less seriously if it were a morph or variety of *Z. marina* than otherwise. If it is a separate species, however, then the possibility that its distribution might be limited largely to Britain gives added responsibility for its protection and management.

There are various putative distinguishing morphological characteristics in *Z. marina / angustifolia*, including leaf size (larger on *Z. marina*), leaf width (wider in *Z. marina*), shape of the leaf tips (rounded in *Z. marina* but notched in *Z. angustifolia*) flowering shoot size (larger in *Z. marina*) and stigma:style ratio (2:1 in *Z. marina* but 1:1 in *Z. angustifolia*). According to Cleator (1993) *Z. marina* is perennial, subtidal, fully marine and reproduces mainly by vegetative propagation, while *Z. angustifolia* is more commonly intertidal, estuarine, relies more upon seed set and some populations may be annual. Taken collectively these numerous differences would seem to indicate that *Zostera marina* and *Z. angustifolia* are different species.

However, *Z. angustifolia* is apparently regarded by many workers as a form of *Zostera marina* (eg den Hartog 1970; Portig *et al* 1994). On the Atlantic coasts of both North America and continental Europe annual and perennial, as well as intertidal and subtidal, populations of *Z. marina* have been commonly described (eg den Hartog 1970; De Heij & Nienhuis 1992; Gagnon *et al* 1980; Keddy 1987). Many of these workers have pointed out great morphological differences within and between these populations, with intertidal forms often having narrower leaves (eg Den Hartog 1970; Rae 1979, cited in Cleator 1993; De Heij & Nienhuis 1992; Nienhuis 1983). It appears that some of the populations described correspond more closely to what is considered to be *Z. angustifolia* in Britain. A possible species difference in continental populations is indicated by the results of Van Lent & Verschuure (1995), who germinated and grew seeds from annual and perennial populations of *Z. marina* and concluded that there was a genetic basis for differences in morphology, germination success under differing salinities and incidence of flowering. However, De Heij & Nienhuis (1992) looked at isozymes in five populations of *Z. marina* from lagoons and estuaries in the south west Netherlands and Roscoff, Brittany by starch gel electrophoresis; they concluded that most of the considerable variation in plant morphology, biomass allocation and the ratio between perennial and annual offspring along the coast of the Netherlands should be attributed to environmental factors and not to genetic differentiation. In Maine, U.S.A., Gagnon *et al* (1980) concluded from starch gel electrophoresis that differences in taxonomic characters, phenology and distribution reported elsewhere between the annual and perennial forms of *Z. marina* must be ascribed to non-genetic factors. Rae (1979, cited in Cleator 1993), working in eastern Scotland, raised serious doubts over the separation of the two species, and observed differences in stigma: style ratio within the populations of *Z. 'marina'* and *Z. 'angustifolia'* studied which were not consistent with those generally regarded as diagnostic of the two species.

Proposals have been made in section 4.10 for initial molecular work into this problem in U.K. populations.

4.3 Longevity

Zostera angustifolia appears often to be annual (eg Cleator 1993). No new information on longevity of perennial populations of *Zostera marina* was found; knowledge thus appears to be limited to the observation of Olesen & Sand-Jensen (1994a) in a shallow subtidal population of *Z. marina*, who reported low survival of shoots (0-24%) after 1.5 to 2.5 years, but reduced mortality of patches of *Zostera* beyond the age of 5 years or so. As with many other workers, Olesen & Sand-Jensen (1994a,b) mention that the rhizomes of *Z. marina* are long lived but do not quote actual ages. It is not clear from any literature found during this study to what degree rhizomes are able to split and thus form independant plants. The rhizomes of *Zostera marina* certainly branch during growth (eg Dawes 1981) and growth of rhizomes is widely recognised as being responsible for reproduction of perennial forms of *Zostera* by lateral expansion of patches (eg Olesen & Sand-Jensen 1994a). In the absence of more definitive information, perennial forms of *Zostera marina* should probably be regarded as extremely long-lived.

4.4 Stability

Zostera beds undergo very strong seasonal variation. In annual populations (usually intertidal) this is represented by complete die back during the winter, and recovery is dependant upon local seed supply. In perennial (often subtidal) populations, die back of the below ground parts is much less significant than die back of the above ground parts. Recovery is dependant more on vegetative growth, with new shoots being produced from the rhizomes.

In the long term, stability is less predictable. There is some suggestion that the massive die offs experienced as a result of the wasting disease may be part of a long term natural cycle, but if this is so it is not predictable. In a time scale measured in years, however, there tends to be reasonable stability especially where beds are perennial.

Intertidal beds are thought to be susceptible to frost, as reported for example at Bembridge, Isle of Wight (Critchley 1980), and significant losses are thought to be possible as a result of cold winters (den Hartog 1987). However, since intertidal populations are often effectively annual, it is speculated that recovery should often be good.

Storms have been reported to be able to decimate entire areas of *Zostera marina* (Orth & Moore 1983, Den Hartog 1987; Wyer et al 1977, the latter working in the Thames estuary).

Changes to epiphyte grazer populations such as *Hydrobia ulvae* can also affect the stability of *Zostera* beds (see 4.7) but since this occurs as a result of increased epiphyte growth the degree to which this effect is heightened by eutrophication can not be gauged. Reasons for the reported changes in grazer numbers are also not known.

Many forms of disturbance seems likely to cause instability because reduced densities of plants can lead to reduced sedimentation, or even removal of sediments, which can result in further losses of plants or difficulty in reestablishment (see 4.6). Olesen & Sand-Jensen (1994a) reported that mortality of patches of shallow subtidal *Zostera marina* in Limfjorfden, Denmark, was very strongly influenced by the size of the patch. Small patches consisting of less than 32 shoots with an average age of less than five years showed high mortalities, while sharply declining patch mortality with increasing patch age and size was presumed to be due to improved anchoring, mutual physical protection and phyiological integration among the shoots.

Overall it is difficult to quantify the stability of *Zostera marina* beds in the absence of man's influence, but there are clearly a number of possible stochastic influences (including wasting disease, storms and frost events) which appear to be superimposed on an otherwise reasonably stable habitat. There is considerable evidence that there is a threshold of loss below which destabilisation and further losses of the beds can occur.

4.5 Fragility

Z. marina, like other seagrasses, is physically not very robust. The root systems are found within the top 20 cm or so of the sediment and are easily dislodged by dredging (for example Fonseca 1992, discussing seagrasses in general). *Zostera* beds have previously been described as sensitive to trampling effects where oil cleanup has been attempted (S.J. Hawkins, pers comm) and in the wake of the Sea Empress oil spill, Anon (1996) reported that *Zostera angustifolia* beds in the SSI at Angle Bay and Pembroke River were exposed to both crude oil and heavy fuel oil, but that damage appeared to be limited to the rutted areas left by the clean-up vehicles. Thom (1993) reported that *Zostera marina* beds in Washington state were damaged by trampling, ironically during mitigation work being carried out in response to crab mortalities.

It is widely accepted that *Zostera* is very sensitive to hydraulic bivalve fishing, as is sometimes used for cockles, due to damage and break up of rhizomes, so that perennial populations are likely to be more sensitive than annual ones. It is also vulnerable, cockles and *Zostera noltii* in particular being frequently associated (eg Connor *et al* 1996). Perkins (1988), discussing cockle harvesting by suction dredge in Auchencairn Bay, Solway Firth, suggested that it could cause widespread damage, or even completely eradicate *Zostera* from the bay. Sediment was also thought to have been destabilised subsequently, potentially worsening the situation. There is presently no hydraulic cockle fishing in Scotland due mainly to concerns over the sustainability of the cockles themselves if harvesting is not very tightly regulated, and to concerns over *Zostera* beds. Eno (1995) reported that *Zostera* beds were damaged due to dredging for *Mercenaria*. Damage to *Zostera* beds caused by dredging for cockles has also been reported from areas of the Dutch Waddensee (E.I. Rees, pers comm).

4.6 Intolerance to changes in environmental conditions, including water quality

According to Dawes (1981) *Z. marina* occurs sparsely in the Mediterranean and Black Seas and also penetrates just into the Arctic circle, so presumably subtidal populations at least must be unlikely to be very temperature sensitive within British waters. Frost damage can occur to intertidal populations, however (see 4.4). Optimum temperatures ranging from 5°C to 30°C have been reported depending upon irradiance (Marsh *et al* 1986; Builthuis 1987) and *Z. marina* generally tolerates temperatures up to 20°C without showing signs of stress (den Hartog 1970). Giesen *et al* (1990b) summarised present knowledge of the effect of temperature on *Z. marina* and concluded that temperature could not have been an important factor in large scale losses in the Wadden Sea. However, stress due to desiccation during the late 1980's was one of the factors which Raines *et al* (1992) considered may have stressed *Zostera marina* populations sufficiently to trigger an outbreak of wasting disease in the Scilly Isles.

Likewise, salinity tolerance of adult *Z. marina* plants seems to be wide; optimum salinities of 10-39 ppt were reported by McRoy (1966) (cited in Giesen *et al* 1990b), while salinities of 5 ppt are tolerated in the Baltic (den Hartog 1970).

The causes and importance of 'wasting disease' have been debated for many years; initial suggestions by Renn (1935; 1936) that the slime mould *Labrynthula* sp was the causative organism have been confirmed recently by Muehlstein *et al* (1988). Muehlstein *et al* also showed that the *Labrynthula* sp does not generally cause disease in low salinities, where the wasting disease was relatively absent, and Short *et al* (1988) noted that intertidal populations usually survived, factors which help to explain why *Zostera angustifolia* appeared to be relatively unaffected. Vergheer and den Hartog (1991) demonstrated experimentally that *Zostera noltii* could also contract wasting disease from the same causative agent, and concluded that it's intertidal habit was the reason it did not generally succumb to any great extent. However, the relative importance of wasting disease in eelgrass decline is still debated; it has recently been suggested that plants only succumb, or are more likely to succumb, when they are stressed for other reasons (Giesen *et al* 1990a; Giesen *et al* 1990b; Raines *et al* 1992). Several workers have recently suggested that phenolic content may play an important part in resistance to the disease (eg Buchsbaum *et al* 1990; Vergeer *et al* 1995). Phenolic content of *Z. marina* is known to vary seasonally in Canada (Harrison & Durance 1989) and has been shown experimentally in the Netherlands to increase with increasing irradiance, to reduce with increasing temperature and to be unaffected by salinity (Vergeer *et al* 1995).

Giesen and co-workers suggested that in the Wadden Sea turbidity was a major factor in the decline of eelgrass, that salinity and temperature fluctuations were of minor importance, and that many of the plants would have succumbed even in the absence of the wasting disease. Giesen *et al* (1990a) further elaborated on this theme by suggesting that increased eutrophication, deposit extraction and dredging activities were probably important in causing the increased turbidity along with natural changes in insolation. Eutrophication leading to phytoplankton blooms which increase turbidity has also been implicated, though not proven, in the loss of seagrass beds in Australia.

Many studies have correlated seagrass loss with increased growth of blanketing, floating or epiphytic algae, often as a result of eutrophication due to sewage or agricultural runoff (eg Borum 1985; Twilley *et al* 1985; Wetzel & Neckles 1986, working on *Zostera marina* in Europe; den Hartog and Polderman 1975 working on *Z. marina* and *Z. noltii* in the Dutch Wadden Sea; Orth *et al* 1985 working on *Z. marina* in the USA; Shepherd *et al* 1989 summarising work on a variety of seagrasses in Australia; Kikuchi 1974 working on *Z. marina* in Japan). In contrast to these studies, however, Tubbs & Tubbs (1983) reported that rapid increases in *Zostera* beds, particularly *Z. marina*, were closely correlated with rapid increases in volumes of treated and untreated effluent in three areas in the Solent; Chichester, Langstone and Portsmouth Harbours, though they maintained that there was still no direct evidence of a causal relationship. This spread represented a recovery in areas which had suffered a decline before the 1950s for reasons which probably included the building of new docks and the dredging of channels (Butcher 1941 cited in Tubbs & Tubbs 1983). However, den Hartog (1994) reported that an entire 10 Ha bed of *Z. marina* and *Z. noltii* was lost from Langstone harbour, as a result of a dense blanket of *Enteromorpha radiata* which grew in 1991, so that by the summer of 1992 not a single specimen of *Zostera* was found. Although most of the loss was as a direct result of the *Enteromorpha*, there is some suspicion that the last remaining plants were grazed by brent geese *Branta bernicla* (see 4.8).

Burkholder *et al* (1993) found that nitrate enrichment could directly cause death or decline in American seagrasses, stating that under conditions simulating poorly flushed areas "even low level of chronic water column nitrate enrichment can promote the decline of eel grass"; they found that *Z. marina* was much more sensitive than *Halodule wrightii* or *Ruppia maritima*, and that the effect was exacerbated by associated heavy epiphyte growth. However, a number of other American workers have reported increased growth rates in *Z. marina* upon application of nitrate bearing fertilizers (Fonseca *et al* 1987; Kenworthy & Fonseca 1992; Fonseca *et al* 1994) and seemingly every case must be evaluated separately in this regard. It seems likely that in many situations, especially in areas away from high nutrient inputs, low levels of nitrate addition can sometimes stimulate growth, but at higher concentrations or in estuaries or near other sources of nutrient enrichment swamping by ephemerals can occur.

A number of further causes of seagrass loss worldwide have been reported: foremost amongst these are both sediment erosion and sediment accretion. Sediment erosion, caused for example by increased wave or currents due to inappropriate dredging, has been strongly implicated in loss of *Posidonia* beds in the Mediterranean (Boudouresque & Meinesz 1982, cited in Peres 1984) and *Posidonia* and *Heterozostera* beds in Australia (Shepherd *et al* 1989). Furthermore, in both the Mediterranean and Australia it has been shown that the resulting loss of seagrass can create negative feedback in which the lack of stabilisation by the seagrasses leads to increased sediment in the water, and hence to further losses (Bulthuis *et al* 1984; Jeudy de Grissac 1984, cited in Shepherd *et al* 1989). On the other hand, increasing sediment accretion, which can be caused by inappropriate groyne or harbour construction, for example, has caused losses of seagrass beds in several parts of Australia (eg Clarke & Thomas 1988; Kirkman 1988; Shepherd *et al* 1989). While simple blocking out of light seems the most likely mechanism in this case others, such as changes in redox potential of surface sediments, have been suggested (eg Thayer & Williams 1975).

Philippart *et al* (1990) used ecological modelling methods to suggest that no seagrass could be expected in the region of the main river estuaries in the Wadden Sea area, even under optimal conditions of emersion times, sediment type and sediment stability, and recommended further research on the effects of river output on seagrass growth.

A review by Williams *et al* (1994) summarises present knowledge on heavy metal uptake and toxicity in saltmarsh plants, including *Zostera marina*. They concluded that *Z. marina* readily takes up heavy metals and that it can be used as an indicator species for levels in the surrounding water and sediment, though leaf uptake from water is more important than rhizome uptake from sediments. They also concluded that TBT was readily concentrated, but that neither this nor any of the metals they had studied had caused any observable damage to plants in the field. They further quoted Dunstan & Windom (1974) and Waddell & Kraus (1990) who had found evidence of effects on germination and/or seedling development in *Spartina alterniflora*, with an ability to develop heavy metal tolerance evident from field observations by the latter, but did not mention *Zostera*. Overall, Williams *et al* (1994) concluded that to date "evidence suggests that the concentration of heavy metals in most estuaries is not sufficiently high to cause ill effects to salt marsh plants" which they defined as including seagrasses.

Sensitivity to chronic oil refinery effluent may also not be particularly high: Hiscock (1987) reported that there were no long term effects in Littlewick Bay, Milford Haven attributable to the presence of an Esso oil refinery, though he suggested this may be due to lack of penetration into this area by the effluent; while Cambridge *et al* (1986) and Shepherd *et al* (1989) reported that *Posidonia sinuosa* (Western Australia) was "rather insensitive" to oil refinery effluent based on both experiments in aquaria and field observations, though they nevertheless attributed some local, but not large scale, decline to this cause. A number of studies have suggested that in general the associated faunal communities may be more sensitive to oil pollution than seagrass plants themselves (eg Jacobs *et al* 1980; Zieman *et al* 1984; Fonseca 1992). If grazers were to be affected, this could potentially have detrimental effects on *Zostera* via increased epiphyte growth (see 4.7). Jacobs *et al* (1980) reported little damage to *Zostera marina* beds in Roscoff after the Amoco Cadiz spill, other than a blackening of many of the leaves for a week or so. However, Howard (1986) was able to produce a significant decline in *Zostera* beds after eight weeks by controlled application of crude Nigerian oil and concluded that the addition of dispersant should be avoided in the vicinity of seagrass beds. In the wake of the Sea Empress oil spill, Anon (1996) reported that *Zostera angustifolia* beds in the SSI at Angle Bay and Pembroke River were exposed to both crude oil and heavy fuel oil, but that damage appeared to be limited to the rutted areas left by clean-up vehicles, neighbouring populations appearing to be healthy. It was not stated how long after the event these observations were made. Rae (1979 cited in Cleator 1993) suggested that *Zostera noltii* was more vulnerable to being covered in oil than *Z. marina* or *Z. angustifolia* due to its habit of growing in well drained areas. No published information on the effects of oil in sediments on germination of seeds was found. This could, of course, be crucial in annual populations.

Rosemarin *et al* (1994), in discussing the extraordinary sensitivity of brown algae to pulp mill chlorate, included *Zostera marina* amongst a list of unaffected plants. However, in general there is a worldwide lack of research on effects of chemicals other than oil or dipsersants on growth or survival of seagrasses, as pointed out by Fonseca (1992).

Not surprisingly, it has repeatedly been suggested that more than one factor is often implicated in large scale seagrass bed losses.

4.7 Alien introductions - *Sargassum*

Givernaud *et al* (1991) (abstract only seen) have reported that in northern France, the accidently introduced alien *Sargassum muticum* has replaced *Zostera marina* in parts of the beds "injured by human activities". *Sargassum* has been observed found in seagrass beds within Britain. Critchley (1980) and Farnham et al (1981) reported that frost damage to *Zostera marina* at Bembridge, Isle of Wight, created bare rock space which was colonised by *Sargassum* germlings. Tubbs (1996) reported that *Sargassum* and *Z. angustifolia* compete for space in low shore lagoons in the same area. In the Scilly Isles *Sargassum* was widespread in *Zostera marina* beds in 1991 and 1992 (Fowler 1991; Raines et al 1992) having not been seen in 1988 (Fowler 1991). Although not yet demonstrated conclusively on a wide scale, it seems likely that at least under some circumstances it can compete with *Zostera*. However, Davison & Davison (1995) concluded that *Sargassum muticum* has generally performed opportunistically, without significantly out-competing or displacing indigenous algae, and that original fears regarding the ecological impact were too dramatic. In discussing various ecological implications of its presence in Strangford Lough they did not mention serious threats to the considerable *Zostera* beds in the lough.

4.8 Changes to grazing animal populations

Numerous studies have surveyed or monitored changes in eelgrass populations in relation to bird grazing, particularly wigeon *Anas penelope* and brent geese *Branta bernicla,* in Britain (eg Ranwell & Downing 1959; Tubbs & Tubbs 1983; Portig *et al* 1994) and elsewhere. These have concluded that large amounts of eelgrass are consumed, but this probably forms part of the large seasonal fluctuations which are normal for *Zostera*. However, it is not inconceivable that increases in bird populations as a result of interference by man could increase pressure on intertidal *Zostera* populations, as suggested by Jacobs *et al* 1(981), particularly in the case of brent geese *Branta bernicla* which are thought to concentrate their feeding on *Zostera* and to graze on other plants only after depletion of the stock (Charman and Macey 1978). Den Hartog (1994) thought that the beds of *Z. marina / angustifolia* in Langstone harbour which were decimated by overgrowth of *Enteromorpha,* may in fact have been finished off by brent geese *Branta bernicla* grazing on the few remaining healthy plants.

Phillipart (1995) experimentally demonstrated that increasing numbers of the gastropod grazer *Hydrobia ulvae* can reduce epiphyte density and increase the growth rate of *Zostera noltii*. He also notes that several Dutch marine biologists observed a considerable decrease in the densities of *H. ulvae* on the tidal flats of the Wadden See in the early 1970s, which coincided with the appearance of very heavy epiphyte fouling in some areas, and may have been influential in the decline of *Z. noltii* observed following this period. *H. ulvae* is an important part of typical *Z. noltii* communities in the U.K. (Connor *et al* 1996, see Table 4). Other gastropods associated with *Zostera* beds include *Littorina littorea,* which may be abundant on intertidal populations (Tubbs 1996) and topshells such as *Jujubinus striatus* subtidally. Clearly anything which affects grazers such as *Hydrobia* may indirectly influence *Zostera* populations. Reduction of epiphytes by amphipod grazers at densities typical of natural beds has been observed experimentally on *Heterozostera* in Australia (Howard 1982).

4.9 Recoverability

The main means of reproduction is generally vegetative growth, which can be rapid, but according to Dawes (1981) each plant is capable of producing up to 200 seeds in a season, which can germinate and develop into mature plants within 1-2 years. This results in a very high seed production per unit area - eg 3600 - 17,600 /m^2 according to one study in Denmark (Olesen & Sand-Jensen 1993). Many workers have pointed out that sublittoral populations of eelgrass, not subjected to greatly lowered salinities, are generally perennial and produce few, if any, generative shoots (eg Giesen *et al* 1990b). Moreover, light limitation and removal by currents reduce sublittoral seedling success (den Hartog 1970; Jacobs 1982). Laboratory studies by Hootsmans *et al* (1987) using specimens from the Netherlands indicated maximal germination at 30°C and 1 ppt salinity, but optimal seedling survival at 10°C and 10-20 ppt. This is slightly surprising given that *Z. marina* is reported to occur principally in fully saline conditions.

Growth rates in *Z. marina* can be very high given the correct conditions. Olesen & Sand-Jensen (1994) reported that an average of 17 new leaves/shoot/year were produced in a population in Denmark, for example. Nevertheless, recolonization after total loss can be extremely difficult. Few areas have fully recovered from the two major episodes of loss this century (Giesen *et al* 1990a), though "a remarkable increase of the *Zostera marina* beds" seen in a newly formed marine lake at Grevelingen in the Osterscheldt perhaps demonstrates the potential under ideal conditions. According to Verhagen & Nienhuis (1983) eelgrass cover there increased from 1200 to 4400 ha during a ten year period. Within European waters, improvements to illumination, including reduced turbidity, are thought by some to be the main precondition for successful recovery (Giesen *et al* 1990a; Jonge & Jong 1990), while reduced nutrient inputs (which could, of course, increase illumination by virtue of reduced phytoplankton growth) are also seen as beneficial (Olesen & Sand-Jensen 1994).

Annual populations can increase in area much more rapidly than perennial, vegetatively reproducing ones. Expansion rates in excess of 30 m / year have been reported (Harrison 1987) in contrast to likely expansion rates of around 0.5 m / year in perennially growing populations (Olesen & Sand-Jensen 1994). However, despite reports of generally high germination success in the field (Churchill 1993) Olesen & Sand-Jensen (1994) maintain that "colonisation of new areas is probably restricted by a limited dispersal and the subsequent successful development of seedlings into patches" and report that seedling development into patches is often unsuccessful or slow.

Because of the general lack of natural recovery, numerous workers in the North America and Australia, and to a lesser extent Europe, have put a great deal of effort into researching methods of transplanting seagrass plants into suitable areas. A great deal of progress has been made and some workers have claimed considerable success with *Zostera marina* (Backman *et al* 1985; Thayer *et al* 1985; Fonseca *et al* 1987; Kenworthy & Fonseca 1992; Fonseca *et al* 1994). Thayer *et al* (1985) in particular have claimed that densities comparable with natural seagrass meadows have been attained within one year. However, no cost analysis has been seen by the present authors, and at least some studies have cast doubt on the overall ecological value of such 'artificial' meadows in comparison to natural ones (eg Smith *et al* 1989).

Only one reference to transplantation experiments within Britain has been found. This was small scale work carried out by Boorman & Ranwell (1977) in the south-east of England; it was unsuccesful in the long term, although some success had seemed apparent initially. Further work is urgently needed.

4.10 Proposals for further work

There is probably a much greater need for research on *Zostera marina* than on brown algal shrubs or *Sabellaria spinulosa* within British waters. The following is a selection of research proposals which are necessary, worthwhile and feasible, but it is acknowledged that many other suitable proposals could have been included. Any future work would need to be carried out as part of, or in parallel with, proposed work under the U.K.'s Biodiversity Action Plan (BAP), which has specific requirements for *Zostera* beds, and for which the lead organisation is the Department of Environment for Northern Ireland. A workshop on *Zostera* is one likely output from this work; see the proposal for a workshop made in 4.10.1 here. Another likely output may be further collation of knowledge of the present status of *Zostera* in the UK as a whole, which would form the first part of the proposal made in 4.10.3. Work would also need to liaise with the EU LIFE II programme in support of the UK Marine Special Areas for Conservation. In this regard Countryside Council for Wales are the lead organisation for on-going studies of the dynamics and sensitivity of Annex I/II features* and for literature reviews and workshops to increase understanding on the biological characteristics of Annex I/II features*, which include estuaries, shallow subtidal and intertidal sediments, and lagoons. *Refers to Annexes I (habitats) and II (species) of the EU Habitats Directive.

4.10.1 A workshop to discuss sensitivity and vulnerability of *Zostera* in Britain and Europe

There is considerable expertise on *Zostera* in Europe, particularly in Scandinavia and Holland, and to a lesser extent France. The Mediterranean countries also have a long tradition of seagrass work. In contrast, in Britain much less work has been done. A workshop would be a cost effective way of accessing this expertise. A three day working long weekend would cover the subject well. It is worth pointing out that one of the concluding remarks from a published treatise, produced after a workshop in Australia, was "The decline of seagrasses has been brought into sharp focus, since only with the assemblage of information for this book has the magnitude of seagrass loss around Australia become clear" (Larkum *et al* 1989).

The aims of such a workshop would be:

1 Pool available knowledge on the ecology and the sensitivity to environmental impacts on *Zostera* from Britain (likely to be limited) and from other European countries.
2 Summarize such knowledge via a handbook to be produced at the end of the workshop. Each expert would be asked to bring a draft on disc for compilation and editing.
3 Prepare summaries of reserarch needs / action plans to investigate impacts on *Zostera* and means of restoring impacted communities.

Deliverables would therefore be:
1 Summary of knowledge
2 Summary of research needs
3 Action plan for restoration work

Suggested programme:

Day 1 Review session concentrating on status and known sensitivities

Experience in
Denmark / Sweden (45 mins)
Holland (45 mins)

France (45 mins)
Mediterranean (45 mins)

Elsewhere in world (if a suitable expert can be found) (45 mins)
Britain (45 mins)

Discussion session integrating findings, with particular relevance to Britain (60 mins)

Day 2

Research needs workshop (a.m.)

Restoration: experience and experiment (p.m.)

Day 3

Editing and compilation of handbook

Drafting of terms of reference for future research / action

Likely direct costs			Costs
1	Host workshop at a venue ≤ 1.5 hours from Heathrow		
2	Invite 8* experts from Europe (Including Britain)	: SAPEX fare average £250	£1,500
		: Subsistence £180 per person	£1,440
		: Honoraria of £200	£1,600
3	Printing and production costs		£1,000**
4	U.K. travel - minibus or individual travel		£ 600
5	Costs of organisation - if done internally		nil
	if done externally (including editing of proceedings)		£2,000
		Total	£8,140

Plus costs of JNCC and country agency attendees

* Minimum number

** Obviously could be more depending on desired final standard.

4.10.2 Clarification of taxonomy of *Zostera marina / angustifolia*.

It is suggested that isozyme electrophoresis should be used to study genetic differentiation between, and hence the specific status of, *Zostera marina* and *Z. angustifolia*. This technique is to be preferred to other molecular methods because it is generally considered to be the most cost effective for investigating genetic phenomena at the molecular level (Murphy *et al* 1990, Allcock *et al* 1997). Electrophoresis normally gives precise information on the level of genetic differentiation and this generally provides a very good indication of taxonomic status.

The proposal here is for an initial study to assess whether selected populations of *Z. angustifolia* differ genetically from *Zostera marina*. It would be sensible to include samples of *Zostera noltii*, which is universally accepted as a separate species, in order to better interpret differences in polymorphism and heterozygosity.

Gagnon *et al* (1980) succesfully analysed meristematic tissue of *Z. marina* from Maine, U.S.A. by electrophoresis and found that twelve out of fourteen enzymes and general proteins tested were monomorphic, the other two exhibiting two alleles each. Heij & Nienhuis (1992) analysed Dutch and French populations of *Z. marina* using starch gel electrophoresis of seedlings. They tested 21 enzyme systems, of which 12 showed activity on the gels used. Of these, only one was clearly polymorphic. Laushman (1993) concluded that in hydrophilous plant species, including *Z. marina*, at the species level, the percent of polymorphic loci is equal to, or higher than, the average reported for all plant species. At the population level, however, hydrophilous taxa have lower percent of polymorphic loci, fewer alleles per locus, and lower levels of heterozygosity than nonhydrophiles.

It thus appears that starch gel electrophoresis would be very suitable for distinguishing between species of *Zostera;* a high level of polymorphic loci would be very strong evidence of speciation.

It is suggested that the most cost effective approach would be to secure a supply of material suitable for electrophoresis of each of the three nominated *Zostera* species from perhaps four different sites for each, perhaps via site managers of designated conservation sites. This would considerably reduce the overall costs compared to sending someone specifically to collect samples.

Ideally, the most suitable material to work on would probably be seedlings. However, this may necessitate development of techniques for germination of the seeds. Previous workers using seedlings almost all seem to have relied on field conditions for germination, which normally takes some months. Seedlings collected from the field might be subject to misidentification and so should not be used. Another difficulty may be in collecting sufficient numbers of seeds from perennial populations, which often produce few generative shoots.

For these reasons, it is suggested that this initial work is carried out using fresh samples of basal meristematic tissue, as successfully used by Gagnon *et al* (1980).

If there are no hold ups or other problems with the supply of samples a suitably qualified post doctoral researcher (PDRA) should be able to complete a survey of about eight total samples inside about two months. Direct costs for this work would be largely consumables (electrophoresis starch, staining and buffer chemicals), and the salary of the PDRA, with a small bench fee component. Any travelling required or transport of samples would be additional.

Electrophoresis of the samples would concentrate on a number of loci to confirm whether these are suitable for using in a larger, taxonomic, study. The design of, and perhaps even necessity for, such a further study would depend upon the results obtained, and a number of scenarios can be envisaged, eg:

All *"angustifolia"* samples clearly distinguishable from *"marina"* samples - clear evidence of speciation. Further work to confirm the observed pattern in more populations required. May also be thought necessary to involve samples from elsewhere in Europe in case *Z. angustifolia* exists elsewhere.

No apparent differences between any of the samples - likely that only one species exists. Further work to confirm the observed pattern in more populations required.

Some differences found but not consistently. Many possible explanations including the possibility that *"angustifolia"* is a true species but is easily confused with intertidal forms of *"marina"*. A much larger study would probably be required to provide clearer answers.

Estimated direct costs:

Bench fees including lab space, culture facilities	£ 500	
Consumables	£2,500	
Salary component for post doctoral researcher 3.5 man months	£7,000	
		£10,000

Further work which can be envisaged subsequently to this initial study includes wider analysis for within population variation, and morphological and related studies, including transplantation experiments, to further confirm the relationship between form and environment.

4.10.3 Broad surveys of status of *Zostera* including comparison of impacted and unimpacted areas.

The first priority would be to establish the nature of the *Zostera* resource in the United Kingdom and its current status. Work on impacts can then be undertaken. A contract could be let for this purpose as outlined below.

PHASE A Distribution. Primarily a desk study: liaison with JNCC and Country Agencies, with mailshot to these and other likely souces of information. Existing *Zostera* beds would be mapped and information on habitat characterstics collated.

PHASE B Distribution. On the basis of A, fieldwork could be undertaken to map the extent of current *Zostera*, including assessment of apparent influence of any wasting disease. Make measurements of physicochemical conditions at selected sites in order to characterise sites in more detail. Collect specimens for taxonomic/population genetics work (see separate costing) if appropriate.

PHASE C Comparison of impacted and unimpacted areas. This work would involve more detailed survey of impacted (eg eutrophic areas, areas subject to heavy recreational use) and unimpacted (light or zero usage) beds. The work would concentrate on the density and size of plants and their condition. Emphasis would also be placed on studying the associated flora and fauna, as much of the value of *Zostera* beds derives from their provision of habitat for other species. At least 3-5 impacted sites and 3-5 unimpacted sites would need to be studied. If intermediate levels of disturbance/impact can be found then 3-5 of these should be incorporated into the survey. At each site salinity, temperature, nutrients, dissolved oxygen, sediment characteristics, *Zostera* density, size and condition and associated fauna and flora would be studied using standard stratified random sampling techniques. The data could then be subjected to univariate and multivariate analysis (MDS etc).

At selected sites detailed short term observations of the nature of disturbance could be undertaken. One example would be to involve a site subject to heavy recreational usage such as windsurfing. In identified areas windsurfers could be excluded by buoyed areas and or stakes (clearly permission for this would need to be obtained from the local authorities, as would cooperation from other interested parties). At least three replicate exclusions of 25 x 25 m would need to be set out. Adjacent control areas would be interspersed within them. Within each replicated area random quadrats would be studied at three monthly intervals for two years.

This project would take 2 man years, Phases A, B and C could be let to one contractor in a three year rolling programme. Phase C could be initiated in parallel with Phase B.

Direct costs (exclusive of overhead components)

PHASE A	3 months PDRA level	£ 6,000	
	travel costs	£ 600	**£6,600**
PHASE B	12 man months PDRA level	£22,000	
	Field work costs	£ 3,000	
	Consumables	£ 1,000	**£26,000**
PHASE C	Supervision	£ 3,000	
	Staff (2 year PDRA)	£49,000	
	Travel	£ 3,000	
	Consumables	£ 5,000	<u>£60,000</u>
			£92,600

4.10.4 Studies of effects of eutrophication / light limitation on *Zostera* within Britain.

These should be costed out in further detail, if still felt appropriate, after the workshop.

4.10.5 Further experimentation on transplant methods.

Work on both reseeding and transplanting of seedlings in intertidal and subtidal areas is undoubtedly needed. It would be sensible to await clarification of the taxonomic status of *Zostera angustifolia* before initiating work since this would help enormously in planning work for intertidal estuarine areas, however.

4.11 Assessing the extent to which present knowledge of sensitivity allows assessment of criteria for identifying Critical Natural Capital (CNC).

The following questions are those which need to be asked in order to identify CNC in the maritime zone, according to Masters and Gee (1995, Appendix 2) who used the term Critical Environmental Capital (CEC). Comments on the present state of knowledge regarding sensitivity are made where relevant. Some of the questions can only be effectively answered in relation to specific sites.

a) **Species Reproduction** These questions test the ability of key species to regenerate and reproduce themselves.

What key species are present on site?	All species of *Zostera* can be regarded as key species. Unlikely to be other key species associated with them.
Are any key species longlived (25+ years)?	Unlikely. Actual longevity of perennial plants not known in detail.
Do these [long lived] species have reproductional rates such that generational turnover is 25+ years?	Unlikely, but see above.
Is the populational trend of any key species declining?	Numerous losses nationally over the last 60 years. Almost certainly still in decline.
Can this decline be halted and reversed by human intervention?	Unlikely in many cases.

b) **Species Physical Sensitivity** This section addresses the sensitivity of key species to physical disturbance, and the effect this may have on their fitness.

Are these species habitat specific?	Yes. Reasonable knowledge exists (except with regard to problems of taxonomic status of *Z. angustifolia*).
Are any of key species particularly sensitive to physical damage, disturbance or pollution?	Yes in all three cases.
If the site is threatened by these impacts, could human intervention make good the resulting damage?	Insufficient experience or knowledge to answer this properly, though generally seems unlikely.

c) **Island Biogeography** These criteria relate to the ability of key species to (re)colonise a site.

Are any key species at the site isolated by physical space or barriers from the nearest neighbouring colony?	Not relevant to this study.
Are these barriers impenetrable? **or** Is the nearest neighbouring source of recolonisation beyond the normal dispersal range of these key species?	Not relevant to this study. Needs consideration of each situation. Dispersal range not known in detail but thought to be small. Many populations perennial, others (especially intertidal) probably annual and dependant upon regular local seed set.
Could recolonisation of key species be achieved by human intervention (technically and financially)?	Has not been succesfully achieved in Britain, though has been elsewhere.

d) **Natural Processes** These criteria relate to the role a site may play in coastal processes, in earth science interest, or coastal defence.

Does the site contain features that potentially make a significant contribution to coast protection / sea defence?	Probably in the case of extensive beds especially intertidally (eg sediment stabilisation). Needs careful consideration of each individual situation.
Would it be technically and financially feasible to replace these natural features with engineered coastal protection/sea defence?	Not relevant to this study.
Does the site play a significant role in natural coastal processes?	Probably in the case of extensive beds especially intertidally (eg sediment accretion, stabilisation). Needs careful consideration of each individual situation.
Would it be technically and financially feasible to maintain these processes at the site artificially?	Not relevant to this study.

e) **Technological Factors: Ecological Restoration** These criteria consider whether it is technically and financially possible to restore a natural habitat/community artificially.

Should the site be destroyed, could the conditions that existed previously be reinstated/recreated at the same site and or another available location within the natural area?	Negligible experience within Britain. It is difficult to envisage exactly what is being asked. If large areas of intertidal or subtidal sediments are 'destroyed' it is very difficult to see how they could be recreated.
Would key species be able to recolonise site naturally? (refer to biogeography criteria)	Seems very unlikely in many cases. Particularly unlikely in case of subtidal perennial populations? Would need careful study of each situation.
Would it be technically and financially feasible to restore these key species to the site artificially?	Has never been succesfully done in Britain. Experience elsewhere suggests it can sometimes be done though there may be doubt over ecological value of restored seagrass beds compared to natural ones.

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5 Numerical scores for sensitivity

Table 5 attempts to update the sensitivity scores of intertidal brown algal shrubs, *Zostera* beds, and *Sabellaria spinulosa* reefs, using the same criteria as Holt *et al* (1995), which are shown in Appendix 1. "Damage" scores (longevity, stability, fragility and intolerance) have not been averaged in this study as this is not felt to be sufficiently meaningful. It is accepted that some sort of overall scores would be valuable, and that the concept outlined by Holt et al (1995) of producing separate 'damage' recoverability scores may be a useful one. However, to create a useful 'damage' score there probably needs to be some sort of appropriate weighting applied to the individual scores, as used by MacDonald *et al* (in prep) in defining numerically the sensitivities of benthic species to fishing. This was not carried out as part of this work, however.

As reported by Holt *et al* (1995) assignation of numerical values of sensitivity in this way is potentially misleading as it has the potential to effectively mask problems. Some of these problems we are presently aware of - eg the generality of sensitivity of brown algal shrubs to chlorate, despite their overall relative insensitivity to changes in water quality parameters (intolerance). There will almost certainly be many others we are not aware of, particularly in relation to chemical pollutants which can result in very specific and unpredictable effects.

Ascribing numbers to fragility is also, in the final analysis, somewhat subjective. If some sort of physical test could be applied more objective scores could be produced, but these would have little meaning in relation to the environment and impacts the species might actually encounter, which must be taken into account. It is necessary to consider the fragility of species with very widely differing structures, living in very different environments where they are vulnerable to different impacts - eg *Zostera* plants and *Sabellaria* reefs - and yet needs to be comparable. In practice, it is difficult to be convinced that a fragility score of 3 (for example) assigned to one community or species is truly equivalent to a fragility score of 3 for another.

Scoring of the categories of stability and recoverability is slightly more objective, but there is often insufficient knowledge to make a very informed judgement.

Longevity is clearly the easiest category to score, but even here there is difficulty in defining longevity in vegetatively growing plants such as *Zostera marina* or *Ascophyllum nodosum*. Similar arguments might be invoked for reef building animals such as *Sabellaria spinulosa*, but this has been dealt with here by assuming that longevity of individual animals is the important factor, while longevity of the structure is considered to be an aspect of stability. Knowledge of the longevity of individual *S. spinulosa* is, however, not well known.

Table 5 An attempt to update the sensitivity of intertidal Brown algal shrubs, *Zostera* beds, and *Sabellaria spinulosa* reefs, using the same criteria as Holt *et al* (1995), which are shown in Appendix 1.

	Longev-ity	Stability	Fragility	Intoler-ance	Recover-ability	Notes
Fucus spp)	3	2	3	2*	3-4**	* Lack of experimental data on tolerance to chlorate. ** Dependant on size of damaged area
Fucus spiralis	3	2	3	2*	3-4**	* Lack of experimental data on tolerance to chlorate. ** Dependant on size of damaged area
F. vesiculosus	3	2	3	2*	3-4**	* Lack of experimental data on tolerance to chlorate in U.K. waters - known to be very sensitive in the Baltic. ** Dependant on size of damaged area
F. serratus	3	2	3	2*	3-4**	* Lack of experimental data on tolerance to chlorate. ** Dependant on size of damaged area
Ascophyllum nodosum	5	4	3	2*	4	* Lack of experimental data on tolerance to chlorate.
Rock pool algae (*Cystoseira* spp, *Halidrys*, *Bifurcaria*)	Perennial. Probably all 2 or 3?	*	3?	*	*	*Inadequate data - any values would be complete guesswork. Some suggstion that *Cystoseira tamariscifolia* may be susceptible to pollution by hydrocarbons and detergents and that *Cystoseira* in general might be susceptible to eutrophication.
Zostera marina	'Annual' populations 1-2 'Perrennial' populations 3-5	5	4	5	4-5*	*Recoverability is probably good in annual populations not deprived of source of seed and if sediment structure and other factors remain suitable. More prone to wasting disease than other species, which may be influenced / triggered by anthropogenic factors
Zostera angustifolia	1 - 2?	5	4	4	4-5*	*Recoverability is probably good in annual populations not deprived of source of seed and if sediment structure and other factors remain suitable
Zostera noltii	1? - 3?	5	4	4	4-5	Data for *Z. noltii* less certain than for the other two species
Sabellaria spinulosa	1-3	1-3?**	3*	1	1-5?***	*Clearly fragile enough to be destroyed by fishing gear though may not necessarily be very badly damaged by single events. **Likely that in some situations reefs may be found in same place year after year but population structure may vary greatly. More information required. ***Probably very much scale dependant. Many annual populations will no doubt recover very quickly. There appear to be several examples of large scale losses which have not recovered over long time periods, but reasons unknown.

6 Discussion

This discussion brings together the various sections of this report and highlights problems and priorities for further work.

6.1 Methodological problems

A major problem is the life form categories themselves. Whilst classification is a useful tool in assembling and analysing data, it should always be borne in mind that most categories (including life forms and biotopes) blur into each other and continua rather than discrete units are the rule in the natural world - particularly along the sharp environmental gradients of coastal waters. Of the case studies examined here, *Zostera* is the most useful and robust category, although subtidal beds have a very different physical structure than the rather thin lawns typical of many intertidal habitats. *Zostera* itself also forms a discrete habitat for other species, including specialists such as the small topshell *Jujubinus striatus* therefore the life form maps well onto one or more definable and useful biotope(s). *Zostera* also modifies the physical environment, principally by encouraging sediment deposition, thus emphasising its discreteness. *Sabellaria spinulosa* was originally included under the heading of faunal accretion in Holt *et al* (1995) based on the BIOMAR life form classification. For the purpose of this study we were asked to consider it as a subtidal reef. In practice we have considered 'accretion' and 'reef' to be synonymous, although it could be argued that 'reef' has the connotations of a rather more substantial structure than 'accretion'. From the literature search it is clear that *S. spinulosa* can indeed form substantial reefs, and that this is not a confusion with the more obviously reef forming *S. alveolata*. It seems certain that *S. alveolata* is not now found in the North Sea and early records must be treated with extreme caution. Although in some locations *S. spinulosa* forms reefs, in many places it forms a much thinner sheet or crust at most a few centimetres thick binding together large particles. It can also occur singly, and the sheets when they occur are often sufficiently fragile to be effectively sampled by Day grabs. Clearly *S. spinulosa* dominated communities can occur in a variety of forms; but the frequency with which it forms very substantial and stable reefs is unclear, though it does seem to occur relatively rarely.

The category 'brown algal shrubs' highlights the problem of within category variation. *Pelvetia canaliculata* is related to other intertidal fucoids phylogenetically and clearly is part of an upshore progression of diminution of size. The end result is that *Pelvetia* is not unlike algal turfs such as *Chondrus* and *Mastocarpus* in size. However, these red algae do have a tendency to proliferate vegetatively and physically intermesh to form a turf rather than the individual plants typical of brown algal shrubs, including *Pelvetia*. At the other extreme, *Himanthalia elongata* is also an intertidal fucoid, but can form dense stands with plants up to 2m or more long in the summer and very unshrublike in appearance. *Ascophyllum*, whilst still a fucoid, in size at least is equivalent to kelps and has a similar major structuring capacity on the shore. Unlike other fucoids, *Ascophyllum* has a tendency for vegetative reproduction which enables great longevity of genetic individuals (perhaps 50-100 years) but not necessarily of individual fronds (10-15 years). These problems need not be insuperable, as long as they are borne in mind and the classification is viewed as a useful approximation and no more.

The problems inherent in assigning numerical values to sensitivity have been outlined in Holt *et al* (1995) and again here in section 5. The difficulties encountered in assigning numerical scores to sensitivity to a single impact, ie bottom fishing, experienced by MacDonald *et al* (in prep) serve to emphasise the difficulty in assigning scores to sensitivity in such a broad sense as attempted here. It must be emphasised that these scores can give only very general indications of sensitivity to which there will undoubtedly be exceptions in relation to some, and possibly many, impacts or situations. Despite this, there may well be some value to the scoring system in very broad sensitivity mapping but it should not be used in place of a combination of expert opinion, survey work and consultation for important management or conservation decisions.

As part of the brief for this work, application of the concept of Critical Natural Capital (CNC, Gillespie & Shepherd 1995) as outlined for marine communities using the similar term Critical Environmental Capital (CEC, Masters & Gee 1995) was to be considered. It should be pointed out that features such as *Zostera* beds are dynamic features which do seem to show natural fluctutations, in response to perhaps wasting disease (though the degree to which this occurs in healthy populations is in doubt), storms, and intertidally low temperatures, so that identifying the importance of their "loss" might potentially be difficult.

The flow charts of Appendix 2 do help to clarify ones thoughts about the importance of a particular species. However, they are couched in terms which make general applicability to life forms or categories of species, eg brown algal shrubs, difficult. Their use did highlight the lack of key basic natural history, ecological and coastal process information needed to answer these questions for the species under study. Most of the biological knowledge for these species is derived from curiosity driven research or very specific surveys typical of more applied studies. It is not surpising that information derived from investigations exploring one set of aims is not applicable to another context. It would be well worth commissioning both desk and field research with the concept of CNC driving the aims at the outset. The flow charts are particularly valuable for a hypothesis driven approach. We would recommend that *Zostera* be the first focus for such work in the U.K.

An important problem in any study of this nature is the vast amount of relevant literature whch is essentially 'grey', being primarily in reports of limited circulation and unavailable for computer literature searching via BIDS or ASFA. There is a need to make this information more widely accessible, but clearly this requires resources for JNCC/country agencies who have an important archiving role in the united Kingdom.

6.2 Overview of the three case studies

Since the case studies were no doubt initially selected to represent very different life forms, it is not surprising that the outcomes of the analyses were largely different. One recurring theme was the lack of sometimes basic biological knowledge such as longevity (*Sabellaria spinulosa, Zostera* spp and pool dwelling fucoids), and recruitment rates and processes (*S. spinulosa* and *Zostera* spp). Obtaining this knowledge should take high priority in all cases but especially for *Zostera*.

Allied to the issue of recruitment rates and processes is the issue of artificial regeneration / recolonisation, which is also little studied in all of these communities within Britain. Study of this should take very high priority for *Zostera*, but less so for *Sabellaria spinulosa* and pool dwelling fucoids which are presently less threatened.

Another recurring theme was the lack of knowledge of long term effects of relatively low levels of pollutants. This should take a medium priority for *Zostera* in view of the urgent requirement for other studies, a medium priority for brown algal shrubs in view of their general tolerance/invulnerability to changes in water quality - with the possible exception of the chlorate sensitivity problem outlined in 2.9.4 and elsewhere, and a very low priority for *Sabellaria spinulosa* since it appears in general to be very tolerant and not vulnerable.

Whilst some impacts can be tolerated well (eg oil for brown algal shrubs) others are not (eg chlorate for brown algal shrubs). Similarly *Sabellaria spinulosa* would seem to be remarkably tolerant to small scale damage but unable to recover from more extensive damage. Clearly in the latter case some threshold scale of disturbance is crossed above which recolonisation becomes impossible either due to lack of available larvae or suitable substrate for settlement, although the importance of continuation of the impact in this regard is not known. A similar threshold would be likely in *Zostera* and probably also *Ascophyllum* due to problems of recruitment from remote sources. In *Fucus* and *Pelvetia* colonization from remote sources is unlikely to be a problem as patches of fucoids always occur, particularly in sheltered microhabitats. Thus after the Torrey Canyon oil spill even the most remote and wave beaten sites in Cornwall showed some *Fucus* recruitment (Southward & Southward, 1978).

Both *Zostera* and pool dwelling brown algal shrubs appear to be threatened by invasive species *Sargassum*, (and possibly also *Undaria pinnatifida*, at least in the case of pool dwellers). While the damage so far caused to either of these communities does not seem to be excessive, the lack of success generally achieved by attempts to control *Sargassum* means that further damage might be difficult to avoid and, once it occurs, will be difficult to mitigate.

This study has confirmed the general conclusions of Holt *et al* (1995) regarding the high sensitivity of *Zostera*, and there is much potential future work, beyond that already described above, which should be regarded as high priority. This includes the consolidation of present expertise and knowledge via a workshop, determination of the taxonomic status of *Z. marina/angustifolia*, determination of the present status of *Zostera* in the UK as a whole via collation of regional studies plus additional survey work, and investigation of the effects of a range of potentially damaging impacts including eutrophication, increased turbidity and physical damage by recreational or dredging activities.

This study has also confirmed the general conclusions of Holt *et al* (1995) regarding the generally low sensitivity of brown algal shrubs, though there are undoubtedly potentially damaging impacts. Pool dwelling fucoids, with their more restricted habitat, vulnerability to competition from alien species, and possible sensitivity to eutrophication and hydrocarbons in the case of *Cystoseira tamariscifolia*, are less well studied than those inhabiting open rock and might be considered to be more sensitive. *Sabellaria spinulosa* seems to be a generally robust and tolerant species which is nevertheless sensitive to extensive damage caused by bottom fishing from which it may not recover over long time scales.

A summary of knowledge of impacts related to the relevant life forms or species communities is given in tabular form in Appendix 3.

6.3 Critical Natural Capital (CNC)

Of the species studied *Zostera marina* probably is the one which most clearly constitutes CNC. It is a major structuring species providing habitat for other species; it stabilises sediments and influences coastal processes, and is vulnerable to natural disturbance (eg disease) and anthropogenic impacts such as eutrophication and siltation. The link between disease and environmental degradation has been postulated but not confirmed. *Zostera* beds in the subtidal seem to reproduce predominantly vegetatively. Thus remote colonization by seeds would probably be a problem should *Zostera* beds be destroyed in a locality. Once a bed is destroyed the sediment characteristics are likely to change thus further reducing the chances of natural recolonization, unless active restoration techniques are employed. *Zostera noltii* is probably even less well understood, both within Britain and within Europe, than *Zostera marina*. There are similar arguments for its representing CNC although, occurring relatively high up the shore, it seems to have a less important role in providing habitat for other species. There are likewise arguments for considering *Zostera angustifolia*, if it proved to be a separate species, as CNC.

Ascophyllum also has an important role in structuring sheltered shore communities, where it may represent CNC. It is very slow to recover - recolonization of small clearings from adjacent areas is slow, and will be slower in larger areas from which *Ascophyllum* has been removed.

Sabellaria spinulosa probably does not represent CNC. It is widespread, opportunistic and seems to colonize well. Paradoxically, *S. spinulosa* has been recorded as disappearing from large areas. Therefore on a very broadscale it could be considered to represent CNC. Its overall influence on community structure is probably considerable, and it is therefore justifiaby classed as a key species, but effects on sedimentary processes are likely to be generally small.

The questions posed in order to determine whether a site / species / community represent CNC are not all related directly to the general sensitivity or vulnerability of the species or community, but are often very site specific and cannot be answered until details of a specific site are known. The consideration of these questions in sections 2.10, 3.8 and 4.11 reveals again that there are important gaps in our basic knowledge, especially in relation to the ability of *Sabellaria* and more particularly *Zostera* to recover, or be reinstated, after loss.

6.4 References for sections 5 & 6

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Appendix 1.

The suggested scoring system for assessing sensitivity on a numerical basis. A score of one indicates minimal sensitivity and a score of five indicates maximal sensitivity. From Holt *et al* (1995).

--------------->-------------- > increasing sensitivity--------------->--------------->

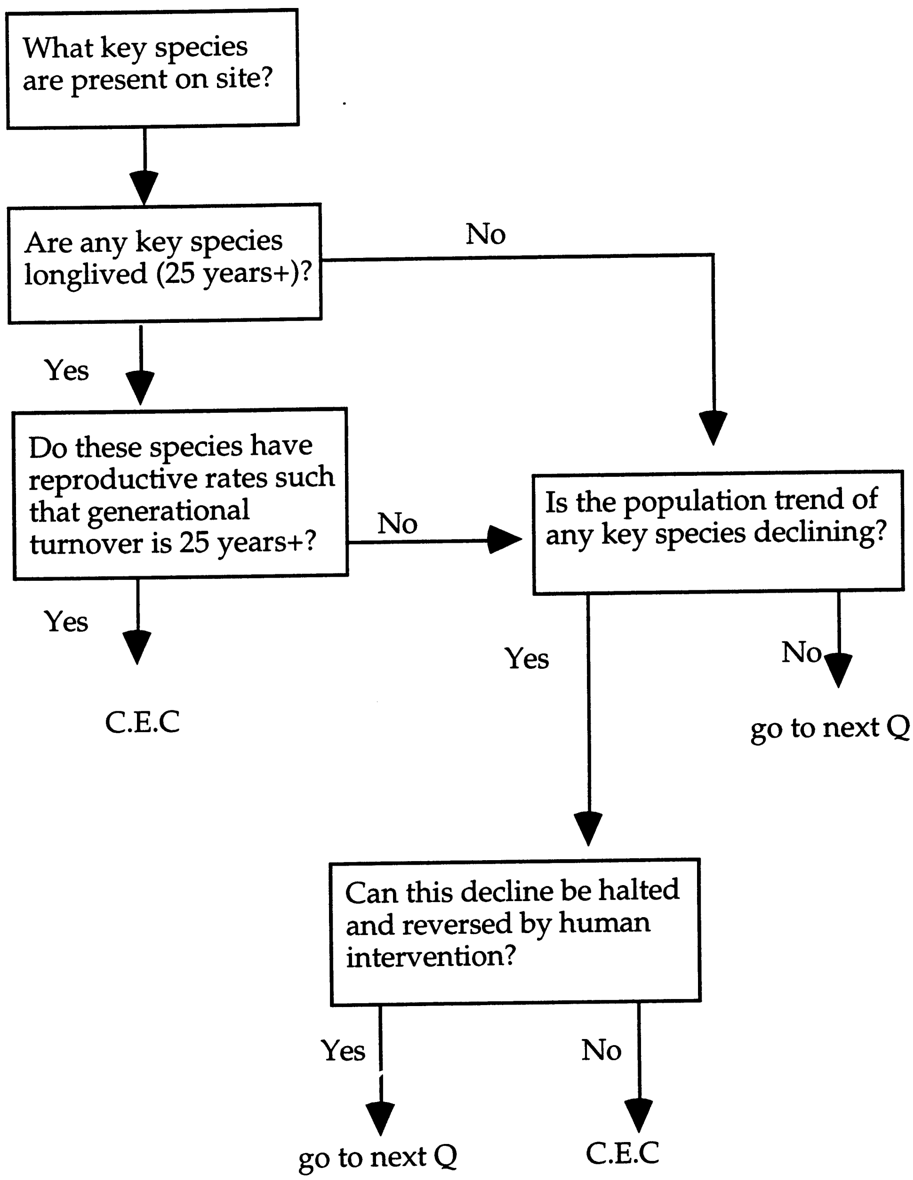
Score:	1	2	3	4	5
Longevity	Annual or shorter	lifespan 1-2 years	lifespan 3-5 years	lifespan 5-10 years	lifespan >10 years
Fragility	Very robust	Fairly robust	Moderately fragile	Fairly fragile	Very fragile
Stability	Shows characteristics of rapid colonisers or very transient communities	Major fluctuations in populations likely every 1 - 2 years	Major fluctuations in populations likely every 3-5 years	Major fluctuations in populations likely every 5-10 years	Major fluctuations rare
"Intolerance" to environmental stresses or changes	Very tolerant to a wide variety of environmental changes	Tolerant to a moderate variety of environmental changes	Neither tolerant nor intolerant	Intolerant to a moderate variety of environmental changes	Very intolerant
Recoverability	Recovery from most damage likely within one year	Recovery from most damage likely within 1/2 years	Recovery from most damage likely within 3-5 years	Recovery from most damage likely within 5-10 years	Recovery from most damage unlikely within 10 years

Appendix 2

Checklist of criteria for identifying Critical Environmental Capital (CEC) in the maritime zone, from Masters & Gee (1995). CEC is considered with Critical Natural Capital (CNC) Gillespie & Shepherd (1995).

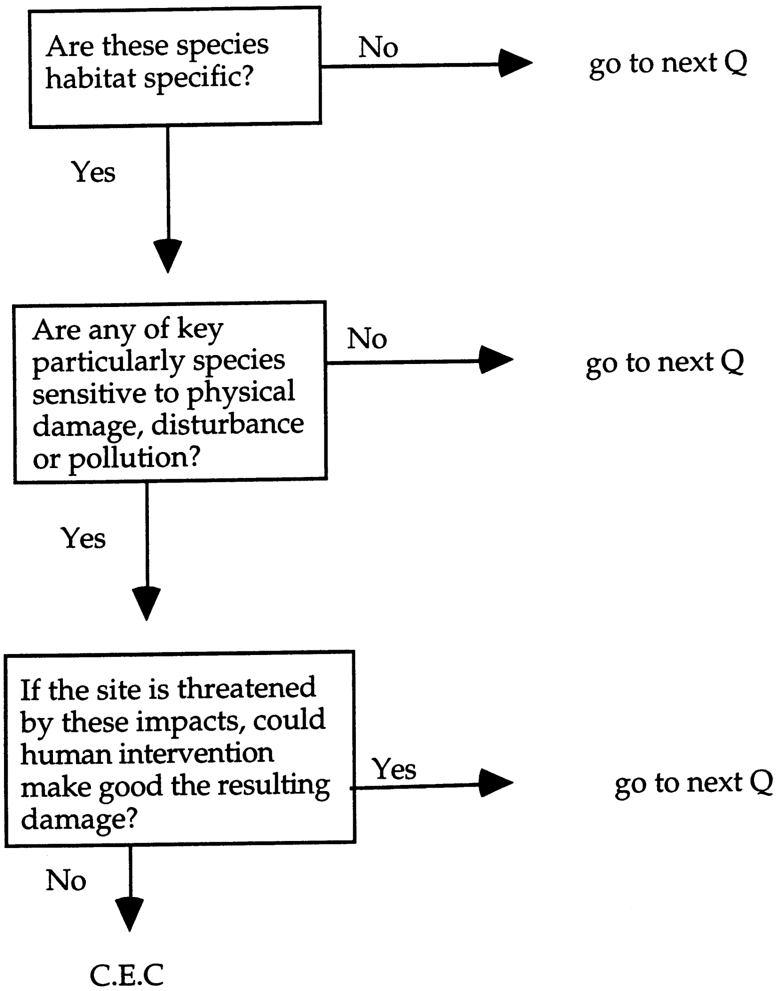
Species reproduction

These questions test the ability of key species to regenerate and reproduce themselves



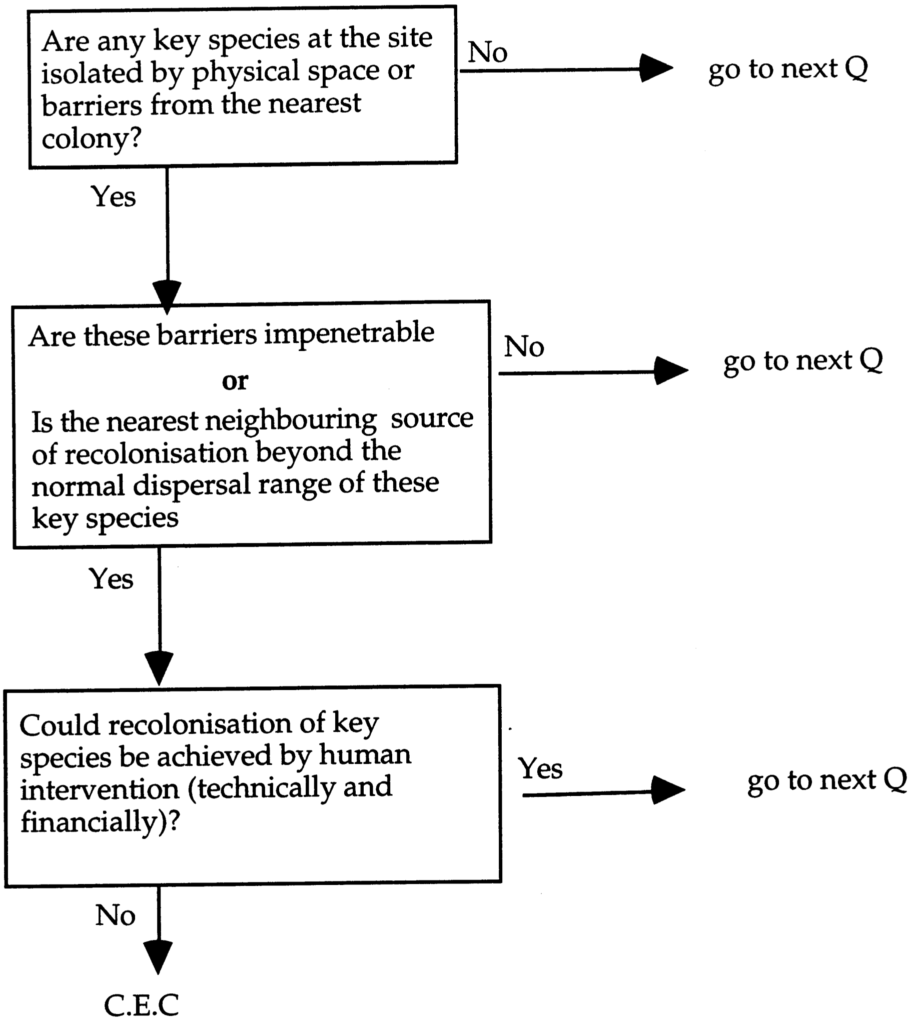
Species physical sensitivity

This page addresses the sensitivity of key species to physical disturbance, and the effect this may have on their fitness



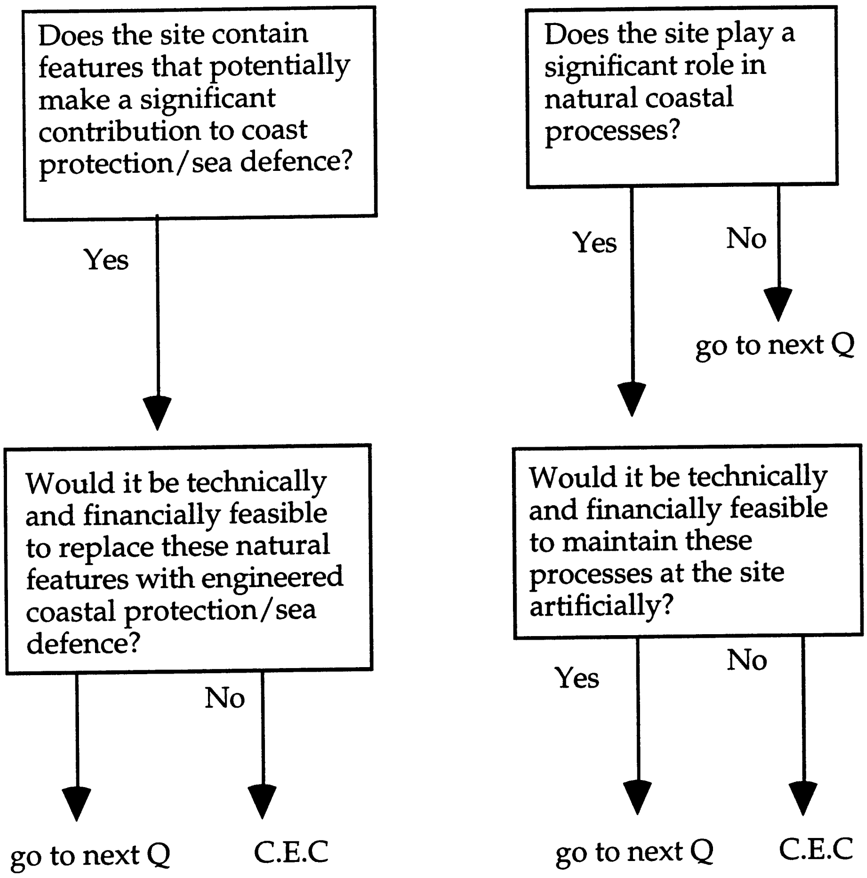
Island Biogeography

These criteria relate to the ability of key species to (re)colonise a site



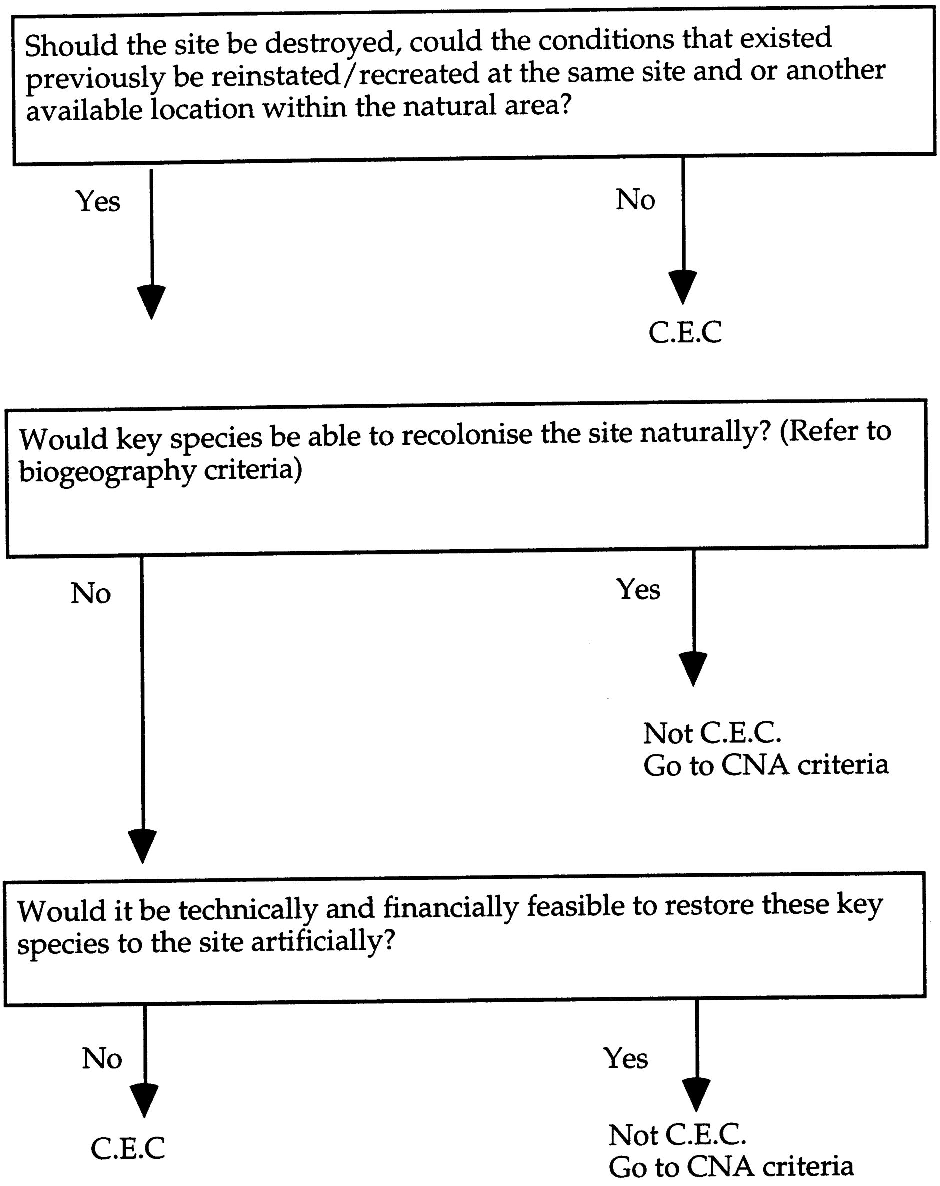
Natural processes

These criteria relate to the role a site may play in coastal processes, in earth science interest, or coastal defence



Technical factors: ecological restoration

These criteria consider whether it is technically and financially possible to restore a natural habitat /community artificially



Appendix 3

An updated version of Table 3.3 given in Holt *et al* (1995). The table represents the output from a Paradox database in which information on sensitivity of life forms is presented in relation to activities as defined by Eno (1991) (with a few additions).

Barren (L)
LITTORAL

Activity	Notes
Coast Protection and Sea Defences	Possible that some barren areas e.g. shingle, cobble could become populated by flora and fauna if exposure to wave action is reduced. May also apply to sea level rise, barrages and artificial reefs.

Saltmarsh Vegetation (L)
LITTORAL

Activity	Notes
Collection of Higher Plants	*Salicornia* collected for food. No knowledge of problems caused, *Salicornia* is an annual therefore recovery likely to be high.
Introduction of Alien Species	Known severe damage from *Spartina anglica* invasion. Beds surviving but there is dispute about their "naturalness".
Oil and Gas Industry	Range of responses varying from very susceptible (shallow rooting annuals, seedlings) to very resistant (*Oenanthe lachanalii*). See Baker 1977. Trampling damage can occur with cleanup operations. Oil gets trapped in mud and may remain for a long time.
Coast Protection and Sea Defences	Natural saltmarshes are constantly adjusting to change in sea-level and exposure, but if landward extension of the marsh is prevented this cannot happen during periods of sea level rise.
Land Claim	One of the major threats to saltmarshes, particularly estuarine ones.
Drainage	Upper saltmarsh frequently lost to drainage / agricultural improvement, no known experience of recovery.
Recreation	Trampling likely to be a problem in some areas. Shooting and other disturbance potentially problematical for associated communities.
Industrial Wastes	Heavy metal inputs to saltmarshes thought unlikely to have serious effects on vegetation, though accumulation occurs, especially in *Zostera*.
Sea Level Rise?	If coastal sea defences are in place, landward extension of saltmarsh during periods of sea-level rise is prevented. Ability of saltmarshes to keep pace with rapid sea level rises is in doubt.

Seagrass Beds (L)
LITTORAL

Activity	Notes
Molluscan Shellfisheries	Direct damage to rhizomes thought to be serious. Likely destabilisation of sediments could lead to exacerbation o f the problem. Thought to have occurred in Auchencairn Bay, Solway Firth. Probably more serious for perennial forms.

Seagrass Beds (S)
SUBLITTORAL

Activity	Notes

Seagrass Beds (L&S)
LITTORAL & SUBLITTORAL

Activity	Notes
Hydraulic Dredging	Inappropriate dredging can cause increased tidal or wave action which can be detrimental. Can result in negative feedback as loss of plants causes further destabilisation of sediment as demonstrated in *Posidonia* (Mediterranean) and *Heterozostera* (Australia), and possibly in Auchencairn Bay, Solway Firth, Scotland (dredging for cockles). Seagrasses can also suffer directly from dredging as they are not very robust. Direct damage to rhizomes thought to be serious.
Molluscan Shellfisheries	See above.
Docks and Marinas	Building of docks and dredging of channels said to be the cause of widespread decline of *Zostera* in the Solent prior to the 1950s. Inappropriate groyne and harbour construction has caused loss of seagrass beds in Australia due to increased sediment accretion.
Aggregate Dredging	Has been implicated in *Zostera* losses via increased turbidity in Netherlands.
Introduction of Alien Species	In N. France, *Sargassum muticum* has replaced *Zostera marina* in parts of the beds "injured by human activities". Intertidal populations probably much more vulnerable than subtidal ones. *Sargassum* has been seen to be competing with *Zostera* intertidally in several parts of Britain, but no very major effects yet demonstrated.
Oil and Gas Industry	Generally thought not particularly sensitive, though associated fauna may be. May be sensitive to dispersants and to trampling during clean up efforts intertidally. Only damage reported in Milford Haven area after the Sea Empress spill was damage by vehicles.

Seagrass Beds (L&S)
LITTORAL &
SUBLITTORAL (cont)

Activity	Notes
Coast Protection and Sea Defences	Increased sediment accretion can cause problems, probably by causing reduced light levels. Changes in redox potential of sediment may also have negative effects, however.
Land Claim	Much loss to land claim.
Sewage Disposal	Eutrophication can kill, or reduce growth, in *Zostera*. Can be either directly, or by reducing light levels due to increased growth of epiphytic algae, planktonic blooms or mats of eg *Enteromorpha*. However, situation is complex: low level addition of nitrates often shown to be beneficial; in several areas around the Solent increased sewage effluent (treated and untreated) seemed to correlate strongly with rapid spread of *Zostera*, though more recently there was a massive die off of intertidal *Zostera* in the same area due to overgrowth by *Enteromorpha*. Agricultural runoff is also important.
Industrial Wastes	Heavy metals and TBT known to be accumulated but little evidence of unusual sensitivity. Possibility of effects on phenolic content of plants, reduction of which in turn may lead to increased susceptibility to wasting disease. Insensitive to pulp mill effluent containing chlorate, (as are many aquatic plants except for brown algae).

Lichen (L)
LITTORAL

Activity	Notes
Oil and Gas Industry	Many lichens have been shown to be very sensitive to early dispersants, but oil itself is generally non-toxic.
Energy Generation (not thermal discharge)	Many lichens are very sensitive to air pollution, including to some extent *Xanthoria parietina* in terrestrial environments, and it is therefore likely that many seashore lichens would be sensitive also. It is thought that supralittoral lichens are more sensitive than littoral ones, as the former have disappeared in industrial areas while the latter have not.
Coast Protection and Sea Defences	Any development which reduces wave action could potentially reduce supratidal lichen growth, but no hard evidence found.
Artificial Reef Construction	Any development which reduces wave action could potentially reduce supratidal lichen growth, but no hard evidence found during this work.

Lichen (L)
LITTORAL (cont)

Activity	Notes
Sewage Disposal	Eutrophication in general appears to have some effects, but very limited work within Britain. *Verrucaria mucosa* can decline as a result of competition with *Prasiola*, and large amounts of *Candelariella vitellina* may be indicative of eutrophication.
Sea Level Rise?	Potentially damaging to upper shore lichens which could easily be outcompeted by algae and be very slow to move upwards?

Brown Algal Shrubs (L)
LITTORAL

Activity	Notes
Exploitation Of Algae (not maerl)	Care needed in collection of *Ascophyllum* as regrowth can take very long times. Cutting should leave considerable proportion of each plant. Mechanical harvesting methods usually leave longer portions of the plants than hand cutting.
Salmonid Fish Farming	Local effects include overgrowth by green algae. In many cases it is likely that effects of anoxia on benthic animals will be more serious than effects on brown algal shrubs.
Introduction of Alien Species	No evidence of major loss yet despite presence in Britain of potentially damaging aliens including *Sargassum* and *Undaria*. Pool dwelling species including *Halidrys siliquosa* thought to be susceptible to competition from *Sargassum*.
Oil and Gas Industry	Relatively unaffected except e.g. *Ascophyllum* in sheltered situations. May be indirect effects due to e.g. loss of *Patella* likely to lead to increased growth. Chronic effects on juveniles in doubt. *Cystoseira tamariscifolia* has been quoted as being susceptible to changes in water quality, including detergents and hydrocarbon contamination.
Recreation	Some damage to fucoids, especially *Ascophyllum* beds, has been reported in UK. Associated increases in bare space and *Enteromorpha* cover have been reported.
Sewage Disposal	Generally moderately tolerant except in the most extremely affected areas. *Cystoseira tamariscifolia* has been quoted as being susceptible to changes in water quality, including detergents and hydrocarbon contamination. It has been stated tha *Cystoseira* plans are susceptible to dense epiphyte cover, in which case further stimulation of epiphyte growth might be damaging (this is speculation).

Brown Algal Shrubs (L)
LITTORAL (cont)

Activity	Notes
Industrial Wastes	Extraordinary sensitivity of brown algae to pulp mill chlorate seems to be atypical of their response to industrial wastes in general, but effects of increasing turbidity are seen in places. Widely thought to be tolerant of heavy metals. Lack of knowledge on effects on young stages, however.
Experimental manipulation	Clearance of large areas could potentially take a long time to recover, especially for *Ascophyllum nodosum*, though unlikely to be widespread.

Algal Turf (L)
LITTORAL

Activity	Notes
Exploitation of Algae (not maerl)	Beds of *Chondrus crispus* have occasionally been lost in Canada (replaced by *Furcellaria*) due to harvesting for carrageenan, but usually controlled harvesting leads to sustainability. Total removal can result in three year recovery period to original biomass but less intense harvesting leads to shorter recovery times. Use in Britain and Ireland declining.
Oil and Gas Industry	Physical damage to *Chondrus crispus* by oil smothering has been reported but reports of damage to *Chondrus* beds after "Amoco Cadiz" incident are unclear and contradictory- may have been some effect on development of young stages.
Recreation	No work on trampling effects on British turf algae found but international literature suggests likely effects on some species, with fragile foliose species likely to be replaced by shorter turf forming species or barnacle/mussel communities.

Algal Turf (L&S)
LITTORAL & SUBLITTORAL

Activity	Notes
Oil and Gas Industry	Red algae, which include v many turf forms, may be more sensitive to dispersants than other algae. Filamentous forms possibly most sensitive of all.
Sewage Disposal	Eutrophication generally detrimental to many red and brown algae, which are replaced by many greens but also reds such as *Ceramium* spp or *Porphyra* spp, browns such as *Ectocarpus* agg, or even blue green algae (though many of these could be classified as turf algae themselves). Frequently reported in estuaries and enclosed bays. Many other inputs contribute, including industrial wastes agricultural runoff, fish farm waste etc.

Algal Turf (S)
SUBLITTORAL

Activity	Notes
Salmonid Fish Farming	Replacement of red and brown algae by greens in vicinity of fish farms has been reported.
Oil and Gas Industry	*Delesseria sanguinea* damaged by oil and/or dispersant down to 12m after "Torrey Canyon" incident.

Algal Accretion (L)
LITTORAL

Activity	Notes

Algal Accretion (S)
SUBLITTORAL

Activity	Notes

Algal Accretion (L&S)
LITTORAL
SUBLITTORAL

Activity	Notes
Coast Protection and Sea Defences	*Audouinella floridula* is often one of the first colonisers of new structures but is often outcompeted by larger macroalgae within 12 months.
Artificial Reef Construction	*Audouinella floridula* is often one of the first colonisers of new structures but is often outcompeted by larger macroalgae within 12 months.
Inorganic Mine and Particulate Waste	*Audouinella floridula* found to be quite tolerant of inorganic discharges from iron ore loading/unloading terminals in Scotland.

Algal Crusts (L)
LITTORAL

Activity	Notes

Algal Crusts (S)
SUBLITTORAL

Activity	Notes

Algal Crusts (L&S)
LITTORAL &
SUBLITTORAL

Activity	Notes
Sewage Disposal	Low shore and subtidal coralline crusts possibly more sensitive to overgrowth by epiphytes due to eutrophication than eulittoral ones, though little hard evidence for this found.
Experimental manipulation	Changes in grazer levels could be important, especially subtidally where beneficial effects of grazers in reducing epiphytes on coralline crusts have been reported.

Faunal Crusts (L)
LITTORAL

Activity	Notes
Oil and Gas Industry	Intertidal barnacles not very heavily impacted by oil but much more so by dispersants (though less sensitive than limpets) eg "Torrey Canyon" incident. Barnacles were dominant on shore after ten years, having increased in density from 5 years. Dynamic interactions, especially with limpets and fucoids, mean that it can be 7-13 years or more before "normal" communities occur after oil spill incidents.
Recreation	No reports of major effects in Britain. However, living barnacles on relatively lightly trampled shores in Oregon were crushed and removed, the community being replaced by short algal turf. Similar studies on South African shores reported that only dead barnacle shells were removed.
Docks and Marinas	Extreme sensitivity of one of the main predators, dog whelks, to TBT gives potential for increased barnacle populations in vicinity of docks. However, clearly barnacles are also sensitive or it wouldn't be an effective antifouling agent - net result on barnacle populations not clear.
Sewage Disposal	Little data on effects of eutrophication on barnacles, though in cleared areas green algae can swamp *Semibalanus* so there is potential for sensitivity to extreme eutrophication.
Experimental manipulation	Dynamic interactions with limpets, fucoids and probably dog whelks and mussels mean that potential manipulation of any of these could affect barnacles but usually only on a very local scale.

Faunal Crusts (S)
SUBLITTORAL

Activity	Notes
Dredging and Hydraulic Dredging	Sublittoral barnacles may be sensitive to siltation, though *Balanus* species e.g. *B. crenatus* are generally tolerant.

Faunal Crusts (L&S)

LITTORAL &
SUBLITTORAL

Activity	Notes
Thermal Discharge	Chthamalids fairly tolerant of increased temperatures, more so than *Semibalanus balanoides*. Large changes (+10C) in Swansea Dock led to colonisation by *Balanus amphitrite* instead of *B. crenatus* in Swansea Dock..

Faunal Beds(L)

LITTORAL

Activity	Notes
Molluscan Shellfisheries	Surprisingly, no information found on potential for overfishing of *Mytilus*. Fisheries can be closed because of red tides. Severe and perhaps long lasting damage to *Modiolus* beds likely from scallop dredging. *Ophiothrix* beds appear to be unable to recolonize areas of English channel due to bottom fishing but probably more related to beam trawling.
Docks and Marinas	TBT can have an effect on *Mytilus* and in areas of high boating activity it can be completely replaced by polychaete worms and filamentous algae.
Industrial Wastes	Heavy metals known to accumulate in *Mytilus* and cause reduction or cessation of growth.
Pesticides	PCBs known to accumulate in mantle cavity of *Mytilus*, leading to gonad contamination. Spawning reduces this but can lead to transfer of PCBs to next generation. Ecological importance of this not clear.
Vehicle exhaust emissions	It has recently been suggested that polycyclic aromatic hydrocarbons, principally from vehicle exhaust emissions, are responsible for reduced growth of mussels on much of the UK's north sea coast

Faunal Beds(S)

SUBLITTORAL

Activity	Notes
Commercial Finfish Fishing	Beam trawling (and dredging for scallops) known to have severe effects on *Ophiothrix* beds. *Modiolus* beds also thought to be very sensitive and could potentially take a long time to recover even in absence of fishing. There is evidence that seabed sediments can be altered sufficiently to change the epifauna.

Faunal Beds (L&S)
LITTORAL &
SUBLITTORAL

Activity	Notes
Oil and Gas Industry	Suspension feeders such as m ussels are sensitive to oil pollution, probably more so in the shallow subtidal. Can cause reduction or cessation of growth. Larger individuals more sensitive to crude oil than smaller ones. Recovery usually rapid. *Amphiura filiformis* appears to have an extreme sensitivity to oil based drilling muds. Effects can be severe, widespread and long lasting.
Sewage Disposal	Mussels generally tolerant of suspended particles and *Mytilus* often increases in abundance towards sewage outfalls. However, fisheries can be closed due to the accumulation of toxins during red tides, which can be related to general eutrophication.

Short Faunal Turf **(L)**
LITTORAL

Activity	Notes
Oil and Gas Industry	All sessile suspension feeders likely to be sensitive and vulnerable to oil spills.

Short Faunal Turf (S)
SUBLITTORAL

Activity	Notes
Commercial Finfish Fishing	Trawling and dredging uproots hydroid and bryozoan colonies and subsequent transformation of substrate may prevent them from recolonizing. Bryozoan colonies are slow to recover from physical injury.
Molluscan Shellfisheries	Trawling and dredging uproots hydroid and bryozoan colonies and subsequent transformation of substrate may prevent them from recolonizing. Bryozoan colonies are slow to recover from physical injury.
Oil and Gas Industry	All sessile suspension feeders likely to be sensitive and, if shallow, vulnerable to oil spills.
Docks and Marinas	*Tubularia* thought to be less sensitive than other hydrozoa to copper in anti-fouling paints.
Sewage Disposal	*Tubularia* and *Obelia* are more tolerant than other hydrozoan species to turbid water, but more detailed information not found.
Spoil dumping	*Tubularia* and *Obelia* are more tolerant than other hydrozoan species to turbid water, but more detailed information not found

Faunal Accretion (L)
LITTORAL

Activity	Notes

Faunal Accretion (S)
SUBLITTORAL

Activity	Notes
Crustacean Shellfisheries and Potting	Shrimp trawling, along with mussel and oyster exploitation, responsible for loss of *Sabellaria spinulosa* reefs in large areas of the Southern Wadden sea. These have not recovered but have in at least one instance been replaced by *Mytilus edulis* and assemblages of sand dwelling amphipods. *S. spinulosa* reefs have also been reportedly lost in Morecambe Bay and the Wash due to shrimp fishing. Again there has apparetnly been no recovery.
Molluscan Shellfisheries	Shrimp trawling, along with mussel and oyster exploitation, responsible for loss of *Sabellaria spinulosa* reefs in large areas of the Southern Wadden sea. These have not recovered but have in at least one instance been replaced by *Mytilus edulis* and assemblages of sand dwelling amphipods.
Sewage Disposal	Sludge dumping has had a positive effect on *Sabellaria* reefs in Dublin Bay. Generally tolerant of high sedimentation except when it drastically changes the substrate.
Industrial Waste	Was the most tolerant organism to effluent from a bromide plant off N Wales coast. Little other information.
Aggregate extraction	No relevant published work found for *Sabellaria spinulosa*, . Clearly there will be substantial direct damage, but effects of sediment plumes likely to be very limited as *S. spinulosa* is not very sensitive to increased sedimentation. Recovery likely to be good if some areas left undisturbed, but this is somewhat speculative as recoverability of *S. spinulosa* has not been well studied.

Conspicuous Infauna (L)
LITTORAL

Activity	Notes
Bait Collecting	Reduced densities of *Arenicola marina* have been reported in several areas including Northumberland and Wales as a result of bait digging, which is now prohibited or restricted in some places. Automated bait digging machines caused a two fold decline in *A. marina* biomass in the parts of the Dutch Wadden Sea which took several years to recover. *Mya arenaria* was almost extinguished and took five years to recover original biomass and age structure. *Cerastoderma edule* declined drastically in parts of Norfolk due to bait digging.
Introduction of Alien Species	Large areas of mud flat have been colonised by *Spartina anglica*. This has presumably altered the infauna though no information was found in this study (Holt *et al* 1995).
Land Claim	Large areas of mud flats and salt marsh lost to land claim, particularly in estuarine areas.
Sewage Disposal	Effects of sewage disposal, sludge dumping and general organic enrichment are well studied. Organically enriched areas are usually characterised by lowered diversity but increased biomass. Increased growths of algal mats on the surface of muds may exacerbate this. Algal blooms, which could be related in part to general increased eutrophication, have caused massive mortalities of intertidal infauna including *A. marina*, which seems to be particularly sensitive, and others including *Cerastoderma edule, Macoma* sp, *Venus striatula, Tellina tenuis, Scrobicularia* spp and *Echinocardium cordatum*. Other polychaetes were unaffected.

Conspicuous Infauna (S)
SUBLITTORAL

Activity	Notes
Commercial Finfish Fishing	Beam trawling, scallop dredging and similar activities thought to have impacts but little long term work. More has been done on epibenthos. Sea pens likely to be badly damaged, particularly those which are slow to retract, and may take a very long time to recolonise - may be absent from areas of dredging. *Echinocardium cordatum* is fragile and may be damaged but usually recovers easily. *Arctica islandica* is less easily damaged but may take a long time to recover.

Conspicuous Infauna (S)
SUBLITTORAL (cont)

Activity	Notes
Molluscan Shellfisheries	Beam trawling, scallop dredging and similar activities thought to have impacts but little long term work. More has been done on epibenthos. Sea pens likely to be badly damaged, particularly those which are slow to retract, and may take a very long time to recolonise - may be absent from areas of dredging. *Echinocardium cordatum* is fragile and may be damaged but usually recovers easily. *Arctica islandica* is less easily damaged but may take a long time to recover.
Dredging and Hydraulic Dredging	Beam trawling, scallop dredging and similar activities thought to have impacts but little long term work. More has been done on epibenthos. Sea pens likely to be badly damaged, particularly those which are slow to retract, and may take a very long time to recolonise - may be absent from areas of dredging. *Echinocardium cordatum* is fragile and may be damaged but usually recovers easily. *Arctica islandica* is less easily damaged but may take a long time to recover.
Aggregate Dredging	Some North sea studies have shown biomass to decrease by up to 80% and take up to 1 0 years to recover after sand / gravel extraction. Effect of sedimentation on filter feeders such as sea pens and some bivalves thought to be severe. In the Wadden sea large scale extraction caused severe effects, with long lived bivalves being particularly affected, and full recovery had not occurred after 15 years.
Oil and Gas Industry	Oil based drilling muds are more toxic than water based. Both probably a more serious threat to offshore benthos than oil spills. Effects of oil based drilling muds are commonly reported within 500-1000m. Effects include reduced diversity, increased dominance by opportunistic species such as *Capitella capitata, Chaetozone setosa* and *Jassa marmorata*, while *Amphiura filiformis* (see faunal beds) *Scoloplos armiger, Abra prismatica, Montacuta substriata Sthenelais limicola* are all sensitive and may decline drastically or disappear.
Docks and Marinas	Sea pens may be absent from areas where boats are moored.

Conspicuous Infauna (S)
SUBLITTORAL
(cont)

Activity	Notes
Sewage Disposal	Effects of sewage disposal, sludge dumping and general organic enrichment are well studied. In extreme cases almost no macrofauna found, but opportunists such as *Scolelepis fuliginosa* and *Capitella capitata* are very tolerant. Many large conspicuous species only emerge from the sediment at 8-15% oxygen saturation, which they would tolerate for several weeks (although in nature this could expose them to predation). It is generally thought that long term exposure to oxygen levels below 2 m 1/1 (25% sat at 5C) leads to substantial die-off in many NE Atlantic sublittoral shelf fauna. Organically enriched areas are usually characterised by lowered diversity but increased biomass. Sea pens thought sensitive - absent from sewage polluted areas.
Inorganic Mine and Particulate Waste	Studies in the vicinity of China clay waste disposal in S-W England showed that deposit feeders such as *Melinna palmata, Nephtys* (arguably a carnivore) *Abra alba, Tellina fabula,* tolerated high levels of clay while suspension feeders such as *Venus fasciata* and *Dosinia exoleta* were entirely absent. The immediate vicinity of the discharge point contained no macrofauna at all.

Inconspicuous Infauna (L)
LITTORAL

Activity	Notes
Introduction of Alien Species	Large areas of mud flat have been colonised by *Spartina anglica*. This has presumably altered the infauna though no information was found in this study.
Land Claim	Large areas of mud flats and salt marsh lost to land claim, particularly in estuary areas.

Inconspicuous Infauna (S)
SUBLITTORAL

Activity	Notes

Diatom Film (L)
LITTORAL

Activity	Notes

Diatom Film (S)
SUBLITTORAL

Activity	Notes

Diatom Film (L&S)
LITTORAL
SUBLITTORAL

Activity	Notes
Sewage Disposal	Little published information. Probably generally tolerant to increased nutrients and organic loading, but it seems likely that at least some changes (probably reduced diversity and species compositional changes, but not necessarily reduced biomass) could be expected in sheltered conditions eg saltmarsh or other mudflats under high dosage rates.

Tall Faunal Turf (S)
SUBLITTORAL

Activity	Notes
Dredging and Hydraulic Dredging	Many probably intolerant of high sedimentation.
Oil and Gas Industry	Mainly suspension feeders and therefore thought to be sensitive to oil impingement.
Industrial Wastes	Little information. Dense *Metridium senile* replaced sublittoral macroalgae in an area affected by sulphurous pulp mill effluent (Sweden). Thought that macroalgae were affected by increased turbidity.

Mixed Algal / Faunal Turf (S)
SUBLITTORAL

Activity	Notes
Oil and Gas Industry	Communities codominated by kelp and suspension feeders such as hydroids considered less vulnerable to oil impingement than communities dominated by suspension feeders in the absence of kelp, while both are considered sensitive to the effects of an acute spill.

Algal Gravel (S)
SUBLITTORAL

Activity	Notes
Dredging and Hydraulic Dredging	Studies of effects of fishing (dredging and beam trawling?) are being carried out at UMBS Millport. No reports yet seen but likely that there are significant effects.
Maerl Gravel and Shell Sand Gravel	Extraction rates off Brittany unlikely to be sustainable. Damage clearly likely to be extensive, and to affect associated infauna and epifauna/epiflora. No detailed studies in Britain.

Algal Mat (L&S)
LITTORAL &
SUBLITTORAL

Activity	Notes
Salmonid Fish Farming	Increased growths of algal mat species e.g. *Enteromorpha* occurs close to salmonid farms but no reports of development of true mats found

Algal Mat (L&S)
LITTORAL &
SUBLITTORAL (cont)

Activity	Notes
Estuarine Barrages	Increased freshwater influence, retention of nutrients and reduction in water movement could potentially stimulate green algal mat formation, but little hard evidence (for or against) found in literature.
Artificial Reef Construction	Increased retention of nutrients and reduced water movement could potentially lead to increased growths of green algal mats on nearby shores.
Sewage Disposal	Eutrophication encourages algal mats of green algae (especially *Enteromorpha* and *Ulva*), *Ectocarpus* and similar brown algae, and sometimes blue green algae, especially in sheltered conditions. Agricultural runoff may be more important in some areas.
Experimental Manipulation	Anything which leads to reduced grazers likely to result in increased green algal growth but normally only seen on very localised scale ie a few square metres.

Forest (S)
SUBLITTORAL

Activity	Notes
Exploitation of Algae (not maerl)	Potential damage over wide areas - studies under way in Scotland. Recovery may take considerable time due to the important associated communities.
Oil and Gas Industry	Seems to be relatively unaffected in most respects. Potential damage to young stages?
Sewage Disposal	Generally unaffected except in very severe cases. Turbidity could be a problem but increased growth reported in some instances.

Faunal Cushions (S)
SUBLITTORAL

Activity	Notes
Commercial Finfish Fishing	One study found which suggested several species damaged but only *Cliona* sp was significantly reduced: recovery occurred in 12 months. It has been suggested that some long lived slow growing sponges such as *Geodia* and *Chondrocladia* could be nearly exterminated by a single encounter with fishing gear and would recover only very slowly, or possibly not at all if fishing continued, though this seems presently only to be supposition.
Aggregate Dredging	As suspension feeders, likely to be sensitive to anything which increases particulates.

Faunal Cushions (S)
SUBLITTORAL (cont)

Activity	Notes
Docks and Marinas	Evidence of a general intolerance to TBT, and also of some species to physical stresses associated with boat mooring.
Sewage Disposal	As suspension feeders, likely to be sensitive to anything which increases particulates. Studies in the Mediterranean suggested sewage pollution generally reduced species number, diversity and evenness but not percentage cover of sponges. It seems some are tolerant of sewage inputs.