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Disturbance of benthic species by fishing activities: a sensitivity index

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ABSTRACT

1. Preliminary estimates of the relative sensitivity of sea bed types and benthic species to physical disturbance, particularly fishing activity, have been made in order to identify areas where further studies are required and to help formulate management plans for sites of marine conservation importance.
2. Physical disturbance is considered in the context of a single encounter with fishing gear followed by a recovery period during which there is no fishing, but with a view to qualifying, in the future, the effect of multiple fishing events. Disturbance is considered in terms of the physical action of the gear on the sea bed and the unit area over which this action occurs.
3. The effects of a wide range of gears are considered. Static gears, which can be employed on a variety of substrata, generally result in low level impacts for single fishing events and impacts are localized compared with the effects of mobile gears, which can extend over considerable areas.
4. The theoretical sensitivity of individual species is assessed on the basis of how well they cope with an encounter with fishing gear and on their likely recovery from destruction in terms of their reproductive strategies.
5. Species considered of key importance in the structuring of communities are suggested and examples of particularly sensitive species, which are therefore likely indicator species of physical disturbance, are listed.
6. Fragile, slow recruiting animals are considered to be most susceptible to disturbance, while the least sensitive species are generally fast growing and have good recruitment. ©1996 by John Wiley & Sons, Ltd.

INTRODUCTION

There is a growing body of evidence that the pursuit of certain fisheries is likely to lead to long-term changes in marine ecosystems (e.g. Reise, 1982; Reisen and Reise, 1982; Pearson *et al.*, 1985; Wöss, 1992; Bergman and Hup, 1992; Brylinsky *et al.*, 1994; Kaiser and Spencer, 1996). Some of that change will be undesirable because it over-fishes stocks, removes non-target species, or affects other aspects of environmental management (such as the conservation of biodiversity or the maintenance of aesthetic values). In conserving biodiversity, it is particularly important that those parts of the natural environment that are irreplaceable (or of which the loss cannot be made good) are not damaged or destroyed. 'Irreplacibility' is a key criterion in assessing the importance of sites and species. This is expanded in the concept of Critical Environmental Capital (CEC), which 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 time scales' (Masters and Gee, 1995, p. 6). A challenge inherent in the practical application of the CEC concept in environmental management lies in determining those elements of the natural environment that qualify and those that do not. This depends on our ability to

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identify what can and cannot be replaced once lost. One of the characteristics suggested by Masters and Gee (1995) to assess CEC is the physical sensitivity of species.

Definition of terms

'Sensitivity' is sometimes considered synonymous with 'vulnerability', but we prefer to maintain an important distinction. We define sensitivity as: 'the intrinsic intolerance of a habitat, community or individual (or individual colony) of a species to physical damage or removal from an area due to an external factor beyond the range of environmental conditions normally experienced'. By contrast, the vulnerability of a species describes its exposure to an external factor. This includes, for example, behavioural characteristics such as position, circadian rhythms or abilities to withdraw or avoid capture. Thus, a species may be sensitive to fishing disturbance but is only vulnerable to such disturbance if it occurs on the kinds of substrata where the disturbing fishing activity takes place and is likely to come into contact with the gear. Therefore, we might conclude that the sea pen, *Funiculina quadrangularis* (Pallas, 1766), is sensitive to bottom trawling, but is only vulnerable to bottom trawling in areas where its distribution coincides with trawled areas. Similarly, sensitive species that occur in fine sands are generally not very vulnerable to disturbance by crab potting because such pots are more usually set on rocky substrata.

Sensitivity must be assessed in relation to the human activity that might impact upon it. For example, a particular species may be very sensitive to damage from physical disturbance, but be tolerant of some particular form of localized pollution, such as nearby fish farm effluent. Being able to assess the sensitivity of species would therefore be an advantage when determining if a site should be given CEC status and this would feed into the management of activities in or near such sites. This in turn would implicitly require that the process also takes into account the vulnerability of species to the particular activity for which its sensitivity was being considered.

Types and effects of disturbance

There are many different forms of anthropogenic disturbance to which benthic species, habitats and communities are subjected (e.g. Probert, 1975, 1984; Conner and Simon, 1979; McLusky *et al.*, 1983; Leidy and Fiedler, 1985; Hall, 1994). Fishing activities have long been regarded as particularly disturbing physically with protests dating back to the fourteenth century (de Groot, 1984). Until recently, much evidence of disturbance caused by fishing had been anecdotal. However, there is currently a strong interest in the impacts of fishing on benthos and a growing number of scientific studies have been undertaken (see for instance, Rumhor and Krost, 1991; Bergman and Hup, 1992; Eleftheriou and Robertson, 1992; MacDonald, 1993; Brylinsky *et al.*, 1994; Kaiser and Spencer, 1993, 1995, 1996; Currie and Parry, 1996; Eno *et al.*, 1996). Therefore, the present study, which focuses on fishing activities, is based on interpretations of available literature (e.g. de Groot and Apeldoorn, 1971; Margetts and Bridger, 1971; de Groot, 1984; Caddy, 1973; de Graaf and de Veen, 1973; Fonesca *et al*, 1984; Fowler, 1989; Eleftheriou and Robertson, 1992; Jones, 1992; Kaiser and Spencer, 1993, 1995, 1996; MacDonald, 1993; Rees and Dare, 1993; ICES, 1994a,b; Eno *et al.*, 1996; Hill *et al.*, 1996). Such literature was combined with the authors' experience and communication with marine scientists in these fields.

Not all fishing activities will have detectable effects and the severity of the impact can depend on the frequency and/or intensity of the disturbance (MacDonald, 1993). Stable habitats with long lived species will generally take longer to recover following disturbance (Pickett and White, 1985). Such stable environments are often found in low energy systems such as sealochs, or in deep water offshore, and may be substantially affected by even low frequencies of disturbance (Dayton and Hessler, 1972; Grassle and Sanders, 1973). Conversely, communities found on or in mobile sands and gravel banks frequently disturbed by wave action are expected to be more resilient to high frequencies of physical disturbance because of the inherent instability of the habitats. In terms of species richness, the richest benthic communities often occur in stable sediments where long-lived species, which settle only occasionally, can survive and add cumulatively to the richness (the 'biologically accommodated' community of the 'stability-time hypothesis'; Sanders, 1968).

Theoretical considerations of disturbance can be complex (e.g. Levin and Paine, 1974; Connell and Slayter, 1977; Connell, 1978; Fox, 1979; Sousa, 1979a,b, 1980, 1984, 1985; Miller, 1982; Denslow, 1985; Menge and Sutherland, 1987; Hall, 1994) and disturbance due to fishing can be broken down into several components including intensity, frequency, size and shape (MacDonald, 1993). For the purposes of this study, however, disturbance refers only to the combination of the physical action of the gear on the sea bed and the area over which this action extends. Manifestations of disturbance to the benthic species may therefore range from no or minimal physical damage through to major redistribution of substrata and high, instantaneous mortality of benthos.

Development and application of sensitivity critiera

The present work sets out to develop criteria that can be used to assess the sensitivity of species to physical disturbance from fishing activities, and to apply these criteria within a framework that indicates particularly sensitive species and the levels of disturbance experienced for defined fishing practices. Physical disturbance is considered in the context of a single encounter with fishing gear followed by a recovery period during which there is no fishing, but with a view to qualifying, in the future, the effect of multiple fishing events. Such a framework would highlight where field studies are required to improve our assessment of the extent and importance of sensitive species in an area, and therefore improve the effectiveness of applying concepts such as CEC and of formulating management plans for sites of marine conservation importance. In the context of this paper, it is important to note that sensitivity refers both to species' susceptibility to physical damage caused by contact with gear in a single fishing event and to their ability to cope with such damage through regeneration or recruitment.

METHODS

Rationale

In order to define an index for sensitivity, the components of sensitivity must be understood and taken into account. These are:

1. the fragility of individuals of a species that come into physical contact with the disturbing force;
2. the ability of the species to recover to its former population or physical status within the disturbed area.

The first component of sensitivity (fragility) depends on the organism's physiolgy and/or structure including stength or flexibility. For example, a certain minimum force would be required to crush the test of an adult common urchin, *Echinus esculentus* Linnaeus, 1758. The susceptibility of the organism to physical damage will therefore depend on its inherent fragility and the intensity of the impact. As many as 70% of tests of *Echinus esculentus* caught by scallop dredges can be smashed by the gear upon contact or by the material in the dredges (MacDonald, 1993), but we would expect this figure to be lower for a beam-trawl and substantially lower for crab potting.

The second component of sensitivity (recovery) incorporates several concepts:

- the ability of damaged organisms to repair or regenerate lost or damaged parts—for example, brittlestars are well known for being able to regenerate arms;

- the ability of the organisms to continue occupying the disturbed habitat—for example, if seapens are uprooted by *Nephrops* creels, they are subsequently able to reinsert their peduncle (Eno *et al.*, 1996);
- the supply of larvae to the disturbed habitat and their settlement success;
- recruitment to the adult population from settled larvae.

The time taken for the species to recover to its former status locally can vary from less than 24 hours (in the case of mobile species), through a few months to decades, and in some instances, full recovery may never be achieved (Rosenberg, 1974, 1976, 1977; Bonsdorff, 1980, 1983, 1986; Reise, 1982; Reisen and Reise, 1982; Guillou and Hily, 1983; Peterson *et al.*, 1987; Frid, 1989; Jones, 1992).

An index of sensitivity

A meaningful index of sensitivity must be based upon consistent assessment of each of those factors discussed above and this might be done using a formula. We consider the recovery potential to be the most important and this should therefore be weighted. We propose the following index of sensitivity (*S*):

$$S = (FxI)\ e^{R}$$

where *R* is *recovery* (scored on a scale of 1 to 4, equivalent to short, moderate, long and very long recovery period or no recovery is likely); *F* is *fragility* (scored on a scale of 1 to 3, equivalent to not very fragile, moderately fragile, and very fragile—a recent study, which examined effects of pot fishing on benthic species (Eno *et al.*, 1996) and used a five point damage scale, suggests that such a three point scale may be more easily applied); and *I* is the *intensity of the impact* (scored on an arbitrary scale of 1 to 3, equivalent to low, moderate and high intensity).

Recovery represents the time taken for a species to recover in the disturbed area. Where the organisms are largely unaffected by the passage of gear, *R* will be short. If the organisms are damaged or killed but migration into the disturbed area is rapid, then *R* may also be short. Where recovery depends on regeneration of damaged organisms or recruitment to the adult population from larval settlement and growth, recovery times will then depend on the recruitment and growth rates of those species. Consequently, slow growing, poorly recruiting species will have high *R* scores. With more information on the various life history and ecological parameters affecting recovery, it might be possible to further refine *R* by breaking it down into constituent components. These might include immigration of mobile species and infilling types of growth by colonies, and recruitment of juveniles but including juvenile mobility or space occupancy where this is normal. However, without sufficient information available for all the species examined in this study, we opted to maintain the simpler approach. It is important to bear in mind that in considering recovery times, the context taken in this study was a single fishing event followed by a recovery period with no fishing: if there are multiple fishing events at the same site then recovery may take much longer or might never even be achieved.

Fragility represents the inability of an individual or colony of the species to withstand physical impact from fishing gear. It is primarily related to the strength of body parts such as tests, shells and exoskeletons. Fragile organisms such as *Pentapora foliacea* (Ellis and Solander, 1986) and *Echinus esculentus* would have a relatively high fragility score. Tougher organisms such as *Buccinum undatum* Linnaeus, 1758, and hermit crabs in *Buccinum undatum* shells, would have a lower fragility score.

Intensity of impact depends on the type (and momentum where applicable) of the gear and the depth of penetration into the substratum. Thus, static gear will generally score low compared with mobile gear. For example, beam trawls would have a much higher score than a long-line.

Application of the index

The relative sensitivities of different species to disturbance from fishing activities were estimated within the context of species having a single encounter with fishing gear followed by a recovery period during which there is no fishing.

The sensitivity scores for various species were then normalized by dividing each score into the maximum possible score using the following relationship;

$$S_{norm} = \frac{S_n}{S_{max}} \times 100$$

where S_{norm} is the normalized sensitivity score for any species n and S_{max} is the maximum possible sensitivity for the most disturbing fishing activity ($S_{max}=241$).

RESULTS

The results of calculating sensitivity indices for a variety of species and difficult types of fishing activities are presented in Tables 1 and 2. For example, for a scallop dredge encountering *Eunicella verrucosa* (Pallas, 1766), fragility would be high ($F=3$), the intensity of impact by a dredge would be high ($I=3$) and the recovery time required by *Eunicella verrucosa* would be long ($R=3$). This results in high sensitivity ($S_n=181$, $S_{norm}=75$). By contrast, the sensitivity of *Buccinum undatum* encountering a gill net would be much lower ($S_n=3$, $S_{norm}=1$) since it is not very fragile ($F=1$), the intensity of the gear is low ($I=1$), and the recovery time would be short ($R=1$).

DISCUSSION

Sensitivity in relation to intensity of fishing

Calculating the relative sensitivities of different species in the context of a single encounter with fishing gear followed by a recovery period during which there would be no fishing is clearly an unrealistic portrayal of what happens in some real fisheries, such as scallop and cockle fisheries, where the same ground may be fished intensively until the catches no longer justify the effort involved in fishing. Multiple fishing events in exactly the same area will obviously cause greater disturbance than a single fishing event. The quantification of the effects of multiple fishing events would be a logical progression from this work. This would allow further development of an index that could take into account the frequency of the disturbance event.

Although the index of sensitivity in relation to static gear for a single fishing event is considered to be low level when compared with that of mobile gear, this does not exclude the possibility of damage to sensitive species by intensive use of static gear in small areas (Eno *et al.*, 1996). Some pot fishermen deploy considerable numbers of pots and their repeated use in a small area could possibly affect fragile species such as *Pentapora foliacea*. The impact of the weights of set nets or pots arriving on the sea bed may physically damage fragile organisms, and this is particularly the case on rocky ground where *Pentapora foliacea* is found. The movement of set nets and pots on the sea bed during rough weather or during retrieval can further detach organisms from the surrounding rock surfaces, but this is likely to be minimal compared to mobile gears.

Sensitivity in relation to gear type

Some types of gear are designed to be fished in rocky areas (*e.g.* the rockhopper type of otter trawl and the Newhaven type of scallop dredge). Although other types of demersal trawl or dredge are designed principally to operate on sediments, they also come into contact with epilithic organisms on mixed grounds.

Table 1. Likely sensitivity of some species to disturbance caused by an encounter with fishing gear on rocky grounds. Fishing gears have been grouped according to the relative scale of disturbance they cause. Low intensity gears include pots, gill nets and long-lines. Medium intensity gears include otter trawls and Danish Seines. High intensity gears include dredges, rockhoppers and beam trawls. The values of F (fragility) were derived from personal knowledge of the species structure and of R (recovery) were derived from a review of literature on the life-histories of the species.

Species	F	R	S for low intensity gear ($I=1$)	S for medium intensity gear ($I=2$)	S for high intensity gear ($I=3$)	S_{norm} ($I=1$)	S_{norm} ($I=2$)	S_{norm} ($I=3$)
Leptopsammia pruvoti	3	4	33	89	241	14	37	100
Eunicella verrucosa	3	3	24	67	181	10	28	75
Caryophyllia smithii	2	3	16	44	121	7	18	50
Pentapora foliacea	3	2	16	44	121	7	18	50
Echinus esculentus	3	2	16	44	121	7	18	50
Flustra foliacea	2	2	11	30	80	5	12	33
Laminaria hyperborea (mature)	2	2	11	30	80	5	12	33
Cliona celata (massive)	2	2	11	30	80	5	12	33
Holothuria forskali	1	2	5	15	40	2	6	17
Crossaster papposus	1	2	5	15	40	2	6	17
Acmaea tessulata	1	2	5	15	40	2	6	17
Gibbula cineraria	1	2	5	15	40	2	6	17
Chitons	1	2	5	15	40	2	6	17
Alcyonium digitatum	1	2	5	15	40	2	6	17
Tubularia indivisa	3	1	8	22	60	3	9	25
Nemertesia antennina	2	1	5	15	40	2	6	17
Antedon bifida	2	1	5	15	40	2	6	17
Nitophyllum punctatum	2	1	5	15	40	2	6	17
Halichondria panicea	1	1	3	7	20	1	3	8
Pomatoceros triqueter	1	1	3	7	20	1	3	8
Encrusting algae	1	1	3	7	20	1	3	8

They may also break-up biological reefs such as those formed by *Sabellaria spinulosa* Leuckart, 1848, and *Modiolus modiolus* (Linnaeus, 1758) (ICES, 1992) or friable rocky reefs such as shale reefs. Larger vessels generally have a greater capacity to fish mixed ground than the smaller inshore vessels because they are able to handle the more robust gear required. On grounds without erect epifauna the disturbance caused by a single fishing event will depend on the size of the gear, its weight, and its degree of penetration into the sediment.

For mobile gears, the type will also determine the ratios of those individuals caught and taken aboard as by-catch, those that are caught but pass through the gear, and those that are impacted *in situ* but not actually caught. Many species when taken aboard suffer increased stress from desiccation, trampling under crew member's feet and from suffocation. Although mortality can often be very high (Wassenberg and Hill, 1989; MacDonald, 1993; Kaiser and Spencer, 1995), we do not yet know enough about these effects.

Applying the sensitivity concept to biotopes

The approach taken in the present study has been to work in terms of disturbance to sea bed types and species. However, it would be useful to conservation managers to provide assessments of the sensitivity of biotopes to various forms of disturbance.

Table 2. Likely sensitivity of species to disturbance caused by an encounter with fishing gear on clean or mixed grounds. Fishing gears have been grouped according to the relative scale of disturbance they cause. Low intensity gears include pots, gill nets and long-lines. Medium intensity gears include otter trawls and Danish Seines. High intensity gears include dredges, rockhoppers and beam trawls. The values of F (fragility) and R (recovery) used in these examples were derived from a review of literature on the life-histories of the species.

Species	F	R	S for low intensity gear (I=1)	S for medium intensity gear (I=2)	S for high intensity gear (I=3)	S_{norm} (I=1)	S_{norm} (I=2)	S_{norm} (I=3)
Funiculina quadrangularis	3	4	33	89	241	14	37	100
Maerl	3	4	33	89	241	14	37	100
Modiolus modiolus	2	4	22	59	161	9	25	67
Virgularia mirabilis	3	3	24	67	181	10	28	75
Echinocardium cordatum	3	3	24	67	181	10	28	75
Artica islandica	2	3	16	44	121	7	18	50
Ensis siliqua	2	3	16	44	121	7	18	50
Sabellaria alveolata/ spinulosa reefs	3	2	16	44	121	7	18	50
Zostera marina	3	2	16	44	121	7	18	50
Ophiura texturata	3	2	16	44	121	7	18	50
Ophiocomina nigra	3	2	16	44	121	7	18	50
Ophiothrix fragilis	3	2	16	44	121	7	18	50
Corystes cassivelannus	3	2	16	44	121	7	18	50
Aporrhais pespelecani	2	2	11	30	80	5	12	33
Pecten maximus	2	2	11	30	80	5	12	33
Aequipecten opercularis	2	2	11	30	80	5	12	33
Turritella communis	2	2	11	30	80	5	12	33
Maja squinado	2	2	11	30	80	5	12	33
Cancer pagurus	2	2	11	30	80	5	12	33
Urticina felina	2	2	11	30	80	5	12	33
Glycymeris glycymeris	2	2	11	30	80	5	12	33
Abra alba	2	2	11	30	80	5	12	33
Spisula spp.	2	2	11	30	80	5	12	33
Donax vittatus	2	2	11	30	80	5	12	33
Tellina fabula	2	2	11	30	80	5	12	33
Asterias rubens	2	2	11	30	80	5	12	33
Luidia spp.	2	2	11	30	80	5	12	33
Astropecten irregularis	2	2	11	30	80	5	12	33
Eupagurus bernhardus	1	2	5	15	40	2	6	17
Portunus depurator	1	2	5	15	40	2	6	17
Lanice conchilega	3	1	8	22	60	3	9	25
Spiophanes bombyx	3	1	8	22	60	3	9	25
Pectinaria koreni	2	1	5	15	40	2	6	17
Buccinum undatum	1	1	3	7	20	1	3	8

The sensitivity of a biotope to an anthropogenic activity is a function of the sensitivity of the different species making up the biotope's component community. This poses a problem in deriving an assessment of biotope sensitivity; should all the species be treated as equally important to the community, or should weight be given to particular species such as key species, rare species, particularly sensitive species, or species with high aesthetic value? Simply averaging the sensitivities of the species present in a community will tend to introduce bias to the estimate for the community as a whole. For example, if the community is comprised of many species with high recruitment rates, the sensitivity of the community may be underrated. However, if attention is focused on particularly sensitive species then unreasonably high or skewed results may be obtained.

A sophisticated method of assessing community or biotope sensitivity is not yet available. Until one is, a crude means of mapping biotope sensitivity in relation to specific impacts and activities would have to rely upon marking those biotopes in which known sensitive species occur. Where many species are present in a community or biotope, a measure of biotope sensitivity will be difficult to arrive at. An alternative approach could be to focus on 'key' species (discussed below) in the community such as *Zostera marina* (Linnaeus 1758) in the case of a seagrass bed.

Sensitivity and 'key' or 'indicator' species

Key species are effectively those species that structure the community (Masters and Gee, 1995). The loss of such species from the community would therefore be expected to seriously change the nature of the community and possibly its viability. Within the context of sensitivity assessment, this suggests that it is only necessary to assess the sensitivity of the key species rather than all the species present. The problem here lies in identifying key species.

In the terrestrial environment, key species often correspond to dominant vegetation types present (e.g. oak trees in oak woodland). In the marine environment, the equivalent situation occurs where species form the substratum for other species (e.g. a *Modiolus modiolus* bed), dominate either by modifying environmental conditions (e.g. shade and shelter from wave action under kelp forests) or by being major grazers or predators (e.g. sea urchins on a rocky seabed), or structure the habitat through bioturbation. However, identifying key species may be difficult in many other cases, particularly with infaunal animals. Where there are no obvious key species, indicator species may provide an alternative focus.

The term 'indicator species' has a number of meanings (ICES, 1994a). For example, an indicator species might be that whose presence may indicate certain contaminations, or whose elimination from an ecosystem may act as an early warning for the system, or whose physical or physiological characteristics change in response to pollution. Indicator species might also be regarded as indicative of certain substratum types (*sensu* Jones, 1950). In the context of the present discussion, we use the term to refer to species whose abundance might provide a guide to levels of fishing disturbance and therefore to whether communities in an area are natural or altered by fishing. Such species would be particularly sensitive to fishing because they are fragile, slow growing and/or have poor recruitment prospects, are likely to be widespread and can be easily recognized.

Indicator species are particularly useful as a measure of long-term fishing disturbance since they reflect the effects of multiple fishing events. An example might be the sea pen *Virgularia mirabilis* (Müller, 1776) which would be expected to be present on muddy sands in depths of 50 to 100 m on open coast but is very sensitive to mobile gear and only likely to be found where fishing is absent or low intensity. Although the ICES Working Group on Ecosytem Effects of Fishing Activities (ICES, 1994b) consider that indicator species have little part to play in monitoring the long-term effects of fishing activities because directly monitoring is the simpler approach, we do not fully agree and suggest that (usually financially) restricted programmes of sampling could concentrate on certain likely indicator species. Table 3 presents some candidate species which may indicate degree of fishing intensity for different seabed types where there are no obvious key species. Although we provide these examples, we recognize a problem where in many instances other potential indicator species may not be helpful since they may have already been fished out.

Table 3. Some candidate species which may indicate intensity of fishing activity for some different seabed types.

Sea bed type	Candidate indicator species
Sand	*Echinocardium cordatum*, *Ensis* spp., *Corystes cassivelaunus*
Muddy bottoms of sealochs	*Virgularia mirabilis*, *Funiculina quadrangularis*, *Pachycerianthus multiplicatus*
Bedrock and reefs	*Eunicella verrucosa*, *Pentapora foliacea*, axinellid sponges

Effects of fishing on community composition

Apart from the direct disturbance and mortality caused by the passage of fishing gear, changes in benthic community compositions after fishing events have been demonstrated (e.g. Eleftherious and Robertson, 1992; MacDonald, 1993; Hill *et al.*, 1996; Kaiser, 1996). Increased levels of disturbance to benthos encourages a shift in species composition from long-lived and slow recruiting species, to more opportunistic, less sensitive species that can quickly colonize disturbed areas through successful recruitment and rapid growth. Whether or not original communities will ever return following heavy disturbances is unpredictable since succession may not be unidirectional (see MacDonald, 1993, for a discussion).

It is important to bear in mind that the majority of the sea bed around the UK coast has been affected to various degrees by fishing and that many communities may be the result of past and continued disturbance. It is also likely that sensitive species will no longer be present in such areas, having become locally extinct.

Significance for nature conservation management

The aims of nature conservation in Great Britain are most eloquently given in Command 7122 (Ministry of Town and Country Planning 1947): 'to preserve and maintain as a part of the nation's natural heritage places which can be regarded as reservoirs for the main types of community and kinds of wild plants and animals represented in this country, both common and rare, typical and unusual'. To achieve such an objective in a scientific and defensible manner requires the development of concepts such as Critical Environmental Capital supported by objective measures of sensitivity. In this paper, we have worked towards establishing a framework for assessing the 'real' sensitivity of species, biotopes and locations around our coasts to fishing activities. This is a substantial advance on previous equations of sensitivity with scientific interest. Certainly, sites that are valued because they include representative or rare features should be protected, but some will be more or less sensitive to different activities than others. Similarly, certain parts of marine protected areas will include species and features more sensitive to certain forms of fishing than others. Restrictions on fishing in those sensitive areas (but not in the other areas) might then be appropriate. Such considerations lead to the sorts of zoned management schemes described by Laffoley *et al.* (1994).

Further development of sensitivity assessment and information requirement

The sensitivity index, as currently scored, tends to place any species with a poor chance of recovery or re-establishment in the higher categories. A further category could be added for those species unlikely to re-establish because of their longevity and poor recruitment prospects. There are other possible ways in which the index could be variously refined, but these rely upon having further information available. For instance, the greatest difficulty in assessing sensitivity is that very rarely do we know enough about the longevity, growth rates and reproductive mechanisms of species to assign appropriate scores. Also, we do not yet have sufficient information about the effects of fishing on the vast majority of benthic species and, at best, we can only calculate sensitivity for a small percentage of the species present in certain communities. If sensitivity scores are to be widely used, this information needs to be compiled.

It is also clear from the literature that the effect of different fishing activities on benthos remains insufficiently quantified. We therefore suggest that further studies of trawl path mortalities, life history parameters, and 'efficiency' of capture for different gears be undertaken for non-target benthic species, particularly sensitive species, in order that the conservation risks associated with fishing may be better estimated. Furthermore, selected benthic communities should be monitored to assess the effects of fishing activity on resident communities and on the recruitment of other biota. This type of information is fundamental to our understanding of interactions between fishing gear and benthos.

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Benthic disturbance by fishing gear in the Irish Sea: a comparison of beam trawling and scallop dredging

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ABSTRACT

1. The distribution of effort for the most frequently used mobile demersal gears in the Irish Sea was examined and their potential to disturb different benthic communities calculated. Fishing effort data, expressed as the number of days fished, was collated for all fleets operating in the Irish Sea in 1994. For each gear, the percentage of the seabed swept by those parts of the gear that penetrate the seabed was calculated.

2. For all gears, the majority of fishing effort was concentrated in the northern Irish Sea. Effort was concentrated in three main locations: on the muddy sediments between Northern Ireland and the Isle of Man (otter and *Nephrops* trawling); off the north Wales, Lancashire and Cumbrian coast (beam trawling); the area surrounding the Isle of Man (scallop dredging).

3. In some areas, e.g. between Anglesey and the Isle of Man, the use of scallop dredges and beam trawls was coincident. A comparative experimental study revealed that scallop dredges caught much less by-catch than beam trawls. Multivariate analysis revealed that both gears modified the benthic community in a similar manner, causing a reduction in the abundance of most epifaunal species.

4. Although beam trawling disturbed the greatest area of seabed in 1994, the majority of effort occurred on grounds which supported communities that are exposed to high levels of natural disturbance. Scallop dredging, *Nephrops* and otter trawling were concentrated in areas that either have long-lived or poorly studied communities. The latter highlights the need for more detailed knowledge of the distribution of sublittoral communities that are vulnerable to fishing disturbance. ©British Crown Copyright 1996.

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