FISHERIES SOCIETY OF THE BRITISH ISLES BRIEFING PAPER 3:

EFFECTS OF FISHING ON BIODIVERSITY IN THE NORTH SEA[1, 2]

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1. EXECUTIVE SUMMARY

Biological diversity means the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems. Any shift in diversity, positive or negative, as a result of fishing disturbance is cause for concern. Here we review current understanding of the impact of fishing on genetic and species diversity within the confines of the North Sea. The North Sea is one of the world's major shelf areas boasting a productive ecosystem and a substantial fishery exploited by eight bordering European countries. Biodiversity measures vary from counts of the number of entities present (species richness) to indices of the abundance distribution among those entities (species diversity). Although many anthropogenic activities can also lead to changes, the largest anthropogenic impact to date has been fishing:

- Fishing techniques in the North Sea vary from gears which have limited direct impacts on habitats, such as hook and line and purse seines, to habitat-modifying techniques such as dredging and trawling. Many of these fishing techniques, particularly trawl fisheries, produce a large bycatch (species not targeted by the fishery), little of which survives after being discarded.
- The passage of towed gear can cause significant direct damage to benthic habitats, sediment resuspension, and a reduction in surface topography of the benthic habitat. The latter features are also linked to higher species richness. Damage to benthic habitats is of particular concern for emergent habitat forming fauna such as hydroids and slow-growing deep water coral reefs that hold up to three times the number of species of adjacent sediments.
- Physically stable benthic habitats, such as deep sea environments or muddy sands, with little natural disturbance are more vulnerable to mobile fishing gear than those in areas of high natural perturbation, for example mobile sandbanks, which may scarcely experience major lasting impacts.
- Selective pressure for larger individuals of some target fish stocks in the North Sea is resulting in an evolutionarily driven reduction in size and age at maturity. Fishing may also be causing a reduction in allelic diversity in some stocks' with loss in particular of rarer alleles.
- In the North Sea fifteen species have become locally extinct and one (the gray whale) regionally extinct as a result of over-exploitation. Such evidence is taken mostly from a small area of the SE North Sea and so actual numbers may be higher and many species are likely yet to be properly identified and catalogued.
- Three of the studies reviewed for this paper suggest fishing has reduced **species richness**, whereas three detected no change and one indicated a possible increase, although the design of the study or the patchiness of fishing distribution may affect these findings.
- The majority of the studies in the North Sea reviewed for this paper indicate local decreases in **species diversity** in response to exploitation, however some demonstrate an increase or no apparent change. The cumulative effects of other natural and anthropogenic influences have to be accounted for and in many cases the effects may be synergistic with each other.
- Recovery of sites after trawling can take days in naturally dynamic environments, months in less disturbed habitats, to years in regions of slow regeneration habitat. Areas of intense trawling disturbance may exist in a permanently perturbed state. Use of different gears varies spatially, with more beam trawling effort in the southern North Sea and more otter trawling in the north, west and east. Fishing intensity also varies greatly at a range of scales, which may limit the area that is permanently perturbed and allow many regions to recover between events.
- Areas with emergent habitat-forming fauna which hold high associated species richness and are important as nursery areas, should receive management and policy priority.
- As well as measures of all biodiversity, monitoring of certain indicator species that are vulnerable to fishery impacts will be useful. More studies addressing fishing effects on genetic and habitat diversity are also necessary.

This briefing paper concludes that fishing practices have altered the biodiversity of the North Sea. It is not currently possible to assess the original pristine status of the area, which is likely held in a long-term imbalance due to fishing, but further major long term impacts are probably limited to a relatively small proportion of the whole.

2. INTRODUCTION

2.1 Aims and Intended Audience

This briefing paper aims to impartially review the current scientific understanding of the effects of fishing on biodiversity in the North Sea. The paper will draw on historical data, studies of temporal and spatial changes in the ecosystem and experimental manipulations and comparisons. Because of the enormous scope of the subject, the paper is restricted to the confines of the North Sea, with potential examples from elsewhere, and will concentrate on organisms that live entirely in the sea (thus excluding seabirds). The anticipated audience is wide, with the hope that the document will be of use and interest to academics and students, government scientists, non-government organisations, conservation groups, the general public and government policy makers both in the UK and Europe. To this end, the document has been reviewed by a selection of key experts from each of these groups to assess its scientific content and applicability for their needs.

2.2 The North Sea

The North Sea (Fig. 1) constitutes one of the world's major shelf areas with a fishery producing more than 3 million tonnes per annum, thus contributing 4% of the world's fishery production (ICES 2000). This high productivity is a result of the relatively shallow depth of the area, being a semi-enclosed shelf characterised by strong mixing mechanisms circulating nutrients from the rich bottom layer to the nutrient-poor upper layers of the sea (ICES 2000). The substrate varies from fine sediments in the deeper and less turbulent north-east region to large areas of gravel and coarse sand in the shallower and more environmentally disturbed western regions (Paramor *et al.* 2002) with isolated areas of more specific habitat forming biota such as sponge beds, reefs formed by *Sabellaria spinulosa* (Polychaeta) and deep water coral reefs (Vorberg 2000; Fosså *et al.* 2002).

Figure 1. *Map of the North Sea showing borders of the sea and the countries that fringe it. Reproduced with the kind permission of Statens Kartverk.*

The North Sea is bordered by eight European member states (Belgium, Denmark, Sweden, The UK, France, Germany, Norway and The Netherlands) all of which fish the area. In terms of number of species exploited, the fisheries are among the richest in the Northeast Atlantic (ICES 2000). Cod, haddock, whiting, saithe, plaice, sole, herring, mackerel, *Nephrops*, *Pandalus*, and brown shrimp are the main species exploited for human consumption, while sandeel, Norway pout and sprat are exploited for fishmeal and oil use (ICES 2000, 2003; OSPAR 2000).

3. QUANTIFYING BIODIVERSITY

3.1 Definitions and Various Measures

Biological diversity is 'the variability among living organisms from all sources including, *inter alia*, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems' (CBD 1992). Fishing may alter diversity within species (genetic diversity) by affecting age and size at maturity, growth rates and reproductive output; diversity among species by altering the existence and abundance of different species; and diversity of ecosystems by altering the size and distributions of different habitat types. Different habitats in the North Sea are impacted by fishing in different ways and recover at different rates, as highlighted throughout this review. Although this will likely lead to reduced habitat heterogeneity, no studies to date have looked at the effects of fishing on habitat diversity in the North Sea, and so this review will not make any inferences as to these effects. Some recent work has looked at the effects of fishing on genetic diversity, which is reviewed here. The majority of studies in the North Sea to date have focussed on diversity at the species level which will be the main focus of the review. This is a complex, yet important task, because biota range from large marine mammals to minute meiofauna species and the marine benthos in particular boasts the highest level of phyletic diversity of any ecosystem on Earth (Gaston & Spicer 1998; Moore & Jennings 2000).

Measures of diversity can be complex and new methods are being developed, but essentially they fall into two categories: 1) number of entities (alleles, species, habitats) and 2) incorporation of the degree of difference in abundance between those entities (Gaston 1996). At species level, the first measure is commonly termed ‘species richness’, while measures of the second are termed ‘species diversity’. Species richness is simply the total number of species recorded and is highly dependent on sampling effort; thus comparisons can only be made if sampling procedures are the same. Species diversity indicates both richness and the distribution of the number of individuals among species of the assemblage (evenness). In measures of species diversity, high evenness and low dominance (the converse of one another) generally indicate a more diverse assemblage than one of low evenness and high dominance (Kaiser 2003). There are many measures of species diversity ranging from the original Simpson’s diversity and the Shannon-Wiener indices to new techniques at the species level incorporating factors such as the taxonomic relatedness of species (Warwick & Clarke 1995). Incorporating evenness into analysis has wide implications, as the removal of target species could increase or decrease evenness, and thus diversity, through predator-prey or competitive interactions. The removal of large fish in the North Sea, for example, appears to have resulted in a steady and significant increase in the abundance of smaller fish (Daan *et al.* 2003). However, this is not to say the ecosystem is in a more productive state and such shifts at a species level are notoriously difficult to measure, particularly in the marine environment. Any change in species diversity, positive or negative, as a result of fishing indicates an anthropogenic impact on the system. However, in such a complex ecosystem and an area with a long history of human perturbation, interpretation of shifts can be problematic.

3.2 Natural Variations in Biodiversity

Biodiversity in the marine environment tends to be in a state of dynamic equilibrium with variable environmental productivity and disturbance causing continuous shifts in community composition (Huston 1994; Rogers & Millner 1996), which obviously complicates attributing changes to specific events or activities (Gislason 1994). Not only is there temporal variability, species richness also varies spatially among habitats; those with greater structural complexity hosting assemblages of greater diversity (Huston 1994). Habitat structure provides refuge from predation for many fishery target and non-target fish and invertebrates (Tupper & Boutilier 1995). In the North Sea, areas of gravel and coarse sand may be expected to host greater species richness than soft sediments (Rees *et al.* 1999), and beds of structural organisms such as sponges, anemones, soft corals and deep water corals are expected to contain more species still (UK Biodiversity Group 2000). As species composition can vary greatly between different depths and habitat types (Rosenzweig 1995; Kaiser *et al.* 1999b), studies obviously need to standardise the substrata and depths they survey if comparison between different intensities of fishing is the goal.

3.3 Human Causes of Changes in Biodiversity

Human activities of one form or another can potentially affect marine biodiversity. The introduction of invasive species, mostly by means of ship ballast water, is often cited as a serious threat to marine biodiversity (Bax et al. 2001, 2003; Lewis et al. 2003). Although certain species such as the lobster *Homarus americanus,* introduced through live import for human consumption, are cause for concern (Anon 2001a), the estimated 80 species of invasives in the North Sea do not appear to be having detrimental effects at present (Eno 1996; Reise *et al.* 1998). Increases in production of small infaunal invertebrates in the North Sea have been attributed to climate-driven increases in primary production as apposed to competitive release following the depletion of larger animals due to trawling (Jennings *et al.* 2001a). Declines in *Sabellaria* reefs off the German coast seem to be the result of coastal defences altering current regimes in the area and not of trawling damage (Vorberg 2000). In many cases effects of human activities, for example eutrophication and fishing, may act synergistically and changes may not be attributed to a single causal mechanism (Frid *et al.* 1999; Caddy 2000; Greenstreet & Rogers 2000). The long history of anthropogenic impacts in the North Sea has resulted in a system that is largely in a long-term perturbed state, thus complicating inferences as to causes of changes in biodiversity (Kaiser 1998; Greenstreet & Rogers 2000). It is widely accepted, however, that commercial fishing represents the greatest anthropogenic impact to the North Sea ecosystem (ICES 2002a; Paramor *et al.* 2002) and this will be the focus of the rest of this paper.

4. FISHERY DEVELOPMENT AND CONCERNS

4.1 Fisheries development

Exploitation of marine resources in Western Europe has a long history, with evidence of changes in abundance of marine molluscs from as far back as the early Mesolithic (*c.* 6000-5200 BC) (Mannino & Thomas 2001). Early fisheries operated from the shore or used rowing boats or sail power and involved mainly passive methods such as fish traps, set nets, crab and lobster pots, hook and line and drift nets (Cushing 1988). Beam trawls were in operation with sailpower by the 17th century. Steam trawlers replaced sailpower at the end of the 19th century and in the early 1900s motor cutters allowed use of otter trawls (Cushing 1988; Rijnsdorp & Milner 1996). As vessels became more powerful in the middle of the 20th century and fishing vessels and gear evolved, larger gears which could be towed at greater speeds became possible (Greenstreet *et al.* 1999b), resulting in an expansion of the fishing effort. On average, fishing mortality on North Sea fish stocks peaked in the mid 1980s and has subsequently experienced a small decline (Daan *et al.* 2003, but see Jennings *et al.* 1999 who indicate continuing increases in fishing effort) and fishing pressure may continue to decline in coming decades (Hall 2002).

The first collectors of scientific data were amateur naturalists, but by the late 18th century professional collectors were using standardised sampling equipment and methods (Frid *et al.* 2000). It was generally accepted until the late 19th century that the seas were inexhaustible, and as problems of stock depletion became apparent, it was assumed that fisheries would become economically defunct before irreversible ecological decline occurred (Smith 1994). The concept of overfishing became better acknowledged in the early 20th century. The cessation of fishing during the world wars resulted in substantially higher catch rates with considerably larger fish in catches (Fig 2) (Beverton & Holt 1957; Smith 1994). By the end of the 20th century it was apparent that fish stocks can be fished down to very low levels, with herring and cod stocks periodically hitting very low levels (OSPAR 2000) and the size structure of the fishery target species being substantially reduced (Jennings *et al.* 2002a).

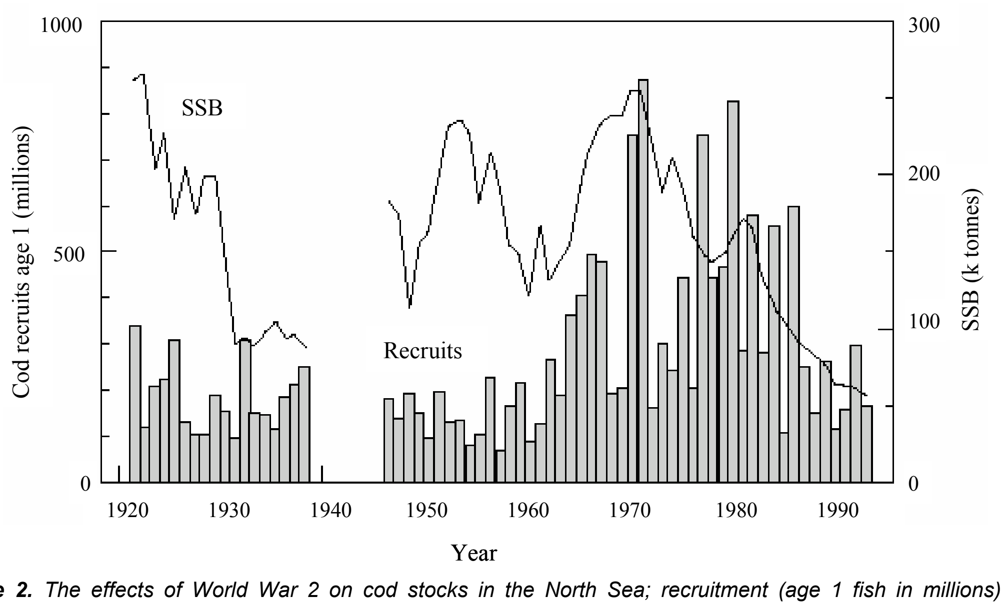

Figure 2. *The effects of World War 2 on cod stocks in the North Sea; recruitment (age 1 fish in millions) and spawning-stock biomass (thousand tonnes) 1921-1993, estimated by Virtual Population Analysis. From Pope & Macer (1996). Reproduced with the kind permission of John Pope and Elsevier.*

In addition to direct effects, involving the removal of target species, fishing can also have indirect effects on the wider ecosystem. Indirect effects of fishing arise through the alteration of predator-prey and competitive interactions, catch and discard practices of bycatch species and through habitat modification. Both direct and indirect effects can act at the population, community or ecosystem levels (Russ 1991). The first concerns about the wider implications of fishing on ecosystems were raised in the British parliament in 1376, but not until the late 19th century was money allocated to investigate the impacts of different gears on stocks and the seabed. Only in the latter decades of the 20th century have scientists begun to seriously examine the wider ecosystem effects of fishing (Moore & Jennings 2000). Although management is now moving from traditional single species assessments to include ecosystem based management, the current level of scientific understanding for this to progress is still weak (Gislason *et al.* 2000; Jennings et al. 2001b; ICES 2003), and data requirements are often prohibitive (Reynolds *et al.* 2001). Although the long history of fishing and scientific interest make the North Sea one of the best studied marine regions in the world, the number of studies that have looked at the effects of fishing on biodiversity, is still limited.

4.2 Fishing activities and their impact

Current fishing activities in the North Sea range from low-impact recreational hook and line fishing to high-impact commercial dredging and bottom trawling. As the scale and intensity of recreational fishing is so small, the focus here is on commercial fisheries. The commercial fishery in the North Sea is intensive and multinational, removing an estimated 30-40% of the total biomass of the fishery target species per annum (Gislason 1994). Pelagic fishing gears include encircling gears such as purse seines, static gears such as gill nets and towed gears such as mid-water trawls (Sainsbury 1986). These pelagic fisheries are non-destructive to benthic habitats and although a proportion of the catch will be by-catch (including seabirds and marine mammals in some cases), the quantity is dwarfed by that of the demersal fisheries. ‘Ghost’ fishing, involving lost gears that continue to catch fish and other organisms, is a continuing problem, but difficult to investigate (Moore & Jennings 2000). Fishing of pelagic stocks has been implicated in large shifts of other species, such as herring, capelin and cod interactions in the Norwegian-Barents Sea (Hamre 1994). However, as the greatest fisheries and impacts are close to the benthic environment, the majority of studies on biodiversity have focussed on demersal fisheries.

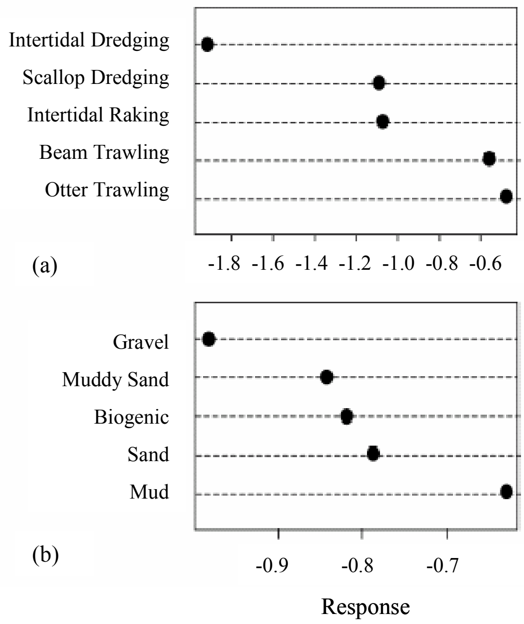

Figure 3. *The predicted mean response to fishing of invertebrate abundance or biomass (a) with different gear types and (b) in different habitats. Data are from a meta-analysis of international studies and are on a transformed scale where values correspond to percentage decline from control as follows: -0.1 = 10%; -0.22 = 20%; -0.35 = 30%; -0.5 = 40%; -0.68 = 50%; -1.35 = 75%; -4.61 = 100%. From Kaiser et al. (2002). Reproduced with the kind permission of Michel Kaiser and Blackwell Publishing.*

Bottom (demersal) fisheries operate in the North Sea from the intertidal zone to the deepest areas of the shelf. The gears range from passive static equipment, such as traps, pots and gill nets to active mobile gears such as dredges, rakes, and beam and otter trawls (Moore & Jennings 2000). All active gears disturb the benthos, but the extent depends on the gear (Collie *et al.* 2000). Dredging and raking are largely confined to the intertidal areas, but have a greater initial impact on the benthos than the more widespread beam and otter trawling techniques (Fig. 3) (Collie *et al.* 2000; Kaiser *et al.* 2002). The doors of otter trawls plough through the seabed while the groundrope slides over the top affecting mainly the epifauna, whereas the beam trawl has tickler chains or mats that penetrate the top layer of the sediment thus impacting the buried infauna (Rumohr & Kujawski 2000). Otter trawls typically catch relatively more fish than invertebrates, whereas beam trawls catch proportionally more invertebrate species (Philippart 1998). Bottom trawl catches are notorious for containing a large proportion of unwanted and therefore discarded material, which can be as much as 5 times the weight of the target species in shrimp and prawn fisheries (Moore & Jennings 2000). The average annual discard in the North Sea is estimated at 480 thousand tonnes, consisting of offal, undersized commercial fish species, non-target fish species and benthic invertebrates (Camphuysen *et al.* 1993). A small percentage of discarded animals may survive, the majority being consumed by seabirds, mammals, fish and invertebrates, possibly affecting the abundance of these consumers (Jennings & Kaiser 1998; Lindeboom & de Groot 1998). Populations of certain vulnerable species such as greater weaver, smoothhound, common skate and angler can be substantially reduced as a result of bycatch (Lindeboom & de Groot 1998).

Bottom trawls also reduce the surface texture of the benthic habitat (Schwinghamer *et al.* 1996). Mobile gears are the greatest threat to emergent epifauna and other marine ecosystem 'engineers' that increase topographic complexity on the seafloor (Auster 1998; Kaiser *et al.* 1999b, 2000a; Coleman & Williams 2002) and add structure to soft-sediment ecosystems (Thrush & Dayton 2002). As areas of higher texture generally host greater species richness, reduction of this habitat structure may decrease diversity locally (Thrush *et al.* 2001). Of particular concern are slow growing habitats, such as deep-water coral reefs that will take extended periods to rejuvenate (Andrews *et al.* 2002; Hall-Spencer *et al.* 2002). These reefs form important refuges and nursery grounds for commercial and non-commercial fish and invertebrates (Husebø *et al.* 2002; Roberts 2002), number of species being up to three times that of surrounding areas (UK Biodiversity Group 2000). An estimated 50% of the extensive *Lophelia pertusa* reefs in Norwegian waters have been damaged or impacted by trawling to date (Fosså *et al.* 2002). Trawling activities in stable sediments with larger particle sizes appear to have more impact than activities in shallower areas of fine sediment that are easily disturbed naturally through wave action (Fig. 3) (Kaiser *et al.* 1998; 2000b, 2002). Imprints of beam trawl passage in coarser sand may only be visible for 2-3 days, whereas otter door tracks may be apparent in sheltered sites for 18 months (Lindeboom & de Groot 1998). The passage of trawl gear also results in resuspension of sediment; particle size and natural disturbance affect the duration the sediment remains suspended and its transport to other areas (Dayton *et al.* 1995; Kaiser *et al.* 2002).

5. THE EFFECTS OF FISHING ON GENETIC DIVERSITY

The DNA sequence of specific genes varies and these different variants are called alleles, the number of which is a measure of genetic variation (ICES 2002a). This variation enables species to adapt to extrinsic factors such as environmental change and pollution (ICES 2003). There are three main classes of threat to genetic diversity: 1) extinction (population or species); 2) hybridisation; and 3) reduction in genetic variability within populations (e.g. through selective fishing) (ICES 2002a). Extinctions in the North Sea are dealt with in the following section, so here the few studies that have investigated the impact of selective fishing on genetic diversity are reviewed. Selective fishing of larger individuals in the population may result in an evolutionarily driven reduction in size and age at maturity, reversal of which may take a long time after fishing mortality rates are reduced (Altukhov 1994; Law 2000; ICES 2002b). Furthermore, reductions in stock size can result in reductions or increases in allelic diversity through genetic drift or gene flow from immigrants (Hutchinson *et al.* 2003).

In female North Sea Plaice, both length and age at first sexual maturity have decreased since 1900 (Rijnsdorp 1993). Large stock sizes in the 1940s and 1960s associated with slower growth were partly responsible, but the remaining change in length at maturity was attributed to genetic selection by the fisheries (Rijnsdorp 1993). A study of Dutch fleet catches of female plaice found age at 50% maturity decreased by ca. 1 year between 1955 and 1995 and length at 50% maturity decreased by ca. 1 cm (Grift *et al.* 2003). Fisheries-induced selection was considered the most likely explanation for the changes (Grift *et al.* 2003).

In western central North Sea cod studied using DNA recovered from archived otoliths, the total number of alleles across loci decreased significantly between 1954 and 1970 (1954, 46; 1960, 42; 1970, 37) and subsequently increased again between 1970 and 1998 (1970, 37; 1981, 42; 1998, 45) (Hutchinson *et al.* 2003). The initial decline in genetic diversity is attributed to a fivefold decrease in spawning stock biomass between 1968 and 1977 resulting in enhanced genetic drift, particularly effecting rare alleles. The subsequent increase in genetic diversity is attributed to occasional immigrants from other populations having an increasingly significant impact on the reduced local population's genetic composition (Hutchinson *et al.* 2003). Although by 1998 allelic diversity had returned to nearly the same levels as 1954, there was significant genetic divergence from the earlier population and thus much of the original genetic diversity may have been lost (Hutchinson *et al.* 2003).

In light of the genetic effects of fishing, management considerations need to address genetic diversity both within and among populations. Management objectives may include: maintaining the number of populations; maintaining the relative size of populations; maintaining a large abundance of individual populations and minimizing fisheries-induced selection pressures (ICES 2002a). However, further research into the effects of fishing on genetic diversity will be required before reference points (measurable properties of systems used as benchmarks for management, e.g. a certain spawning stock biomass size) can effectively be set for the above management objectives (ICES 2002a).

6. THE EFFECTS OF FISHING ON SPECIES RICHNESS

6.1 Extinctions in the North Sea

Although it is commonly thought that marine species are robust to extinction, and few extinctions have been documented compared with terrestrial flora and fauna, their true number may have been substantially underestimated (Roberts & Hawkins 1999; Dulvy *et al.* 2003). Evidence for global, regional and local extinctions of North Sea species is assessed here.

Early naturalists reported the presence of species such as the southern right whale, the narwhal and the walrus in the North Sea (Johnston 1903), however such information should be treated with caution as scientific validation is not available. Furthermore, very little is known from archaeological digs with regards to extinction due to the scale of the digs and attributing causal mechanisms to finds (N. Milner, pers. comm.). Of species that have disappeared from parts or all of their ranges, overexploitation has been the cause for many of the larger species (Wolff 2000a), although a combination of factors including habitat modification, pollution and invasive species can often be implicated (Blaber *et al.* 2000). Species with life history traits such as low fecundity, large size, high age at maturity, narrow distribution and low mobility are generally assumed to be more vulnerable to overexploitation than species that lack these characteristics (Powles *et al.* 2000). Such traits apply particularly to marine mammals and elasmobranch fishes and their morphology often makes them susceptible to fishing gears, resulting in some species suffering population declines as a result of direct exploitation or as by-catch (Stevens *et al.* 2000). The gray whale, for example, used to inhabit European waters including the North Sea, but is now extinct in the entire Atlantic Ocean (Wolff 2000b). Thornback rays and common skates have experienced serious declines and have been locally extinct in Dutch coastal waters since the 1950s (Walker 1995; Walker & Heesen 1996). Serious decline of the sturgeon is reported as early as 1000 AD (Hoffmann 2001) and the species is now extinct from the south-eastern North Sea and a large part of NW Europe (Wolff 2000b). In addition to the gray whale, 15 marine species have become locally extinct in parts of the North Sea due to exploitation (Table 1), although the majority of work and evidence is taken from the southeast North Sea and the Wadden Sea. The converse of extinction is speciation, no evidence of which is documented as a result of fishing in the North Sea.

Table 1. *Local extinctions of marine species of the North Sea.*

Scientific Name	Common Name	Area of extinction	Synergistic causes	Reference
Halichoerus grypus	Grey seal	Wadden Sea	None	Wolff 2000b
Dasyatis pastinaca	Stingray	Wadden Sea	None	Wolff 2000b
Raja clavata	Thornback ray	Wadden Sea	None	Wolff 2000b
Rostroraja alba	White skate	English Channel	None	Dulvy *et al.* 2003
Squatina squatina	Angel shark	English Channel	None	Dulvy *et al.* 2003
Mustelus mustelus	Smoothhound	Wadden Sea	None	Wolff 2000b
Acipenser sturio	Sturgeon	SE North Sea	Habitat loss	Wolff 2000b
Alosa alosa	Allis shad	North Sea	Habitat loss & pollution	Wolff 2000b
Argyrosomus regius	Meagre	Wadden Sea	None	Wolff 2000b
Trachinus draco	Greater weaver	Wadden Sea	Habitat loss	Wolff 2000b
Buccinum undatum	Common whelk	Wadden Sea	Habitat loss & pollution	Philippart 1998
Ostrea edulis	Edible oyster	Wadden Sea	Habitat loss	Wolff 2000a
Homarus gammarus	Lobster	Wadden Sea	Habitat loss	Wolff 2000a

6.2 Changes in Species Richness

Studies of species richness and diversity are reliant on good taxonomic skills to avoid problems of misidentification or inconsistent identification that could have significant effects on the results (Vecchione *et al.* 2000), a problem for even some of the larger more internationally recognised survey databases (Daan 2001). The design of the study must be robust and ensure the same gear type is used throughout and used in the same way, sufficient sampling effort is employed, similar habitat and depth strata are sampled and seasonal differences are accounted for. The results of studies looking at species richness can conflict with those looking at species diversity; for example in some cases richness may increase with fishing pressure, whereas diversity may decrease (Lindeboom & de Groot 1998; Tuck *et al.* 1998). Around the world studies have reported different responses including decreases in richness in response to fishing pressure (Collie *et al.* 1997; Hall & Harding 1997; Thrush *et al.* 1998; Ball *et al.* 2000; Veale *et al.* 2000), no observed change in richness (Kaiser *et al.* 1999a; Bianchi *et al.* 2000) or temporary increases in richness as a result of immigration of scavenging species to recently trawled areas (Kaiser & Spencer 1994). A mean reduction in species richness of 27% based on 39 published international fishing effects studies has been reported, however none of the studies showed statistically significant reductions, perhaps due to low statistical power to detect differences (Collie *et al.* 2000).

Of the studies that have addressed the impact of fishing on species richness within the borders of the North Sea, three report a decrease in richness, one an increase and three report no change (Fig. 5). An increase in richness was detected between samples taken at the beginning of the 20th century and those at the end, however, this was attributed to some species not being recorded in the earlier surveys and different mesh sizes being used (Rijnsdorp *et al.* 1996). Studies looking at long-term changes in species composition and attributes such as size of individuals and biomass rely on the build up of fishing pressure that has occurred over the time frame examined. Among five different fishery target areas in the North Sea, differences in community composition were detected for three of them (Dowsing Shoal, Great Silver Pit and Fisher Bank) between the early 1920s and the late 1980s (Frid *et al.* 2000). However, in the areas where changes were detected, the effect was a result of changes in abundance of many species in the community and not loss of vulnerable organisms. Therefore no decrease in species richness was detected (Frid *et al.* 2000). Large spatial scale allows studies to be representative at the scale of the fishery and the natural environment. One study of the broad differences in diversity across large portions of the North Sea found strong correlations between species richness and hydrodynamic phenomena, bottom temperature and sediment properties (Callaway *et al.* 2002). However, it also reported negative relationships between species richness and trawling effort, although this is patchy in distribution as it is related to areas preferred for trawling (Callaway *et al.* 2002).

Comparisons among smaller areas with differing levels of fishing pressure or between areas closed to fishing and those open to it have also been conducted. A small-scale experimental study concluded that there were no short- to medium-term (1-392 days) effects of trawling on species richness or diversity of meiofaunal communities (Schratzberger *et al.* 2002). In contrast, a large-scale 'natural' fishing experiment of the Silver Pit trawling ground comparing areas of low, medium and high trawling intensity found species richness of nematodes to be significantly reduced in areas of higher trawl frequency. Trawling was found to be more important than environment in these differences (Fig. 4) (Schratzberger & Jennings 2002). These studies highlight the dangers of scaling up from small experimental manipulations to fishery-scale responses. A comparison of the demersal fish assemblage inside and outside the "plaice box" during the first six years, when fishing by large beam trawlers was not allowed during six months of the year, demonstrated higher species richness both inside and outside the box after closure (Piet & Rijnsdorp 1998). The largest increase in richness was, however, outside the box and it was concluded that the increase, both inside and outside of the box, was a result of an influx of southerly species transported from increased water flow through the Straits of Dover, rather than from the effects of differential fishing pressure (Piet & Rijnsdorp 1998). An analysis of 75 ICES rectangles in the northern North Sea categorised as low, medium or high fishing pressure hypothesised that species richness and species diversity of the groundfish assemblage should be lower in areas most disturbed by fishing (ICES 2002a). In fact species richness was highest in rectangles with medium and high current levels of fishing pressure. However, the opposite was true for species diversity indices (see section 7) and there was a long-term species richness decline in areas with high fishing effort and in areas where effort had increased fastest, suggesting fishermen may be concentrating activities in rectangles where groundfish species richness is highest (ICES 2002a). The West Gamma oil platform wreck provided a defacto area protected from trawling disturbance which allowed comparison of trawled and untrawled areas from 1992 to 1995. While juveniles of some species increased in the disturbed area, species richness recorded within the area protected from fishing was generally higher than in the surrounding area. Although caution must be applied when comparing wreck sites to other areas, because of their tendency to attract species, the samples in this study were deemed to be far enough from the wreck to avoid such confounding influences (Lindeboom & de Groot 1998).

The general conclusion from these studies in the North Sea is that fishing can have a negative impact on species richness, although in some cases no effect is apparent or species richness may appear to increase, but this may be an artefact of fishers moving to areas of high species richness. It is important to note that where no effect on species richness is apparent, the species composition may have changed, even though a similar number of species are present overall. The results of such studies will be highly dependent on the type of habitat, gear and the intensity of the pressure exerted. Fishing pressure in the North Sea is highly patchy (see section 9) and so in many cases the actual pressure that certain areas may have experienced can be very hard to determine. Furthermore, a positive or negative change in species richness does not necessarily result in a similar trend in species diversity.

7. THE EFFECTS OF FISHING ON SPECIES DIVERSITY

Fishing alters the abundance and size distributions of target species (Hamre 1994; Smith 1994), but it is less clear what effect fishing has had on non-target species and the community as a whole (ICES 2003). Changes in benthic community structure have been detected through time (Frid *et al.* 2000), but how these relate to species diversity is not always apparent. The abundance of some species may have decreased, but others have increased in abundance. For example, scavengers are attracted by the extra food provided by the disturbance of the trawl and discard from the catch (Kaiser & Spencer 1994; Frid & Hall 1999; Groenewold & Fonds 2000; Rumohr & Kujawski 2000) and smaller non-target species through predation, competition or environmentally mediated responses (Heessen & Daan 1996; Daan *et al.* 2003). Trawling may also be affecting the composition of the plankton (Lindley *et al.* 1995), increasing production of large infauna (Jennings *et al.* 2002b; however, changes in production may also result from climate change; Jennings et al. 2001a) and shifting the overall size structure of the target fish community towards smaller sizes (Jennings et al. 2002a). As with the effects of fishing on species richness, fishing disturbance may lead to a decrease (Engel & Kvitek 1998; McConnaughey *et al.* 2000; Veale et al. 2000), no change or an increase (Bianchi *et al.* 2000) in diversity indices.

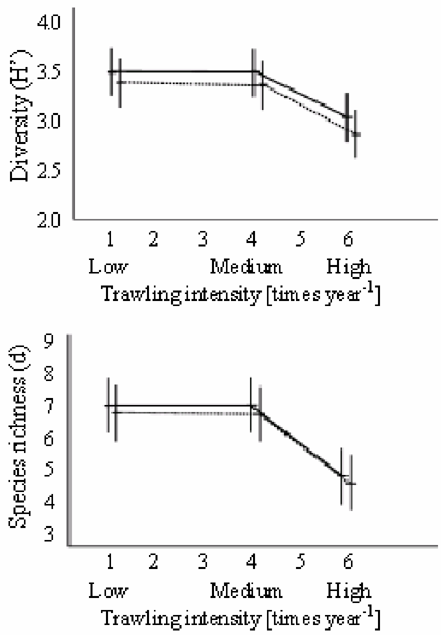

Figure 4. *Mean ± 95% pooled confidence intervals of mean univariate indices for nematode assemblages across a gradient of fishing intensity in the Silver Pit region of the North Sea. Solid line: November 2000, broken line: April 2001. From Schratzberger & Jennings (2002). Reproduced with the kind permission of Michaela Schratzberger and Springer.*

The direction of change in diversity with fishing pressure in the North Sea varies between studies, although the majority of studies report a decline in species diversity (Fig. 5). Between 1925 and 1996 four areas in the central and north / north-western North Sea showed a decline in species diversity of the whole groundfish assemblage for three areas where the fishing intensity had been greatest, but no change in an area with less fishing pressure (Greenstreet *et al.* 1999a). There was a negative trend in diversity of the non-targeted species assemblage for the most heavily fished area. The shifts appear to be the result of changes in relative abundance of dominant species (Greenstreet *et al.* 1999a). The intensity of fishing pressure is thus an important factor affecting biodiversity, and information on the spatial distribution and frequency of fishing activities and recovery rates of the ecosystem are important factors to consider (see sections 8 and 9). Three areas around the UK which were sampled in 1901-1907 and 1989-1997 showed no change in diversity for two of the areas (English Channel and Irish Sea sites), although the composition had changed, and an increase in diversity for an area sampled on the southeast coast of

England (Rogers & Ellis 2000). This increase in diversity resulted from greater evenness in the community due to a decrease in abundance of some commercial target species and an increase in some non-targeted species. The decline in most skate, ray and shark species over the survey period indicates the vulnerability of elasmobranchs (Rogers & Ellis 2000), which has caused the spatial patterns in taxonomic diversity in much of the coastal waters of NW Europe to become more uniform (Rogers *et al.* 1999a). British and Dutch demersal fish data for much of the North Sea over two periods (1906-1909 and 1990-1995) demonstrate decreases in species evenness due to increased dominance by certain species, despite more species being recorded in the later surveys (Rijnsdorp *et al.* 1996). The results demonstrate lower abundances of the total assemblage, reduced sizes for roundfish and flatfish species and reduced species diversity (Rijnsdorp *et al.* 1996). The English Groundfish Trawl Survey data indicate a decrease in the size structure of the community but no clear change in diversity spectra between 1977 and 1993 (Rice & Gislason 1996). Species diversity of the whole groundfish assemblage in the northern North Sea was slightly greater in 1929-1953 than in 1980-1993, but no difference was detected for the non-target species assemblage (Greenstreet and Hall 1996). The changes were the result of small abundance shifts in rarer species such as the grey gurnard and spur-dog (Greenstreet & Hall 1996), which was corroborated by re-analysis of the data sets using new diversity indices incorporating taxonomic relatedness (Hall & Greenstreet 1998). In the West Gamma study there was higher species diversity during the years the area was closed off to fishing activity and this difference was not discernable after the area surrounding the wreck was reopened to fishing, highlighting the speed at which fishing can affect diversity for some species groups (Lindeboom & de Groot 1998).

Large scale studies across the North Sea have included factors that are correlated with species diversity as well as richness. Epibenthic invertebrate and fish species diversity is consistently negatively correlated with trawling effort in the North Sea, and this is particularly apparent in the southern North Sea where sediment types are more uniform (Callaway *et al.* 2002). Other environmental factors also explain much of the variation, but there appears to be a causal link between trawling effort and diversity (Callaway *et al.* 2002). Another large scale comparative study found lower diversity in the southern North Sea and although this may be caused by environmental conditions, strong anthropogenic influence on the area, including fishing, is a possible cause (Rogers *et al.* 1999b). In contrast to species richness, the study of 75 ICES rectangles in the northern North Sea demonstrated lower species diversity at the medium and heavily fished areas than the rectangles with low fishing effort. However, it was not possible to distinguish between medium and heavily fished locations (ICES 2002a).

Comparison of areas subject to towed gear all year round, limited-duration trawling and pot fishing only in the English Channel showed that the abundance of fragile emergent fauna such as hydroids and soft corals decreased, and the abundance of some more resilient mobile species such as some starfish and crab species increased with increasing effort (Kaiser *et al.* 2000b). There was a significant decline in epifaunal diversity with increasing fishing effort (Kaiser *et al.* 2000b). The diversity of nematode assemblages has also been repeatedly lower in areas with the greatest beam trawl intensity (Fig. 4). Low and medium intensity trawl areas do not differ, suggesting that these levels of trawling disturbance were insufficient to cause substantial long-term changes in the assemblage (Schratzberger & Jennings 2002).

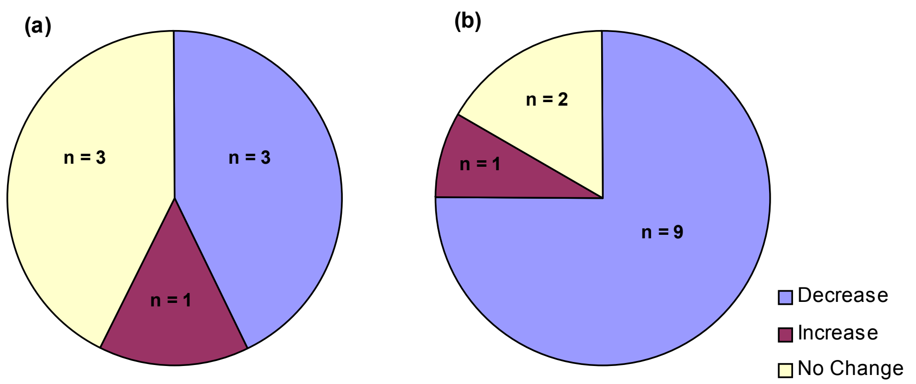

Figure 5. *Proportion of studies in the North Sea reviewed here describing a decrease, increase or no change in* ***(a)*** *species richness and* ***(b)*** *species diversity in response to fishing pressure.*

8. ECOSYSTEM RECOVERY

The initial effects of fishing on the ecosystem in terms of diversity, production, biomass and trophic structure, are likely the most important (Jennings & Kaiser 1998) and so time scales of recovery following different fishing impacts are important. The long history of perturbation in the North Sea makes it hard to assign baseline levels against which to measure recovery. Due to these shifting baselines, comparisons before and after a particular fishing event or with areas experiencing lower levels of disturbance are the best achievable. Recovery rates can vary greatly between different habitats, gears and areas that experience different levels of natural disturbance. Recovery from fishing effects in naturally disturbed sites can be as short as several days to weeks (Hall & Harding 1997; Lindeboom & de Groot 1998) and where large seasonal differences are naturally experienced in communities, effects of trawling can be indistinguishable after these natural shifts (Kaiser *et al.* 1998). Various studies of trawling disturbance in sandy sediment communities around the world indicate recovery after ~100 days, thus suggesting such communities could withstand 2-3 episodes of trawling disturbance per year (Collie *et al.* 2000). However, certain species may not recruit to the disturbed area for longer periods, thus altering the community structure (Currie & Parry 1996). Recovery times in stable habitats, experiencing little natural disturbance through currents, waves or large seasonal changes, may exceed one year (Lindeboom & de Groot 1998; Tuck *et al.* 1998). Even longer recovery periods may be required in areas of slow growing habitat-forming fauna (Thrush *et al.* 1996). An extreme example of this can be seen in the case of deep sea coral reefs. These reefs have extension rates of 1.1 mm yr^{-1} (Hall-Spencer *et al.* 2002), thus recovery of such areas after the destructive path of a trawl will be extremely slow.

The evidence on recovery suggests that areas with high natural disturbance and mobile sediments will generally recover rapidly after trawling disturbance, whereas areas of stable, fragile flora and fauna and in regions of low natural disturbance will have extended recovery periods. However, areas of seabed that experience intensive trawling are likely to be maintained in a permanently perturbed state and contain a faunal assemblage adapted to such physical disturbance (Collie *et al.* 2000).

9. DISTRIBUTION OF FISHING

The distributions of otter trawling and beam trawling effort by ICES statistical rectangle differs markedly, with beam trawling effort concentrated in the southern North Sea and more otter trawling effort in the north, west and east North Sea (Fig. 6) (Callaway *et al.* 2002). There are 211 rectangles in all, each covering 0.5° latitude by 1° longitude, thus encompassing an area of 3720 km^2 at 53°N (Jennings *et al.* 1999; Kaiser *et al.* 2002). At this scale fishing distribution is highly variable, with mean annual fishing effort in 1990-1995 being less than 2000 hours in 29% of rectangles, less than 10,000 h in 66%, and exceeding 40,000 h in only 4% of rectangles (Jennings *et al.* 1999). Even at smaller spatial scales, the effort distribution is patchy and heterogeneous (Rijnsdorp *et al.* 1998). In eight of the rectangles fished most heavily by beam trawls, 5% of the surface area was trawled less than once in 5 years, 29% less than once a year, 30% between 1 and 2 times a year and only 9% more than five times a year (Rijnsdorp *et al.* 1998). Variation in species abundances is smaller when based on environmental strata rather than ICES rectangles, and trawling distribution reflects this pattern (Piet *et al.* 2000). Such patchy trawling distribution may allow communities to recover between trawling events, and thus may explain why not all studies detect an impact of trawling on biodiversity (see sections 6 and 7). The issue of area closures is of relevance here as trawlers tend to fish the boundaries of closed areas in an attempt to reap the profits of the protected harvest inside (Piet *et al.* 2000). In the case of seasonal closures, the re-distribution of trawlers over the remaining area, and to areas previously unfished, is expected to result in a more homogeneous fishing effort and ultimately an increased cumulative impact (Duplisea *et al.* 2002; Dinmore *et al.* 2003), particularly as the initial effects of fishing will be the most important (Jennings & Kaiser 1998). Small closed areas in specific habitats are unlikely to have such impacts. For further review of this see FSBI (2001).

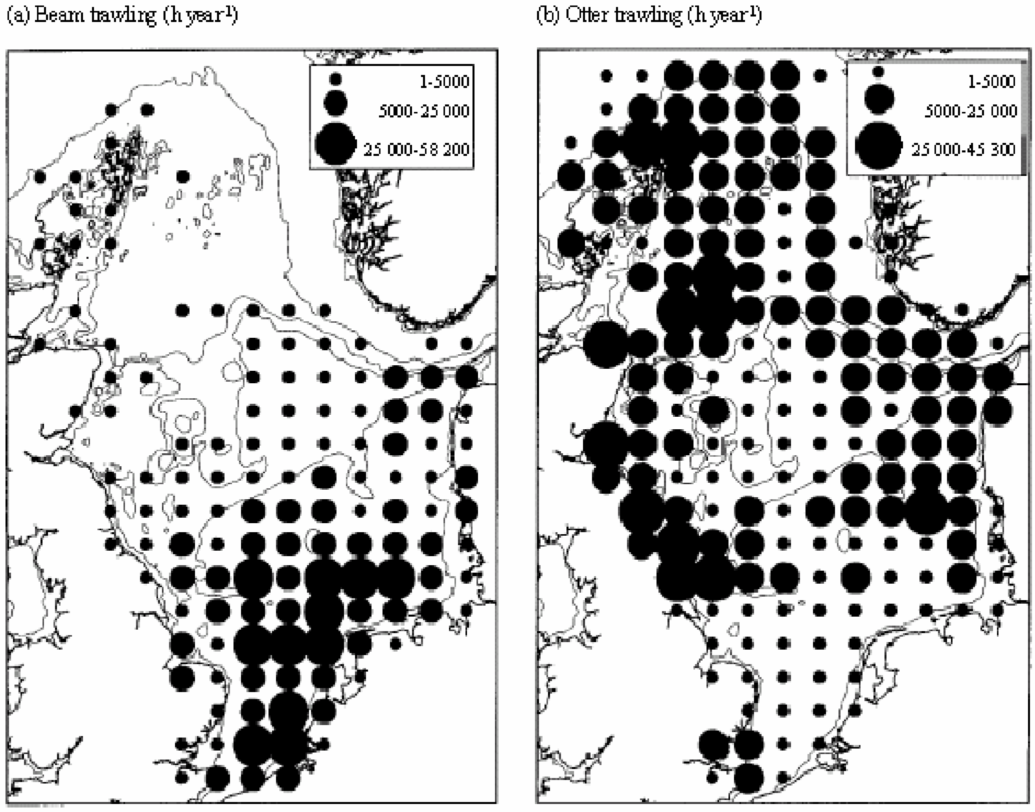

Figure 6. *Beam and otter trawling effort (h ICES rectangle $^{-1}$ year $^{-1}$) of German, Dutch, Danish, Norwegian and Scottish fleets in the North Sea in 1998. From Callaway et al. (2002). Reproduced with the kind permission of Ruth Callaway and Elsevier.*

10. CONCLUSIONS

Where fishing disturbance is sufficiently intense in the North Sea it is having an adverse effect on biodiversity. Fishing pressure on target stocks is resulting in selective genetic pressures and shifts in genetic diversity. Management initiatives to maintain suitable population sizes and minimize fishery-induced selection pressures are needed to reduce these impacts. At the species level, the impact is more apparent in species diversity indices than indices of species richness. Relatively few local extinctions have been recorded, however this may be due to lack of study. Different gears have different effects, with physically destructive gears such as dredges and beam trawls causing greater disturbance to the benthos. Stable habitats with less natural disturbance are more vulnerable to the negative effects of trawling than benthic habitats in high states of natural flux. Areas with emergent habitat-forming fauna which harbour higher levels of species richness are particularly vulnerable and should receive special management measures, such as area closures (as also suggested by ICES 2002a), particularly in the case of slow-growing organisms such as deep water corals. In many habitats, recovery is expected to be fairly rapid and so if trawling activities in any given area are below a certain frequency (e.g. 2-3 times a year in sandy habitats), benthic diversity may recover. The heterogeneous distribution of fishing effort in the North Sea is probably limiting the extent of areas with permanently shifted diversity. Simple measures of biodiversity do not necessarily give an indication of overall ecosystem state. The severe decline in stocks of many target species in the North Sea and the long history of anthropogenic impacts in the area have clearly resulted in an altered distribution of size classes and species distributions (e.g. Daan *et al.* 2003). The effects of these on species diversity can be confusing; complex species interactions affect evenness, and interpretation of the reasons for this and implications for the ecosystem can be difficult. Very few studies look at the whole species assemblage and no studies to date have included the micro-organisms (M. Schratzberger pers. comm.). Given the problems with measuring and interpreting biodiversity, a more reliable and cost-effective method of detecting the effects of fishing in the North Sea, and identifying heavily impacted regions, would be to focus on certain vulnerable species as indicators of perturbation (Jennings & Reynolds 2000). Species with life history traits that make them vulnerable, such as low fecundity and high length and age at maturity, for example elasmobranchs, may be good candidates as indicators (Rogers *et al.* 1999b). However, this should be achieved in the context of ecosystem based management and other new techniques, such as looking at the body size distribution (size spectra analysis) of the community are proving useful to assess the condition of the community (Jennings et al. 2002a) and may be developed to set reference points for ecosystem based management. Holistic well-founded experimental designs to look at the effects of fishing on biodiversity and apply theory to the outcomes are also needed to better inform management. This needs to include more studies on the effects of fishing on genetic diversity and habitat diversity, information on the latter lacking in the current literature.

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