FSBI BRIEFING PAPER 1:

MARINE PROTECTED AREAS IN THE NORTH SEA[1][2]

1. EXECUTIVE SUMMARY

The concept of using marine protected areas (MPAs) to conserve fisheries and the marine environment generally has come largely from sedentary fish living on tropical reefs. Objectives of MPAs include stock maintenance or recovery, habitat restoration, protection of non-target species, development of recreational and educational activities, and promotion of scientific understanding. However, the environment and resources of the North Sea are quite different from those from which the MPA concept has been primarily derived, and therefore the application of MPAs in areas such as Northwest Europe needs careful consideration. Relevant information is scarce, and the concept has had a mixed reception from the scientific community. This FSBI Briefing Paper discusses the extent to which MPAs conserve and protect fish stock and habitat while serving industry and other concerns. Its purpose is to provide a balanced review and to target mainly potential users outside of the 'scientific community' and to provide information and 'advice' to the general public, consultancies and ministries, as well as NGOs active in this area. It highlights the following points:

- Many valuable fishery and wildlife species are highly mobile, thus effects of protection on their recovery are likely to take a long time and only be significant if large areas (e.g. >60 000 km^2) are closed to fishing. Only in such conditions is reversal of any indirect effects on their prey or other linked species to be expected. Only more sedentary and sessile species, such as oysters and mussels can be expected to increase in size and abundance in MPAs.
- Sheltered locations characterised by naturally low levels of disturbance and sensitive habitats will benefit from protection from trawling. In shallow waters and exposed locations where natural disturbance by tides and wave action is high, habitats in trawled areas are expected not to differ significantly from those protected from trawling. Thus, such sites would not be good controls for fishing effects studies.
- Small MPAs can help locally protect vulnerable wildlife such as seabirds and mammals from direct effects of exploitation. They will act as foci for diving tourism and foster educational activities.
- When appropriately designed, MPAs can act as controls of exploitation effects, but only with respect to relatively sedentary organisms (species or critical life stages) and habitats adversely affected by fishing. Monitoring of these areas at appropriate scales of time and space will help determine effects of fishing as against natural and other human impacts.
- The successful design and implementation of MPAs rely on clearly defining objectives for them, and understanding the biology and ecology of the areas concerned. Furthermore, stakeholder participation in the planning, designing and implementation process is essential.
- MPAs are only one part of a suite of fisheries management measures aimed at reducing fishing mortality, which must include reduction in fishing effort, gear modification and sustainable quotas.

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[1] Prepared by Nicholas V. C. Polunin and Colette C. C. Wabnitz, Department of Marine Sciences, Ridley Building, University of Newcastle, NE1 7RU with thanks to Simon Jennings, Michael Fogarty, John Reynolds, Sylvie Guénette, Martin Willinson, Stephan Lutter, Sarah Jones, Graham Pilling, Lieke Berkenbosch, Carien von Zwol and the FSBI council for useful comments and constructive criticism.

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2. INTRODUCTION

The North Sea is one of the world's major shelf areas and thus one of the major fish producing ecosystems in the world. It is a relatively shallow semi-enclosed basin of continental shelf water with a depth ranging from about 30 m on average in the southeast to 200 m in the northwest. The productivity of the North Sea is associated with its comparatively shallow depth and the existence of mixing mechanisms transporting nutrients from the nutrient rich bottom layer to the nutrient poor upper layers of the water column (Anon 1999)[3] (see Figure 1).

Figure 1. Bathymetric map of the North Sea. Purple lines indicate marine boundaries. (Reproduced with the kind permission of the OSPAR Secretariat)

The North Sea harbours a wide range of fish stocks and is in terms of species exploited by commercial fisheries one of the most productive areas in the North East Atlantic. The important species exploited chiefly by the eight countries bordering the North Sea (France, Germany, Belgium, The Netherlands, Norway, England, Scotland, Denmark) (Figure 1) include cod, haddock, whiting, saithe, plaice, sole, herring, and mackerel for human consumption; and sandeel, Norway pout, blue whiting, and sprat for reduction to fish meal.

Concern has been widely expressed about fishery and other impacts on the North Sea, where the spawning stock biomass of most commercially important marine species has been reduced to less than 10% of its unexploited size and many fishery practices may be unsustainable. Besides being a source of mortality for both target and by-catch species, other effects of current fishing practices on stocks such as (i) alteration of the normal age structure, (ii) disruption of reproductive behaviour, (iii) reduction in genetic diversity (Dugan and Davis 1993), (iv) habitat degradation, shifts in ecosystem structure (McGlade et al. 1997; Roberts in press), and (v) long term economic losses are becoming progressively more apparent. Conservation programmes and action plans have been set up to tackle major threats such as habitat damage, biodiversity losses and declining populations as a result of overfishing. The successes of these initiatives have been variable, and the fact that efforts at international, national and local level need to be increased to have any real impact on the problems has become increasingly clear. Most programmes are based on a combination of general measures and specific actions, and one approach that has received much attention of late is to focus conservation on particular areas of sea, so called protected areas.

'Nature reserves', 'sanctuaries', 'refuges' and 'parks' are familiar terms that have been used to describe protected areas. For the purpose of simplicity they will be referred to in this text as Marine Protected Areas (MPAs), a term used here in a general sense to refer to any specified area in which there is partial or total protection from fishing and other potentially damaging impacts (e.g. dredging, drilling). MPAs are increasingly being promoted as an important component of precautionary management (Agardy 1994; Lauck et al. 1998; Williams 1998). The potential benefits of their establishment to ecosystems, fisheries, and relevant stakeholders have been much discussed (White 1988; Cole et al. 1990; Ballantine 1994; Bohnsack 1994; Rowley 1994; Dayton et al. 1995; Agardy 1997; Allison et al. 1998; Bohnsack

[3] The full-citation version is available from the FSBI.

1998; Fogarty 1999; Dayton et al. 2000), but the use of MPAs as efficient means to sustain fishery stocks and protect habitats as well as biological diversity has been advocated largely on the basis of experience gained in reef environments, especially in the tropics. There, fisheries are more characterised by effort management rather than by TACs (the total regulated catch from a stock in a given time period, usually a year) and movement of resident fish across MPA boundaries is generally modest, increasing stock abundance within the closed area (Bohnsack 1994; 1998). However, the larvae of such fish inhabiting reefs disperse widely, thus MPAs can potentially act as sources of recruits for adjacent areas. However, this is not the biology of many of the commercial fish species in temperate marine ecosystems and more specifically the North Sea. Also, there are relatively few examples of the use of MPAs to manage fish and fisheries in temperate waters (Horwood et al. 1998; Horwood 2000), and the effects of those that do exist have been poorly monitored (Rijnsdorp and Leeuwen 1996; Rijnsdorp et al. 1996; Piet and Rijnsdorp 1998) and relate mostly to sedentary species. It is sensible to ask to what extent MPAs could be useful on the northwestern European continental shelf, and especially in the North Sea. This *FSBI Briefing Paper* aims to elucidate the extent to which MPAs could present an effective tool for rehabilitating fish stocks and protecting habitats while also serving industries and concerns other than the fisheries. It will do this through a series of key questions and answers, drawing on available theoretical and empirical evidence. Its purpose is to provide a balanced review and to target mainly potential users outside of the 'scientific community' and to provide information and 'advice' to the general public, consultancies and ministries, as well as NGOs active in this area.

3. Fisheries Management

Changes in abundance of fish species in the North Sea can be inferred from historical data. A comparison of catch per unit effort in the period 1906-1909 with that in 1990-1995 indicates large reductions in stock densities of several species since the beginning of the century; of 19 species recorded, 18 decreased over the period (Rijnsdorp et al. 1996). Through measures related to gears, effort and catch, fisheries management has thus far failed to stop the severe fishing down of stocks in the North Sea. Harvest over-capacity, combined with (i) habitat damage, (ii) inappropriate fishing techniques, (iii) the lack of proper enforcement of regulations, (iv) the inability of management to react in a timely way to changing stocks, (v) the quality of technological development in fishing and (vi) difficulties in addressing allocation issues, are reasons underlying the failure of fisheries to remain manifestly sustainable (Murawski et al. 2000).

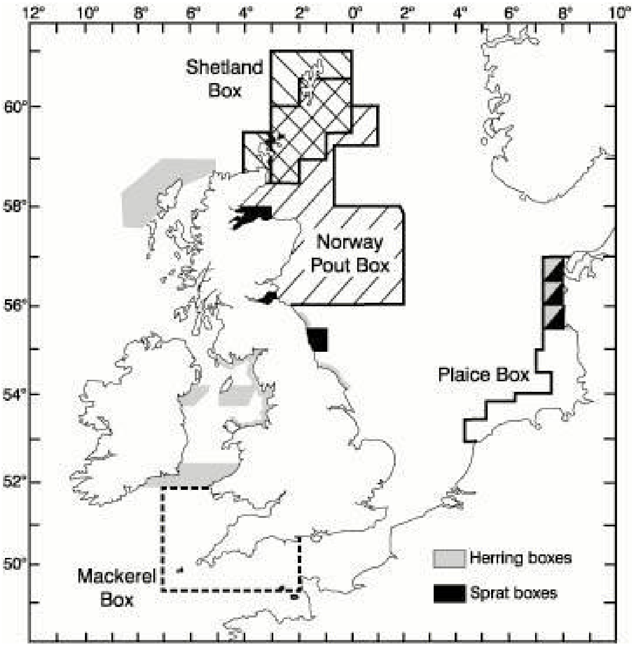

Figure 2. Chart of European waters showing areas closed to fishing at various times adapted from Horwood 1998 © Crown copyright reproduced by kind permission of CEFAS.

That large-scale closure of fisheries can play a role in stock recovery is shown by fish yields before and after both world wars in the North Sea (Smith 1994). Smaller closures, over a range of temporal scales, have also been used in the North Sea targeting particular stocks. Examples of such areas include the Plaice Box (see below; 38 000 km^2 in area), the Norway Pout Box (95 000 km^2) and the Mackerel Box (see below, 67 000 km^2) (Horwood 2000) (Figure 2). Herring spawning grounds are also protected in the North Sea and in the UK fishing for bass is restricted in their estuarine nursery areas (Horwood et al. 1998). However, none of these areas is fully protected *per se*, with fishing, collecting, dredging, dumping, and discharge of pollutants prohibited. Zoning within UK MPAs discourages, limits or prohibits certain activities in certain places, but there is not a single area in any of the three Marine Nature Reserves or in more than 60 proposed and candidate marine Special Areas of Conservation where all extractive activities are prohibited in order to benefit nature conservation or fisheries (Susan Gubbay, pers. comm.).

3.1 Can MPAs protect target species from exploitation and allow recovery?

It is a well-documented fact that the size structure of exploited fish populations changes with increasing exploitation towards lower abundance of larger individuals. The selective removal of larger fishes in the North Sea (Pope et al. 1988; Pope and Macer 1996; Rijnsdorp et al. 1996) has led to changes in population structure, genetic make-up (Ricker 1981; Smith et al. 1991), community composition and habitat. These changes may over time have reduced the resilience (defined as the magnitude of disturbance that can be absorbed before a stock changes its structure by changing the variables and processes that control its behaviour (Holling 1973)) of stocks to fishing pressure. However, natural recruitment and mortality processes also govern this resilience. Within MPAs, fishing mortality will be eliminated (for relatively sedentary species) or reduced (for more mobile species) and stocks will tend to revert to their natural state subject primarily to environmental variability (Bohnsack 1992). Whether MPAs lead to increases in abundance, age, size and fecundity of depleted stocks (Myers et al. 1995; Roberts 1995aHutchings 1996) will however depend on the role of natural mortality and recruitment relative to scales and effects of exploitation. Recovery may be slow (Corten 1986; 1990) or may scarcely occur in some cases, and will essentially depend on the mobility of the target species relative to the size of the MPA concerned.

Closing a large area to fishing can theoretically provide benefits in a number of ways (Beverton and Holt 1957). Not only will it encompass more of the stock but also more species can be expected to fall within the boundaries and is likely to constitute a buffer against unpredictable events. When discussing the optimal size for a fishery MPA, NOAA (1990) suggests that it "should include critical adult habitat and should be sufficiently large to support breeding populations with a stable age structure. Juvenile habitat should be included for species that utilise different habitats as juveniles, especially when juveniles are vulnerable to fishing mortality". Modelling studies based on the transfer rate between open and closed areas, indicate MPAs ranging in size between 50% and 75% of stock area are necessary to optimise yields (Guénette and Pitcher 1999) and as a hedge against uncertainty (Lauck et al. 1998). Fish such as cod, haddock and plaice have complex life histories, and various phases in their life cycle (juveniles, spawning females) may thus be particularly vulnerable to fishing. If a nursery area is protected against destructive fishing practices that reduce recruitment, there could potentially be increased recruitment to a fishery, however, there is little known about habitat limitation of North Sea stocks (see below). Closure of part of the area inhabited by adults will not increase survivorship of animals outside of the MPA unless overall fishing effort is reduced because effort previously targeted at the closed area will tend to be displaced from the closed area to the adjacent open areas. Closure of spawning grounds may help temporarily protect animals at a vulnerable phase and thus benefit the fishery (e.g. herring). However, spawning ground closure may be an ineffective conservation measure if migrating animals are subject to the same overall fishing intensity (Shepherd 1993). The Trevose Head area in the eastern Celtic Sea is an example.

Trevose spawning grounds

This area is located off the north coast of Cornwall, England, and is a spawning ground for most of the important commercial fish in the Bristol Channel and the northern Celtic Sea (Horwood et al. 1998). At the suggestion of the National Federation of Fishermen's Organisation (NFFO), staff from the Centre for Environment, Fisheries and Aquaculture Science (CEFAS) carried out a careful study of the possible benefits of implementing fishing restrictions. The study concluded that prohibiting fishing on the spawning grounds over springtime provided no benefits to cod, sole or plaice populations in terms of long-term catches or spawning stock biomass as the quota that was once taken on the spawning grounds would simply be caught elsewhere. The reason why no benefits would accrue to the fishery even following the implementation of large MPAs is that the fisheries are managed by means of total allowable catches (TACs) which imply that if the fish are not caught in one particular locality then they will be caught elsewhere. Thus, if gains are to be achieved through fishing ground closure these will only be significant if the overall mortality of the population is reduced. There are also uncertainties associated with the biology of the fish (e.g. how much movement there would be across MPA boundaries) and changes in patterns of fishing activity. However, closing the area during spring might give some protection against capture, damage, and disturbance at spawning for plaice, sole, turbot, thickback sole, lemon sole, solenette, long-rough dab, topknot, Norway topknot, cod, ling, whiting, bass, sprat, rocklings, argentine, dragonets and gurnards (Horwood et al. 1998). Should overall fishing effort be appropriately reduced, protection of spawning grounds and refuges for juveniles appear as the most effective conservation measures that can be put in place while maintaining viable fisheries.

Plaice box

The Plaice Box (38 000 km^2) (Figure 3) is an area of the North Sea along the Dutch, German and Danish coast partially closed to fishing since 1989, with the aim of reducing discards of undersized commercial demersal species such as plaice and sole in their main nursery grounds (i.e. protect juvenile fish). The Dutch trawling effort was reduced in two phases. First, trawling was restricted to small fishing vessels harvesting fish according to a number of gear and catch restrictions (Piet et al. 1998; Piet and Rijnsdorp 1998) to reduce, directly and indirectly, the number of juvenile plaice and sole caught and increase recruitment of plaice by 25% (ICES 1994 in (Gubbay 1996a)) and sole by 11% (Rijnsdorp et al. 1991). Heavy exploitation on the edges of the Box and during ‘open’ months (Rijnsdorp et al. 1998), in conjunction with failure to meet the predicted levels of recruitment, possibly due to increased legal fishing within the Box (Gubbay 1996a; Pastoors et al. 2000), led to the regulation being extended to the fourth quarter in 1994 and to the whole year from 1995 onwards. The reduction in effort to around 6% of the original level led to:

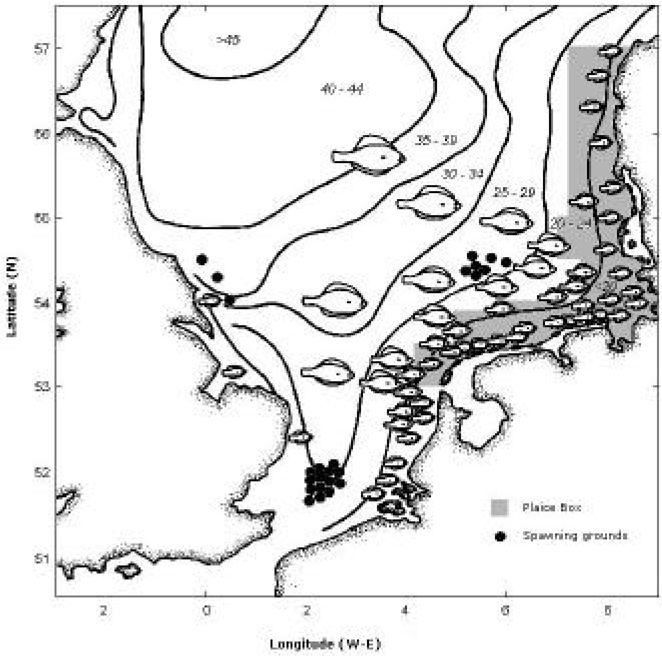

Figure 3. Location of the ‘Plaice Box’ and schematic representation of the distribution of plaice in the North Sea with mean sizes (total length, in cm) given for each depth range (from Rijnsdorp, 1998), modified after Garstang 1908 and reproduced with the kind permission of the European Commission).

i. No change in the species composition (Piet and Rijnsdorp 1998);
ii. Substantial reduction in the discard of juvenile fish (Pastoors et al. 2000);
iii. An increase in the abundance of commercial fish within the marketable size range (Piet and Rijnsdorp 1998).
iv. A general increase in species richness due to the influx of southerly species and a decrease in the relative abundance of plaice, both within and outside the Box.

Despite claims of initial increase in spawning stock biomass and yield of plaice, overall (i.e. from 1995 to 2000), both parameters have decreased substantially (Pastoors et al. 2000). However if the Box were to be removed, long term landings and spawning stock biomass would decline by 8% and 9% respectively (Horwood 2000). The reduction in discard mortality may have been offset not only by a decrease in the growth rate of juvenile plaice but also by changes in the North Sea ecosystem at the time when the Plaice Box was established, revealed by changes in species abundance and composition in the southern North Sea, and reduced growth rates of plaice (Jennings and Kaiser 1998; Pastoors et al. 2000). The Box has provided fishery benefits by reducing mortality of younger fish and hence boosting recruitment to the adult stock (Pastoors et al. 2000). Young plaice do not migrate as widely as the adults and tend to stay within the Box where they are protected from fishing. Adult plaice, on the other hand, move more widely and are accessible to fishermen. Closure of the whole Box to all vessels on a year-round basis would provide greater fisheries benefits (landings and spawning stock biomass would increase by 24 and 29% respectively (Horwood 2000)) than the present limited closure because many young plaice currently die when discarded from vessels such as shrimpers that are allowed to enter the Box. Such total closure would potentially also lead to increased recruitment rates in sole, which also suffer from high levels of discard by trawl fisheries (ICES 1999).

Mackerel Box

The Mackerel Box was established in 1981 off southern England and Ireland in order to protect relatively high concentrations of juvenile mackerel. Following the introduction of the Box, the relative mortality on fish aged 0, 1 and 2 years was reduced by 83%, 60% and 20% respectively (Horwood 2000).

North Sea cod

The North Sea cod has been at, or close to, historically low levels for about a decade and has only recently shown signs of slow recovery (Horwood 2000). In 1993, the EU investigated the possible effects of closing areas of the North Sea covering the main fishing grounds for cod. However, given the current understandings of fish movements and the behaviour of the associated fishing fleets, it was concluded that restricting fishing in areas, even as large as one quarter of the entire North Sea, would do very little to protect cod (Horwood 2000).

An MPA sufficiently large to allow greater survivorship in a stock should allow the average size of fish to recover from size-selective fishing. Fishes that stay within MPAs can grow to considerable size, increasing the mean age of the population, which in turn may render it less vulnerable to natural variations and could also lead to greater fecundity and egg output (Bohnsack 1990). This effect may be enhanced by greater fertilisation efficiency at higher densities and improvements in spawning habitats (Dugan and Davis 1993; Edgar and Barrett 1999) brought about by MPA implementation. However, due to the high mobility of most commercially important species in the North Sea, reproductive output could only increase in MPAs of very large size (e.g. >70 000km^2).

An MPA can function as a source of larvae to fishing grounds provided the conditions are such that stock density is greater within the MPA. However, even where increased egg output does occur, its effects on the magnitude of large-scale recruitment is uncertain, because larvae and juveniles are subject to very variable mortality typically unrelated to stock size and influenced by environmental changes such as in food availability, predation and current transport. Because fishing mortality makes stocks more prone to annual recruitment variation, MPAs may reduce this variability where they reduce fishing mortality. Modelling predicts that MPAs of large size will increase resilience to overexploitation by keeping the spawner biomass and recruitment success at higher levels than in non-protected areas (Guénette and Pitcher 1999).

3.2 What factors affect the scope for MPAs to protect stocks?

Fish stocks vary in their vulnerability to depletion (Jennings et al. 1997). Predicting impacts of an MPA on the level of fishing mortality is difficult, because effects rely on a number of factors including:

- The proportion of a stock encompassed within the boundaries of the MPA;
- The biological characteristics of the fish (e.g. distribution, migration, and recruitment);
- The spatial distribution and magnitude of fishing effort outside the closed area;
- The relative catchability (defined as the capability of a fishing gear to catch fish during a fishing operation) of the fish outside the MPA; and
- What other fisheries management systems are in place.

Protection will affect different species in different ways. Commercial species such as cod typically exhibit life history traits including slow growth, late maturation, long life span and sporadic recruitment (Jennings and Kaiser 1998) which make them more susceptible to exploitation (Trippel 1995) but also slow to recover under effective protection.

The predictability of benefits accruing to a target stock from an MPA is also reliant on knowledge of oceanographic conditions, the effects of these on mortality, recruitment and migration and mobility of the species. For highly migratory species, including cod, mackerel and herring, MPAs may not be very effective as a primary management tool unless extensive proportions of the range of the stock can be closed to fishing (Lauck et al. 1998; Murawski et al. 2000). Given a low dispersion rate and relatively homogeneous distribution, an MPA amounting to 10% of the total North Sea is expected to lead to, at most, a reduction of 5% in fishing mortality of a particular target species and 10-14% reduction if the MPA is increased to 25% of the North Sea (Daan 1993). Thus, less mobile species such as plaice and sole (de Veen 1970), are more likely to increase in size and abundance in an MPA of a given size than cod, which tends to be twice as mobile (Daan et al. 1994). Unless they encompassed a very large part of the stock area, MPAs would be even less likely to affect pelagic species such as herring, which migrate extensively through the North Sea (Beverton and Holt 1957; Polacheck 1990; Roberts 1997; Guénette and Pitcher 1999; Guénette et al. 2000). In contrast, for sessile or more sedentary species, including mussels, oysters, lobsters and bait worms, even small, effectively protected areas are likely to increase survivorship, abundance and mean size. However, MPA size cannot be based on biological factors alone but must also be determined on the basis of administrative practicality and from a social point of view (see Section 3.3).

Rotational closures, whereby fishing is allowed in an area on a cyclical basis have been proposed as a useful strategy for giving certain stocks a chance to recover while still allowing intermittent exploitation

(King 1995). Clearly this depends on the closure being large enough for the stock to recover within it, but even where that is so, the benefits of stock recovery may be very quickly dissipated upon reopening of the area (Bohnsack 1996). This means that if such closures are to be of use, they need to be accompanied by measures to reduce effort generally. Seasonal closure in Cyprus has shown that in cases of severe depletion, even temporary protection at the right time can increase yield. The case for seasonal closures of spawning grounds is more equivocal (Davis et al. 1998; Garcia 1997); clearly if animals remain aggregated upon reopening of the fishery, they may remain highly vulnerable to fishing (Murawski et al. 2000).

Studies of reef-associated species indicate that movement across MPA boundaries, also referred to as 'spillover', does occur, but that the distance over which it occurs is typically less than one kilometre (but see (Yamasaki and Kuwahara 1990)). Many commercial species in the North Sea are highly mobile, with movement across boundaries occurring in a variety of contexts, including home ranging and foraging behaviour (Holland et al. 1996; Pastoors et al. 2000), spawning migration (Holland et al. 1993; Rijnsdorp and Pastoors 1995; Pastoors et al. 2000) and changes in habitat, as animals grow older (Rijnsdorp and Pastoors 1995). However, for spillover effects to be beneficial to a fishery, build-up of spawning biomass needs to occur within MPA boundaries, and so far this has not been demonstrated. In the case of the Plaice Box for example, effects of the MPA on the size structure have been shown, but the expected positive effects on the fisheries have been difficult to demonstrate because it is impossible to disentangle the effects of the reduction in fishing effort from the large natural environmental changes in the ecosystem.

3.3 Can MPAs be sole tools for fisheries or environmental management?

Area closures cannot alone be considered as an effective alternative to present fisheries management regimes (Lauck et al. 1998); additional management measures regulating fishing effort on fishing grounds need to be implemented (Daan 1993; Helm and Plante 2000) especially when referring to migratory species. Only very large MPAs amounting to 80% or more of the fishing grounds in Newfoundland could have prevented the cod collapse of the 1980s and allowed the cod stock to rebuild (Guénette et al. 2000). On the U.S. part of Georges Bank in the Gulf of Maine, closed areas, covering a large proportion of the fishing grounds, have played a role in the increased cod spawning stock biomass. However, the reduction in fishing mortality that occurred is also attributable to an increase in minimum mesh size, reduction of vessel days at sea, and imposition of quotas. Unless clear measures are taken to reduce the fishing mortality (Daan 1993; Guénette and Pitcher 1999; Guénette et al. 2000), especially on vulnerable post-spawning aggregations (Murawski et al. 2000), any benefits of MPAs to spawning stock biomass (such as cod) and fisheries are expected to be negligible. Furthermore, it is important that closures cover not only a large proportion of the fishing grounds, but also as large a part of the species distribution as possible.

Human activities other than fishing may also have an impact on fisheries resources and benthic community structure (Pearson et al. 1985). For example, fish stocks may be adversely affected directly by hazardous chemicals, waste or indirectly by excessive nutrient inputs (eutrophication) (Anon 1997). This emphasises that MPAs set up to protect and restore marine habitats and their ecological communities may not do so without a wide-ranging management regime (Price et al. 1992) which addresses other human impacts, as the OSPAR Convention does (Gubbay 1996a; Gubbay 1996b; McGlade et al. 1997). The North Sea's importance arises not only from fisheries but also from a vast array of other natural resources, species groups and ecosystems, the location and concentration of which are critical in decisions taken about future usage of particular areas. Analysis of areas with heavily overlapping key resources can help identify which areas critically need management measures and which areas will need to remain open for continuing use (Gubbay 1996a). These considerations highlight the need to develop an integrated coastal zone management (ICZM) framework in which strategies are developed to incorporate all stakeholders in the system. Such a management system would allow combining the principles of fisheries and ecosystem management (focusing on critical ecological processes, ecosystem interactions and the chemical, biological and physical environment) so as to conserve natural biodiversity and ecosystem integrity while supporting a sustainable level of human use. One of the key activities in developing an ecosystem approach is the establishment of overall or integrated objectives, and at a specific level, more detailed and operational objectives.

Economic and Social considerations

It is the fishing community which is the principal target of compliance and stands in many cases to be disadvantaged by closure due to initial decreases in catches, and thus loss of revenue, especially if fishermen are unable to relocate their activities or they are not the ones to benefit directly from protecting stocks. In the North Sea concern has been expressed about protecting fish in the areas fished by one nation, only for them to be fished elsewhere and benefit fishermen from elsewhere (MAFF, 1995). There is also a strong political dimension to the introduction of MPAs in the North Sea as it operates through the EU Common Fisheries Policy. There is current widespread perception that MPAs will only succeed with substantial public participation in the developing and managing of MPAs, and thus voluntary compliance with closures. Successful MPAs often have considerable effort devoted to increasing public awareness and education. Public support will invariably lead to stronger regulations, better enforcement and improved compliance (Fogarty et al. ms).

In most instances, consultation with relevant stakeholders has taken place after policies have been fully formed. For example, in 1992 the decision made by the UK Government to limit the number of sea days allocated to fishing vessels (NFFO 1993) through the Sea Fish Conservation Act was vigorously opposed. This opposition resulted in a ministerial announcement that the scheme would not come into effect, until the industry had reviewed the proposal and suggested alternatives. The National Federation of Fishermen's Organisations (NFFO) presented an alternative approach, tackling 3 main issues they believed would generate true conservation benefits:

- Adjustments of licences in order to facilitate a reduction in capacity and thus control effort.
- An increase in the budget for decommissioning.
- Introduction of technical measures to improve the conservation characteristics of a number of fishing gears, increasing the minimum landing sizes of specific species, banning the landing of ungutted fish and protecting spawning and juvenile areas.

This example highlights the inherent lack of a formal vehicle through which professional fishermen may take an initiative in the development of a policy, which will directly affect their operational efficiency or their social and economic well-being (SFF and NFFO 2000). Ignoring such social, cultural and economic effects is unlikely to achieve sustainable and effective resource management (Mascia 1999; McClanahan 1999).

The failure of the European Fisheries Policy to build on the knowledge and experience of professional fishermen especially when setting up closed areas, stop erosion of commercial fish stocks and properly address social dislocation and its cumbersome procedures, has led the Scottish Fishermen's Federation (SFF) and the NFFO to draft measures they believe would lead to sustainable management of commercial fish stocks and protection of habitats (SFF and NFFO 2000). They propose a form of "Zonal Management" which aims at establishing groups of nations, with fishing rights in discrete zones, who would become involved in the management of those fisheries thus decentralising the present form of management and ensuring participation of all the legitimate interests. These groups of nations would be organised in "Zonal Management Committees" made up of professional fishermen, fisheries managers and scientists who would have equal representation from all nations holding quota entitlements in a particular fishing Zone. The Committees would meet on a regular basis allowing for exchange of information between all stakeholders based on continuous stock assessment, inviting other officials such as economists, and environmentalists as the agenda requires. The arrangements described above would not apply to:

- Inshore fisheries (within 6 and 12 mile limits). Such fisheries would still be managed by the adjacent nation state, except when issues affecting spawning grounds or migrations routes become relevant and
- Managing highly migratory species such as tuna and mackerel. For such fisheries, Species Committees rather than Zonal Management Committees would appear more appropriate.

When effective compliance is achieved, the need for enforcement should be much reduced. However, monitoring and enforcement will remain an important tool for the success of MPAs and should be facilitated by the increasingly affordable use of transponders, satellite tracking devices and other vessel monitoring systems (Fogarty et al. ms).

4. BIODIVERSITY

Fishing has impacts on the marine environment beyond its impacts on target populations, potentially also affecting species which interact with target species (e.g. predator and prey), and damage to habitat through the use of destructive gears such as trawls. Thus, the exclusion of fishing from selected areas can potentially bring benefits in terms of increased species richness (or diversity) and/or restoration of the structure and functioning of the ecosystems involved (Roberts and Polunin 1993; Cole et al. 1990; Dayton, 1995; Jennings et al. 1995; Hixon and Carr 1997; Bohnsack 1998;Murray et al. 1999; Murray et al. 2000). Within 'biodiversity', species prone to extinction should also be considered; these are mostly large species which grow and mature slowly.

4.1 What are the indirect effects of fishing and can MPAs reverse them?

Non-target fishery species

A widely-expressed concern about fishing is that selective removal of particular species, and size ranges within each species, will lead to shifts or imbalances in ecosystems, which may have repercussions for non-target species (Dayton et al. 1995; Hixon and Carr 1997; NRC 1999). Fishing has undoubtedly reduced the numbers of large predatory fish in the North Sea and this may have led to increased abundance of the species which they feed on. However, the question is whether changes in the environment over time primarily determine population sizes of such prey, and thus might cancel out, or greatly reduce, any positive effects of MPAs. In the Hecate Strait, British Columbia (Walters et al. 1986) Pacific cod (*Gadus macrocephalus*) and herring (*Clupea harengus pallasi*) provide an example. The stocks have shown fluctuations that indicate that herring recruitment rates are strongly influenced by cod predation. Peak cod abundances in northern British Columbia during the late 1950's may be partly responsible for the collapse of the herring fishery of the 1960's, and management of the two species should be coordinated to reflect the possibility of similar events in the future. Environmental variability may also play a significant role in the recruitment variation as suggested by a modelling study in which predation did not account for trends in recruitment of cod and whiting in the North Sea (Pope and Macer 1996). Similarly, although increases in sandeel populations coincided with depletion of herring and mackerel stocks which prey on them (Fogarty et al. 1991), natural variability was deemed a more likely determinant of the population explosion of sandeels in the North Sea (Bax 1991). Likewise, the rapid decline in capelin abundance in the North West Atlantic during the late 1970s is also attributable to environmental factors (Leggett and Carscadden 1984). In many pelagic fish, susceptibility to natural fluctuations in recruitment is poorly understood, suggesting that outcomes of management, including that involving MPAs, will be uncertain. Large MPAs could potentially help reduce the reliance of stocks on the success of individual recruitment events.

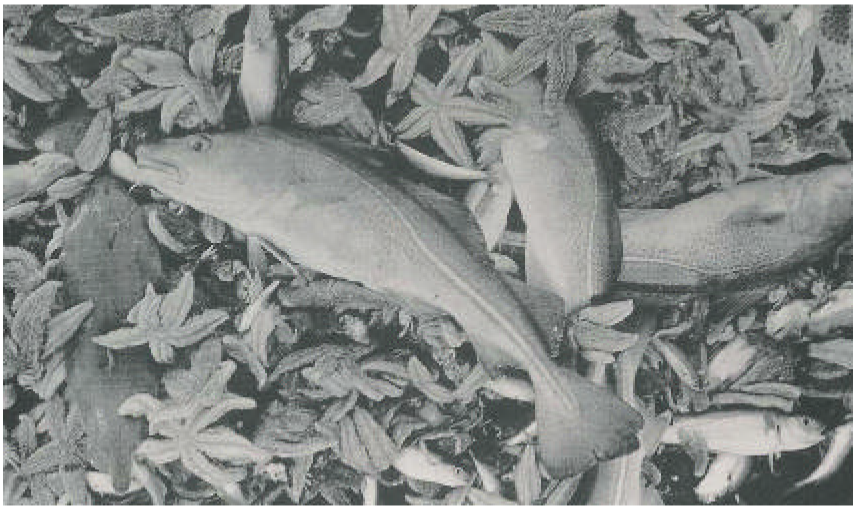

Figure 4. When marketable fish such as cod are caught, a large number of other fish species and invertebrates are also taken as unwanted by-catch (Reproduced with the kind permission of Simon Jennings, ©S. Jennings).

By-catch (Figure 4), ghost fishing and discards are important general environmental consequences of fishing (Alverson et al. 1994; Dayton et al. 1995; NRC 1999). Yet, the mortality that fisheries bring about in non-target fish, seabirds, mammals and benthic invertebrates is seldom directly quantified. Many fishes such as skates (e.g. *Raja clavata and Dipturus batis*) (Dulvy et al. 2000; Walker and Heesen 1996), greater weever (*Trachinus draco*) and smooth hound (*Mustelus mustelus*) are particularly vulnerable to fishing pressure and the fact that some species have not been found in Dutch coastal waters since the mid-1950s (CONSSO 1997) makes their conservation all the more necessary. Some of the features that make such species susceptible to depletion also dictate slow recovery when protected from fishing. Tagged rays where shown not to migrate much further than 20 km from their point of release (Walker 1998 cited in Lindeboom, 2000). Thus MPAs about 3100 km^2 (size of an ICES rectangle) might help ray populations to re-establish themselves locally, although this would impact considerably on local small-scale fisheries unable to operate elsewhere. An alternative to complete protection is to effectively reduce the fishing by-catch mortality on a particular population to a level that ensures sustainability. This might be accomplished by (i) reducing the total fishing effort, (ii) reducing effort at particular times, (iii) restricting the use of specific fishing gears, (iv) some combination of the above (Horwood 2000).

Seabirds

The reproductive success of seabirds is positively related to the availability of prey fish and prolonged periods of low prey biomass may lead to significant decreases in numbers of seabirds (Furness 1982). For example, sharp decreases in guillemot populations have been linked to the collapse of capelin stocks along the Norwegian coast (Anker-Nilssen et al. 1997). Despite strong evidence for indirect effects of fishing on seabird populations, changes in fish stocks, such as of sandeels around the Shetland Islands, appear to result primarily from environmental variability, rather than changes in the total stock size due to fishing (Wright 1996). Since the industrial fisheries confine their efforts to particular parts of the North Sea, some of which support a number of potentially sensitive seabird colonies, sandeel harvesting can lead directly to local depletions and a reduction in breeding success of seabirds. In 1993 for example, there was a measurable negative effect of the fishery on the sandeel stock which coincided with a reduction in breeding success of kittiwakes, but in general, this interaction is impossible to quantify relative to changes in other factors (Eleftheriou 2000). However, extensive closure of such grounds to industrial fishing might reduce variability in fish stocks and thus stabilise seabird populations feeding on target species. In the southern North Sea and Wadden Sea, many birds are dependent on shellfish, such as mussels, as a food source. Areas closed to shellfish exploitation could help protect birds such as waders for example, by reducing the risk of food shortage in years of low shellfish abundance.

Exclusion of fishing would of course also protect birds from direct effects of fishing (e.g. entanglement in gill nets). The most vulnerable species are auks and other diving seabirds (Gubbay 1996b). The implementation of MPAs should significantly reduce mortality of such species, especially around wintering and breeding concentrations where bycatch is highest.

Marine mammals

Many marine mammals feed on fishery target species, and are thus vulnerable to changes in prey stocks. A change in the availability of preferred prey species through exploitation is likely to result in a switch to prey species which marine mammals can often use less efficiently. The collapse of the Norwegian capelin stock for example led to starvation and emigration of grey seals from the Barents Sea (Hamre 1988; Haug et al. 1991; Hamre 1994). However, most marine mammals such as porpoises and grey seals feeding in the northern North Sea show considerable plasticity in their diets and thus only mammals with a limited choice of prey will be affected by fluctuations in diet availability. In the case of the seal populations of the Barents Sea, it appears that were MPAs to be sufficiently large to enhance prey fish abundance, this might have beneficial effects on seals including reduced foraging effort, and increased growth rate and survivorship of juveniles. This would in turn be likely to reduce recovery of fish stocks within the MPA boundaries.

Marine mammals (e.g. seals and porpoises) are also vulnerable to accidental capture, mostly from bottom-set nets and gill nets. The current level of harbour porpoise annual by-catch mortality relating to the Danish bottom-set net fishing effort in the central and southern North Sea is estimated to be roughly 2.6% of the population within the area of interest (Anon 1999; Rees 1998). This considerably exceeds the 1.7% ‘allowable limit’ set by CONSSO (1997) and by-catch could be reduced drastically if large areas were closed to fishing.

4.2 Can MPAs reverse fishing effects on habitat?

Since the early 1980s, every square metre of the Dutch sector of the North Sea was trawled on average at least once or twice a year. However, not every area is trawled with the same intensity (Figure 5); vessels in fact concentrate their efforts (Rijnsdorp et al. 1998). In the most heavily fished portions of the North Sea 5% of the surface area was trawled less than once in 5 years and 29% less than once per year (Rijnsdorp et al. 1998).

There is growing concern about the effects of regular bottom trawling activities on the marine ecosystem (reviews: e.g. Dayton et al. 1995; Jennings and Kaiser 1998; Lindeboom, 1998; Hall 1999). Demersal gears, such as beam and otter trawls, physically disturb the seabed and cause alterations in seafloor habitat structure not only reducing topographical complexity (Auster et al. 1996; Kaiser and Spencer 1996; Kaiser 1998; Kaiser et al. 1999; Kaiser et al. 2000a; Kaiser et al. 2000b) but also overall surface roughness of the ocean floor (Schwinghamer et al. 1996). Trawling also leads to changes in the diversity and composition of benthic communities (Jennings and Kaiser 1998; Thrush et al. 1998; Thrush et al. 1996; Collie et al. 1997; Collie et al. 2000) both because they are in direct contact with the seabed and because water movements generated by the gear induce sediment resuspension (Gislason 1994; Lindeboom and de Groot 1998). The extent to which impacts occur is variable, depending in particular on speed of towing and physical characteristics of the gear. Of all bottom-fishing activities shellfish dredging, and suction dredging cause the greatest disturbance to the sediment (Eleftheriou 2000). The extent to which the abundance of a species and the community structure are affected by trawling is also dependent on the: (i) type of substratum, (ii) strength of currents and/or tides in the area subject to fishing, (iii) duration, extent, and frequency of the physical disturbance (Underwood 1989), and (iv) intrinsic capacity of the population to withstand and recover from the disturbance (Underwood 1989). In areas of strong tide and current for example, the trawling resuspension of the sediments is of short duration and the effects of sediment redeposition on biota which are adapted to storm events and sediment transport by currents are not permanent. Thus, the impact of MPAs will vary according to the prevailing conditions. In such areas, characterised by high levels of disturbance, shifts in benthic community structure following trawling disturbance (Bergman and Hup 1992; Bradshaw et al. 2000; Currie and Parry 1996; Kaiser and Spencer 1996; Thrush et al. 1995; Tuck et al. 1998) are typically less noticeable (Brylinsky et al. 1994). Indeed, these environments may exhibit little or no trawling effects (Kaiser 1998; Shepherd 1983), and species recovery rates are usually fairly rapid (Thrush et al. 1995; Kaiser 1998; Collie et al. 2000). Intertidal dredging for cockles, for example, significantly reduces the abundance of non-target benthic infauna, but recovery may occur within 8 weeks as a result of immigration and recruitment (Hall and Harding 1997).

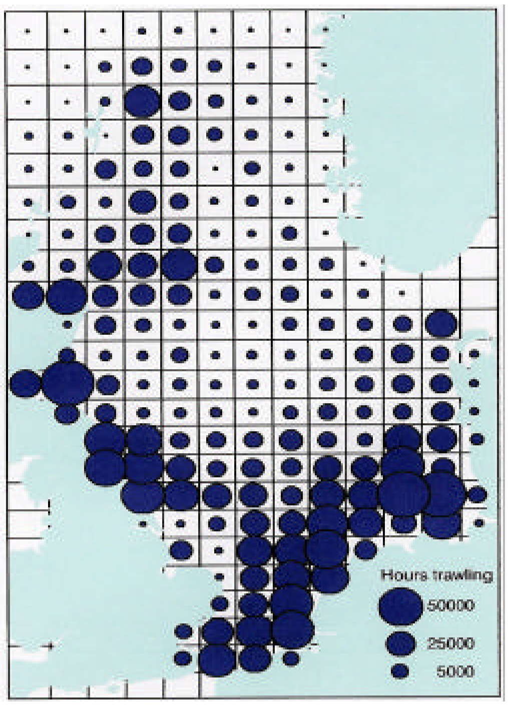

Figure 5. Trawling effort in the North Sea is very patchy. International beam and otter trawling effort for 1995 shows that some areas of the southern North Sea are very heavily fished while areas of the central North Sea are rarely visited (Reproduced with the kind permission of Simon Jennings, ©S. Jennings).

In deeper water (e.g. >75 meters), where physical disturbance by water movement and storms is less frequent and of lesser magnitude, or in more stable areas such as gravel, mud and biogenic habitats (Collie et al. 2000; Tuck et al. 1998), MPAs will tend to reverse structural changes in habitats caused by fishing, and increase the number of species present (Brylinsky et al. 1994). In such stable environments, establishment of MPAs is likely to reduce sediment resuspension (Auster et al. 1996; Collie et al. 1997; Dayton et al. 1995) and nutrient release leading to an increase in three-dimensional complexity and abundance of susceptible infauna. Deep-water coral (*Lophelia pertusa)*, which provides a habitat for other marine life such as crabs, sea cucumbers, sponges and sea spiders, is regarded as a very good case for site protection. Along the Norwegian coast, about half of the coral reefs found have been partially or completely destroyed by bottom trawling and Norway recently passed legislation in order to protect those fragile habitats.

Rocky substrata also often act as important refuges for juveniles and adults of some commercial species (Walters and Fuanes 1993) and have diverse biological assemblages that may be important prey for some organisms (Peattie and Hoare 1981). Oyster beds, seagrass (*Zostera*) beds and reefs formed by the calcareous tubeworm *Sabellaria spinulosa* (Jennings and Kaiser 1998) also foster special communities which should benefit from protection in MPAs. However, threats to emergent sessile fauna other than fishing also need to be taken into consideration. The drastic decline of intertidal S*abellaria* reefs on the German North Sea coast over the last decade may not have been caused by beam trawling for shrimps as had been suspected (Vorberg 2000). Other factors such as the building of dikes, causeways, and storm barriers and the dumping of dredge waste as well as natural climatic factors are more likely agents than fisheries (Vorberg 2000).

Trawling and dredging also cause long-term changes to both epi- and infauna leading to a shift from communities dominated by relatively fragile sessile, emergent, high-biomass species to those dominated by smaller-bodied infauna (Thrush et al. 1996). Short-term effects include mortality of starfish (10-30%) (Ramsay et al. 1999), crustaceans (30-40%) and sea urchins (90%) (Lindeboom and de Groot 1998). Longer-term effects include annual mortalities of 20-40% for benthic species and some change in community structure with a shift towards dominance by opportunistic short-lived species and a decrease in the number of long-lived sessile organisms (Kaiser et al. 2000b; Rumohr and Kujawski 2000; Tuck et al. 1998). On the other hand a study analysing the effects of trawling disturbances on the temporal and spatial structure of benthic soft-sediment assemblages in a protected fjord in Sweden (Lindegarth et al.

2000), showed that after twelve months of intensive experimental trawling, the benthos of trawled and untrawled areas were both different. Changes were only slightly larger in trawled areas, suggesting that trawling might only have influenced small-scale spatial and temporal variability.

The evidence for some general and widespread effects of trawling, such as an increase in benthic productivity due to the proliferation of smaller benthic species with faster life histories (Jennings et al. 2001b), is equivocal. In 2 areas (Silver Pitts and Hills) of the central North Sea, even though the relative infaunal production rose with increased trawling disturbance, it did not compensate for the loss of total production attributable to the depletion of large individuals (Jennings et al. 2001a). Climate change rather than trawling may be responsible for the recent increases in primary production (Jennings et al. 2001a) and these would not be reversed in MPAs. Trawling has led to drastic reductions in the biomass of invertebrate infauna and epifauna in the Silver Pitts and Hills region (Jennings et al. 2001b) but not to changes in the trophic structure of the community. In the latter respect therefore, effects of MPAs are not expected.

At the population level, the annual mortality to the benthic fauna caused by a fishing event will depend on the direct mortality generated by single fishing events and on the overlap in spatial distribution between species and fishing effort. The distribution of benthic invertebrates in the southern North Sea is related to sediment characteristics and water depth (Duineveld et al. 1991). The distribution of beam trawling on the other hand will be influenced by the distribution of the target species and the suitability of the seafloor for fishing. This in turn results in the highly patchy distribution of fishing disturbance in the North Sea (see Figure 2). For instance, in eight of the most heavily fished ICES rectangles, 10% of the seafloor was trawled less than once every five years, 33% less than once per year and 3% more than 10 times yearly (Piet et al. 2000).

Although MPA establishment in areas which have been severely impacted by fishing is expected over time to help restore three dimensional habitat complexity (Bergman and Hup 1992; Thrush et al. 1995; Kaiser and Spencer 1996; Pitcher et al. 1997; Kaiser 1998; Thrush et al. 1998), system function, and species composition and diversity (Roberts 1995b; Roberts in press; Roberts and Hawkins 2000), detailed species compositions will be hard to predict (Roberts and Hawkins 2000). Potential longer-term fishing effects on the benthos and associated communities may be difficult to detect today because the marine ecosystems of the North Sea have been exposed to intensive fishing for many decades and old data are scarce. What may be studied today are thus only variations within a system which has had a long history of impact. Should an MPA be established, factors other than protection from fishing, such as pollution, dredging and oil and gas exploration can be expected to be influential and should be taken into consideration.

5. RECREATION

Fish abundances within MPAs, and associated fauna including many seabirds such as guillemots and skuas (Powers and Brown 1987) and seals are expected to act as significant draws for wildlife-related recreation. This in turn provides social and economic benefits through the development of activities such as recreational diving, photography, cultural and aesthetic uses, and the associated development of accommodation and entrance fees (Dixon et al. 1995). Furthermore, there should be increased opportunities for education and raising of awareness about human threats to the environment. Although it is not clear which species if any could be expected to become substantially more abundant in MPAs of modest area in the North Sea, small MPAs have attracted greater tourism and increased recreational use. There is thus ample scope for recreational and educational projects to be developed and incorporated into the management plan of MPAs.

The St Abbs and Evemouth voluntary reserves in the UK for example were concerned individuals and groups from the local community including landowners, diving clubs and conservation organisations (Gubbay 1993). It is an important site for kelp forests and associated fauna, and the shell and stone gravel sediments support a wide range of burrowing bivalve molluscs. Adjacent land has one of the most important seabird colonies on the east coast of Scotland, especially for guillemot and kittiwake. Conservation of the marine wildlife is upheld through promoting good practice amongst visiting divers and using the reserve as an educational tool (e.g. slide shows, guided shore walks, talks to visitors, interpretation centre).

6. SCIENCE

The most dramatic effects of fishing on diversity and community structures arise at the outset of exploitation. However, once systems enter a fishing state, diversity and production by and large are often relatively stable, despite changes in fishing intensity. Long-term and large-scale studies that ideally should include unfished sites are the best way to elucidate potential fishery impacts on community structure and diversity (Moore and Jennings 2000). Accurate assessment of closed areas in the North Sea is fraught by the lack both of such suitable 'control areas' and monitoring programmes to study their effects.

The existence of unexploited areas provides a benchmark against which the long-term impacts of extractive activities can be scientifically evaluated at, population, community, and ecosystem levels (Dayton et al. 1995; Roberts 1997Jennings and Kaiser 1998; Kaiser 1998; Kaiser et al. 1999; Collie et al. 2000; Kaiser et al. 2000a; Kaiser et al. 2000b). Such reference areas would for example help in gathering data on impacts and recovery of epifaunal structure-forming communities (Collie et al. 2000), thus helping to fill substantial gaps in the available data. Although it is clear that in areas such as the North Sea, many benefits expected from the establishment of MPAs may not occur (e.g. increased abundance of target species in small MPAs), in other cases (e.g. increased abundance of target species in large MPAs, increase in fragile structure-forming epifauna in deep water), reference sites free of fishing impacts can be especially important for understanding long-term change and the influence of natural-environmental variability (Dayton et al. 1995; Botsford et al. 1997; Dayton 1998). Hence, they can help not only in assessment of the status and workings of natural ecosystems but also assist in the development of coastal management and habitat plans in the context of biodiversity conservation (Jennings and Kaiser 1998). In areas like the North Sea, where large expanses of the seabed have been intensely fished for decades, short-term effects of cessation of fishing should be detected in MPAs and other areas with lighter fishing pressure, but recovery from long-term impacts may take decades. This has important and substantial implications for investment in MPA operation and the science needed to learn from the consequent changes in marine ecosystems.

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