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ESTABLISHMENT OF FISH STOCK RECOVERY AREAS

NOTE

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DIRECTORATE-GENERAL FOR INTERNAL POLICIES

POLICY DEPARTMENT B: STRUCTURAL AND COHESION POLICIES

FISHERIES

ESTABLISHMENT OF FISH STOCK RECOVERY AREAS

NOTE

This document was requested by the European Parliament's Committee on Fisheries.

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Abstract

This report examines a proposal to establish a network of ‘fish stock recovery areas’ to cover 10-20% of territorial seas of EU Member States. Such protected areas in Europe and elsewhere have produced rapid and long-lasting recovery of many commercially important species. They have also benefited surrounding fisheries through spillover and export of offspring from protected stocks. Fish stock recovery areas could make a major contribution to improving the status and productivity of fisheries, as well as safeguarding marine biodiversity.

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LIST OF ABBREVIATIONS

EU	European Union
EMFF	European Maritime and Fisheries Fund
ICES	International Council for the Exploration of the Sea
MPA	Marine Protected Area
NGO	Non-governmental organisation
SAC	Special area of conservation
SPA	Special protection area
RAC	Regional advisory council

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EXECUTIVE SUMMARY

Background

The European Commission published draft proposals for reform of the EU Common Fisheries Policy in July 2011. These proposals have since been discussed in Committees of the European Parliament, and the Committee on Fisheries has presented a draft report on the proposed reforms. This draft report recommends an additional conservation measure to those proposed by the Commission. Amendment 68, Part 3, Article 7a (see Box 1 for wording) proposes that Member States establish networks of marine reserves in their territorial waters, referred to as 'fish stock recovery areas'. Within these areas, all fishing would be prohibited to facilitate conservation and recovery of fish stocks. Article 7a proposes that over time these closures should increase in coverage to between 10% and 20% of territorial waters of every Member State.

Aim

This report evaluates the proposed regulation and will (1) explore the present state of our understanding of the value and role of marine reserves as a fisheries management tool, and (2) assess the status and effectiveness of existing European marine reserves. It will examine the specific provisions of the proposed amendment, including the types of target areas for fish stock recovery area establishment, the proposed size of the network, possible timescales for implementation, the duration of protection, the utility of setting up surrounding buffer zones with restricted fishing, and proposals for transit of fishing vessels. The report also discusses the feasibility of the measure, the main benefits and costs, and identifies potential problems which might hinder its implementation. It draws on experience with creation of marine reserve networks in other parts of the world.

Key findings

Marine protected areas have been used to support fisheries objectives for over 100 years. Theory predicts that reserves will benefit fisheries mainly through build up of protected stocks, recovery of their habitats, movement of animals to fishing grounds (termed spillover), and export of eggs and larvae. Evidence from hundreds of marine reserves across the world, including many in Europe, indicates that there are usually very rapid positive responses by protected populations to establishment of marine reserves. Stocks of commercially exploited animals respond most strongly and can increase many times over, sometimes by ten-fold or more. Some species not targeted by fisheries can also increase in abundance. Marine reserves work just as well in temperate waters as they do in tropical seas.

Reproductive output by protected animals increases rapidly after marine reserve establishment, and can rise to levels tens of times greater than in fishing grounds as a result of increasing numbers of large, old and reproductively experienced animals. Evidence from a wide variety of sources, including genetics, oceanography, geochemistry, rates of spread of invasive species, and direct measurements of larval export, indicate that reserves can supply eggs and/or larvae to surrounding fishing grounds, typically over distances of a few tens to more than 100 km. New research using genetic parentage tests has linked parent fish in reserves with their offspring settling into surrounding fishing grounds. The most sophisticated research to date showed that reserves on the Great Barrier Reef supplied offspring to fishing grounds in proportion to the fraction of the reproductive stock that was protected, upholding a key theoretical prediction about how reserves can be used to enhance fisheries.

Spillover of commercially important fish and shellfish has been demonstrated many times from marine reserves and fishery closures in Europe and elsewhere. Spillover has been shown to benefit catches and promote local fishery sustainability. Most spillover is caught close to the boundaries of marine reserves (< 1-2 km) by fishermen 'fishing-the-line'. Buffer zones around marine reserves have been successfully used to promote the interests of small-scale artisanal fishermen using low impact gears, as well as recreational fishers.

By protecting areas from the damage caused by fishing gears, marine reserves also promote the recovery of diverse, structurally complex, biogenic habitats. Over periods of years, habitats in reserves may also change (mainly increase in diversity and complexity) through reorganisation of predator-prey relationships in food webs. Improvements in protected habitats in turn promote population build-up of protected animals.

Protected areas have long been used to protect highly mobile and migratory animals from fishing at vulnerable times and places, such as in nursery areas or spawning aggregations. Fish stock recovery areas could very usefully take on this role. Even apparently very mobile species have benefited strongly from protection, often in small reserves.

Evidence indicates that marine reserves produce benefits quickly, results becoming detectable for some species within a year or two of protection. Other species respond more slowly. Long-term studies of reserves show that benefits to long-lived and slow growing species, and to habitats, can continue to increase over periods of decades. Recovery of protected populations typically translates into fishery benefits within 5 to 10 years of protection and these benefits will continue to increase for decades thereafter. It could take half a century or more to see the full extent of benefits from protection.

The proposed coverage for fish stock recovery areas of 10 - 20% of territorial seas places them within the range that present research predicts will produce strong fishery benefits.

Existing Marine Protected Areas (MPA) cover only a few percent of European seas, cover a narrow range of habitats, and are mostly concentrated in territorial waters. Marine reserves that are protected from all fishing are small, scattered and cover less than 0.01% of European seas. Larger MPAs tend to be weakly protected and/or poorly managed. The introduction of fish stock recovery areas at the scale proposed (10 – 20% coverage in territorial seas) would dramatically improve the state of the European marine environment. There is an opportunity for fish stock recovery areas to be implemented in places with MPAs by upgrading levels of protection.

Establishing networks of MPAs can take many years and requires long-term, legally binding, non-partisan commitment from governments and sufficient financial support. Widespread stakeholder involvement is necessary to see through the process, but not all stakeholders will be happy with the outcome, and the the process of engagement will have to be tailored to local conditions. Good science, transparency, fairness, a willingness to compromise and firm deadlines help to keep progress on track.

Recommendations

Incorporation of fish stock recovery areas into management practice in European fisheries, at the scale proposed, could deliver major benefits for fish stock recovery and habitat protection. They could produce benefits of a form that conventional fishery management tools cannot, such as recovery of depleted, vulnerable species and habitats without the need to shut down productive fisheries. Fish stock recovery areas could make an important contribution toward the adoption of 'ecosystem-based fishery management' and precautionary management. Marine reserve networks – including the proposed fish stock recovery areas – will be essential to achieving good environmental status under the Marine Strategy Framework Directive.

It is recommended that fish stock protection areas be established to cover 20% of fishing grounds.

It is recommended that buffer zones be created around fish stock recovery areas, in which low impact fishing methods are employed by small scale fishers, and recreational fishing is allowed.

Because of the extended timescales of stock and habitat recovery, and the speed with which benefits can be dissipated on resumption of fishing, the establishment of fish stock recovery areas must be seen effectively as a permanent commitment if they are to contribute meaningfully to fish stock recovery and habitat conservation.

The only exception to this would be where particular reserves were demonstrably failing to achieve much in the way of stock or habitat recovery. Such an outcome would need to be determined on a case by case basis through fishery independent survey methods, but the five year suggested timescale in Amendment 68 for such a review is too short. 10 years would be more appropriate based on available evidence of the timescales of reserve benefit.

Fishers will need to be fully involved in the process of establishing fish stock recovery areas. Since the process will need to vary from region to region, reflecting variation in social and ecological conditions, the Regional Advisory Councils would be well-placed to advise on site selection and implementation.

While compromises are essential in processes to establish marine protected areas, reducing the level of protection afforded by fish stock recovery areas would not be a sensible compromise, given that benefits are rapidly reduced by even low levels of fishing.

The process of establishing fish stock recovery areas will be expensive and will impose transitional costs on fishermen as they adapt to the new management regime. Financial support from the European Maritime and Fisheries Fund could facilitate an effective and equitable roll out of the policy.

In accordance with the UN Law of the Sea right of innocent passage, fishing vessels should be permitted to transit fish stock recovery areas, provided that all gears carried on board that are used for fishing are lashed and stowed, during the transit.

1. BACKGROUND

Following a lengthy consultation, the European Commission published draft proposals for reform of the EU Common Fisheries Policy in July 2011. These proposals have since been discussed in Committees of the European Parliament, and the Fisheries Committee has presented a draft report on the proposed reforms. This draft report recommends an additional conservation measure to those proposed by the Commission. Amendment 68, Part 3, Article 7a (see Box 1 for wording) proposes that Member States establish networks of marine reserves[1] in their territorial waters, referred to as 'fish stock recovery areas'. Within these areas, all fishing would be prohibited to facilitate conservation and recovery of fish stocks. Article 7a proposes that over time these closures should increase in coverage to between 10% and 20% of territorial waters of every Member State.

Box 1: Text of Amendment 68, Part 3 – Article 7a

ESTABLISHMENT OF FISH STOCK RECOVERY AREAS
Amendment 68, Proposal for a regulation, Part 3 – Article 7a (new)

1. In order to secure the reversal of the collapse of the fishing sector, and to conserve living aquatic resources and marine ecosystems, and as part of a precautionary approach, Member States shall establish a coherent network of fish stock recovery areas in which all fishing activities are prohibited, including areas important for fish productivity, in particular nursery grounds, spawning grounds and feeding grounds for fish stocks.
2. Member States shall identify and designate as many areas as are necessary to establish a coherent network of fish stock recovery areas amounting to between 10 % and 20 % of territorial waters in each Member State and shall notify the Commission of these areas. The establishment of the network shall be gradual, in accordance with the following timeframe:
(a) By ...*: - Fish stock recovery areas shall amount to at least 5 % of the territorial waters of each Member State
(b) By ...**: - Fish stock recovery areas shall amount to at least 10 % of the territorial waters of each Member State
3. The location of fish stock recovery areas shall not be modified within the first five years of their establishment. If a modification is needed, this shall only occur after the establishment of another area or areas of the same dimensions;
4. The measures and decisions referred to paragraph 2 and 3 above shall be notified to the Commission, along with the scientific, technical, social and legal reasons for them and shall be made publicly available;
5. The competent authorities of the Member States concerned shall decide whether the fish stock recovery areas designated under paragraphs 1, 2 and 3, shall be surrounded by a zone or zones in which fishing activities are restricted and shall decide, after having notified the Commission, on the fishing gears that may be used in those zones, as well as the appropriate management measures and technical rules to be applied therein, which cannot be less stringent than those of Union law. This information shall be made publicly available;
6. If a fishing vessel is transiting through a fish stock recovery area, it shall ensure that all gears carried on board that are used for fishing are lashed and stowed, during the transit;
7. The Union shall also take measures to reduce the possible negative social and economic consequences of the establishment of fish stock recovery areas.

____

* OJ please insert the date one year after the entry into force of this Regulation.
** OJ please insert the date three years after the date of entry into force of this Regulation.

Source: European Parliament

[1] Throughout this report we use the term 'marine reserve' to refer to a place that is protected from all fishing, and 'marine protected area' or MPA, to refer to a place with lower levels of protection (although some may include zones protected from all fishing).

This report evaluates the proposed regulation and will (1) explore the present state of our understanding of the value and role of marine reserves as a fisheries management tool, and (2) assess the status and effectiveness of existing European marine reserves. It will examine the specific provisions of the proposed amendment, including the types of target areas for fish stock recovery area establishment, the proposed size of the network, possible timescales for implementation, the duration of protection, the utility of setting up surrounding buffer zones with restricted fishing, and proposals for transit of fishing vessels.

The report will also discuss the feasibility of the measure, the main benefits and costs, and seek to identify potential problems which might hinder its implementation. In doing so, it will draw on experience with creation of marine reserve networks in other parts of the world. Furthermore, the paper will examine the necessity of funding this measure through the European Maritime and Fisheries Fund (EMFF), and of being coordinated by the Commission in consultation with the Regional Advisory Councils (RACs) in order to draw up harmonised criteria for the marine reserve networks.

2. THE ROLE OF MARINE RESERVES IN FISHERIES MANAGEMENT: REVIEW OF PRESENT UNDERSTANDING

KEY FINDINGS

- Marine protected areas have been used to support fisheries objectives for over 100 years.
- Theory predicts that reserves will benefit fisheries mainly through build up of protected stocks, recovery of their habitats, spillover of animals to fishing grounds, and export of eggs and larvae.

Marine reserves have been called many things, including ‘no-take zones’, ‘fishery reserves’, ‘fully protected marine reserves’, ‘highly protected marine reserves’, and now ‘fish stock recovery areas’. Regardless of the name applied, the underlying principles are the same. Although consideration of the use of such areas to support fisheries is a recent development in Europe, such areas have been used in one form or other for hundreds of years by traditional societies in places such as Pacific islands (McClanahan *et al.* 2006). In fact they have been used in French fisheries for well over a century and the theoretical background to their use in fisheries management was first set out 100 years ago by a French fishery scientist, Marcel Herubel (Herubel 1912).

Marine reserves promote the build-up and recovery of stocks of exploited species because they protect animals from fishing in particular places. These animals will thus experience reduced fishing mortality, which means they will live longer. Most marine species that we exploit grow larger as they age, which means that protection by reserves will increase the abundance of older, larger animals. Because the number of eggs produced by most commercially important marine species increases exponentially with body size, this means that reserves can greatly boost the reproductive output of protected stocks. Most marine species targeted by fisheries disperse as eggs or larvae early in their lives, potentially taking them tens or hundreds of kilometres from the places they were spawned. This means that reproduction of animals protected in marine reserves can potentially replenish populations in extensive areas of surrounding fishing grounds.

As well as increases in reproduction, marine reserves can also promote fishery production via the export of juvenile and adult animals across their boundaries. According to this argument, as densities and biomass (the combined weight of protected animals) increase in marine reserves, competition for food and space resources will increase, so animals will tend to move to places that are less crowded, which means surrounding fishing grounds. This process is usually referred to as ‘spillover’ and the rate of spillover is expected to increase over time as stocks build up in reserves.

As well as these direct effects on populations of exploited species, marine reserves provide other potential benefits for fisheries. Many methods used to capture fish and shellfish have collateral impacts on non-target species and habitats. Impacts on non-target species take the form of removal (bycatch), death *in situ*, or damage. For example, bottom trawls and dredges are typically heavy, mobile fishing gears that are dragged across the seabed to catch their target animals, in the process capturing, killing or damaging large numbers of species that live on, in or near the seabed (Watling and Norse 1998, NRC 2002, Morgan and Chuenpagdee 2003). Protection of bycatch species from fishing mortality will benefit them in exactly the same ways as outlined above for the target species.

In addition, protection from fishing mortality and damage is expected to lead to recovery of seabed habitats, particularly three-dimensionally complex habitats created by the growth of particular plants and animals, such as maerl (formed by coralline algae), seagrass beds, kelp forests, horse mussels or oysters. By increasing the area of high quality habitat, this effect means that marine reserves could in turn reinforce the process of population recovery for species targeted by fisheries.

Several other potential fishery benefits have been highlighted for marine reserves (Roberts *et al.* 2005). They have been suggested to provide a form of 'insurance' against management failure. If fishing takes place everywhere, the argument goes, then management mistakes, such as setting total allowable catches too high, will cause depletion of stocks throughout the entire area of the fishery. By contrast, if there is a network of protected marine reserves, then a proportion of the stock will remain safe from overexploitation and depletion and can form the basis for more rapid recovery once the management mistake has been discovered and rectified.

In a similar vein, marine reserves have been argued to provide resilience to a fishery against natural environmental fluctuations and extreme events. The larger and more productive populations that they support are expected to suffer less depletion and bounce back more rapidly after conditions return to normal.

The predicted benefits of marine reserves for fisheries are also the basis for their use in biodiversity protection. Conservation of biodiversity has been the driving force behind marine reserve establishment in many countries. This means that the evidence for reserve benefits to fisheries often comes from places protected because of their natural beauty, their value for natural habitats, or importance for rare, threatened or declining species. This means that many of these places have not been designed with fisheries management objectives in mind. Nevertheless, a great deal has been learned about the values of marine reserves for fisheries by research at these sites. The following sections summarise current understanding of the effects of reserve protection.

3. EVIDENCE FOR BUILD-UP OF ABUNDANCE AND BIOMASS OF COMMERCIALLY IMPORTANT SPECIES

KEY FINDINGS

- Evidence indicates that there are usually very rapid positive responses by protected populations to establishment of marine reserves.
- Stocks of commercially exploited animals often increase many times over, sometimes by ten-fold or more. Species not targeted by fisheries can also increase in abundance.

A build-up in abundance and biomass of protected species is a pre-requisite for the production of most of the fisheries benefits expected from marine reserves[2]. Since the 1970s, researchers have documented strong and rapid increases in abundance and biomass of a steadily increasing variety of species protected by marine reserves. The evidence base has been reviewed at regular intervals throughout this period (e.g. Roberts and Polunin 1991, Russ 2002, Graham *et al.* 2011) and has expanded very quickly in recent years due to the growth in scientific attention focussed on the performance of marine reserves.

The most recent synthesis of evidence, by Lester *et al.* (2009) examined the effects of protection on abundance and biomass of protected species in 149 peer-reviewed studies of 124 fully protected (i.e. no-take) marine reserves in 29 countries. Depending on the nature of the study, they calculated the ratio of each of several measures of reserve benefit (abundance, biomass, size of animals and species diversity) either (1) between reserves and comparable habitat in nearby fishing grounds, or (2) between pre-protection levels and levels reached after some period of protection. The study included commercially exploited species from a wide range of taxonomic groups including molluscs (snails, bivalves, squids, octopus and their allies), sea urchins, sea cucumbers, barnacles, crabs, lobsters and fish. The study also included non-target species from these groups, as well as habitat-forming species such as hard and soft corals, sea nettles, sponges and polychaete worms.

On average, marine reserves increased density of species by 166% compared to pre-protection conditions or levels in comparable exploited habitats. Biomass increases were greater, averaging 446% higher in protected reserves. It must be emphasised that these are average differences. There were both stronger and weaker responses to protection within the sample. Particularly strong effects are often seen in species that are intensively fished. In many cases there was a ten-fold or greater difference in biomass between reserves and unprotected areas. For example, spiny lobster, *Jasus edwardsii*, biomass was 25 times greater in a New Zealand marine reserve after 22 years of protection (Shears *et al.* 2006). Density of the endangered dusky grouper, *Epinephelus marginatus*, increased 40-fold in the Cabo de Palos Marine Reserve in Spain in 10 years of protection (García-Charton et al 2008). There were also strong increases of 10-fold or greater for three other commercially-valuable species in this reserve.

At the other end of the spectrum, one might expect that increased abundances of species targeted by fisheries, many of which are predators, will keep populations of their prey

[2] An exception to this rule is the case where reserves improve reproductive success by protecting animals when they aggregate to spawn. Such a benefit does not depend on reserves first increasing the abundance of the target species.

species at low levels. This is true in some cases (Claudet *et al.* 2010). However, in practice, there were very few marine reserves where the population levels of the species studied were lower in marine reserves than in exploited areas. Instead, prey species also often increase in abundance very strongly following protection (e.g. Hawkins *et al.* 2006, Mumby *et al.* 2006). The explanation for this apparent paradox is that such species are often caught as bycatch in fisheries or are otherwise damaged by fishing gears (e.g. corals), so they too have benefited from protection from fishing mortality.

4. EFFECTS OF PROTECTION ON REPRODUCTION BY COMMERCIALLY IMPORTANT SPECIES

KEY FINDING

- Reproductive output by protected animals increases rapidly after marine reserve establishment, and can rise to levels tens of times greater than in fishing grounds as a result of increasing numbers of large, old and reproductively experienced animals.

Protection from exploitation and fishing damage increases the biomass of commercially important animals and extends their population age structures so that there are more big, old animals around (Lester *et al.* 2009). These two effects mean that reserves can make major contributions to production of eggs and larvae, such that even relatively small reserves might be able to produce widespread effects if offspring are transported into fishing grounds (see Section 5 below).

There are now many examples of cases in which reserves have produced striking increases in spawning stock size. For example, spawning stock biomass of an intensively fished emperor fish, *Lethrinus harak*, in Guam was 16 times greater in marine reserves than in fishing grounds (Taylor et al 2012). In a small marine protected area in Washington State, USA, lingcod, *Ophiodon elongatus*, produced 20 times as many eggs per area of habitat as in surrounding fishing grounds and copper rockfish, *Sebastes caurinus*, 100 times greater (Palsson and Pacunski 1995). In the Tonga Island Marine Reserve in New Zealand egg output from protected spiny lobsters in reserves was estimated to be 9 times greater than in fished areas after five years of protection (Davidson *et al.* 2002). A synthesis of data from New Zealand reserves concluded that they had supported annual rates of growth in egg production by lobsters of 9.1% (Kelly *et al.* 2000). Table 2 (see Section 6.3) lists many cases where reproductive stock size and/or reproductive output have increased by ten times or more after protection, while the case study in Box 2 gives an example of how enhanced egg production by protected lobsters, *Palinurus elephas*, in Spain's Columbretes Islands Marine Reserve is essential to the sustainability of the surrounding fishery.

There are good biological reasons to expect that effective reproductive output by animals protected in marine reserves will actually be greater than the factor of increase in overall spawning stock size. This is because of the combined effects of increased population density and the extended population age structures of protected animals compared to those in fishing grounds. Many animals experience higher reproductive success at higher densities. One reason, especially for animals with limited movements, is that they are better able to find mates. For example, queen conch in Bahamian marine reserves experience far greater reproductive success than those at lower population densities in fishing grounds (Stoner *et al.* 2012). Hogfish, *Lachnolaimus maximus*, males held harems of females at the higher population density in a Florida marine reserve and were regularly seen spawning (Muñoz *et al.* 2010). Extensive observations in fished areas revealed no spawning activity at the lower population densities seen there.

Aside from their greater egg production, the bigger, older animals protected by reserves may experience higher reproductive success for other reasons. Older animals have more reproductive experience and which may benefit their reproductive success. Large animals often produce larger eggs that hatch into bigger larvae and survive better than those from the smaller eggs produced by younger animals (Berkeley *et al.* 2004, Birkeland and Dayton

2005). For these reasons, measures of increases in spawning stock biomass produced by reserve protection likely underestimates their true contribution to stock replenishment.

5. EVIDENCE FOR SPILLOVER

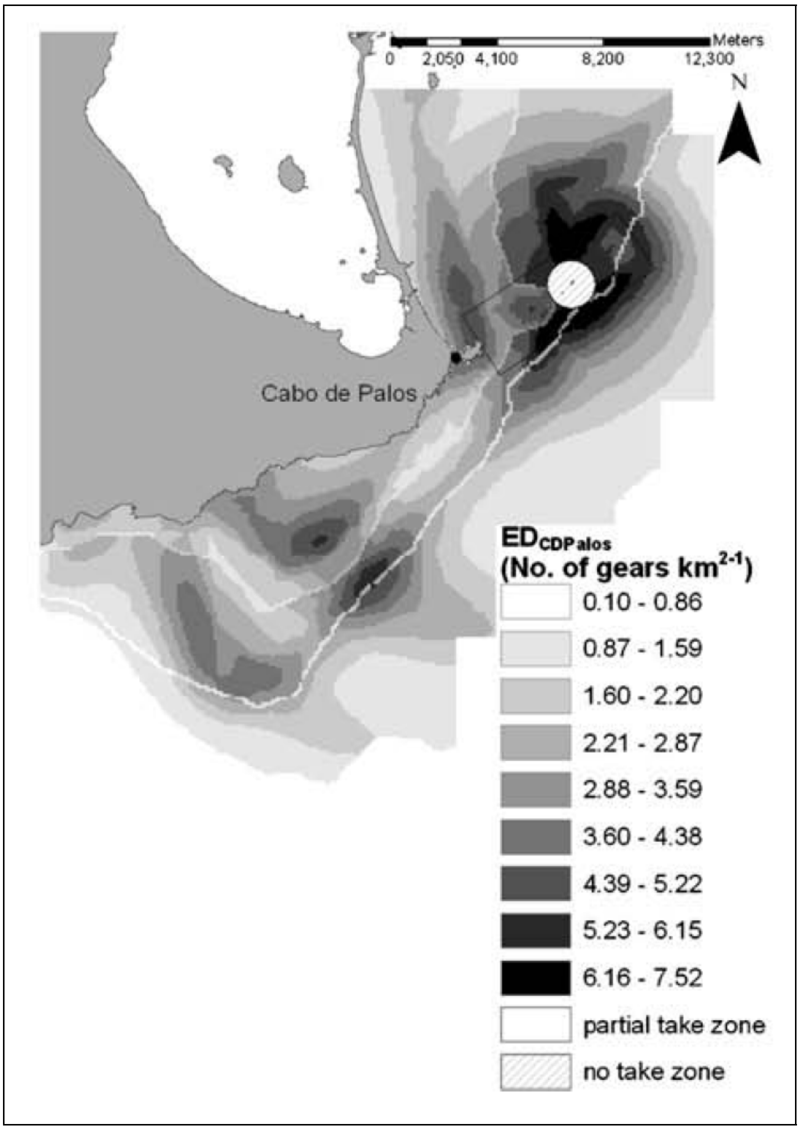
KEY FINDINGS

- Spillover of commercially important fish and shellfish has been demonstrated many times from marine reserves and fishery closures in Europe and elsewhere.
- Spillover has been shown to benefit catches and promote local fishery sustainability.
- Most spillover is caught close to the boundaries of marine reserves (< 1-2 km) by fishermen ‘fishing-the-line’.
- Buffer zones around marine reserves have been successfully used to promote the interests of small-scale artisanal fishermen using low impact gears, as well as recreational fishers. Such an approach could be beneficial around fish stock recovery areas.

Spillover is the movement of adults and juveniles across marine reserve boundaries into surrounding fishing grounds where they can be caught. It can occur as a result of several different processes: movements within home ranges, density-dependent spillover, migrations and ontogenetic movements. Animals typically occupy home ranges or territories that differ in size depending on the mobility of a species. Where home ranges straddle the boundary of a marine reserve, animals will only gain partial protection as they will spend some of their time in fishing grounds. As described in Section 2, density-dependent spillover happens when animal populations build up in reserves, so increasing competition for resources or predation rates. Under these circumstances, animals may seek better places to live, especially young animals, and so move into fishing grounds. Ontogenetic spillover happens when animals shift habitats as they grow. If reserves are sited in nursery grounds, for example, then juveniles may leave after a certain period of growth. Finally, spillover may happen when protected animals migrate in and out of reserves, for example to reach spawning or feeding areas.

If spillover is taking place, the first indication is often a shift in fishing patterns by local fishermen. To take advantage of animals leaving reserves, they begin to preferentially fish close to marine reserve boundaries, an effect known as ‘fishing-the-line’. Such a phenomenon has been demonstrated from reserves all over the world, in a wide variety of habitats, and from artisanal to industrial fisheries (Murawski *et al.* 2005, Pérez-Ruzafa *et al.* 2008, Halpern *et al.* 2010). Fishing-the-line has been documented around many Mediterranean marine reserves, for example (Stelzenmüller *et al.* 2008). Goñi *et al.* (2008) documented higher catch rates and fishery revenues close to the boundaries of six Mediterranean MPAs, for three different fishing methods targetting a variety of fish and shellfish. Stobart *et al.* (2009) found that catch rates for fish close to Spain’s Columbretes Islands Marine Reserve increased steadily over a period of 8 to 16 years after the reserve was created (see also Box 2). A synthesis of research on spillover from seven southern European MPAs showed that spillover benefits to fisheries built up at a rate of 2-4% per year over long-periods of up to 30 years (Vandeperre *et al.* 2010).

Figure 1: Distribution of fishing effort around the Cabo de Palos Marine Reserve in Spain



Source: Stelzenmüller *et al.* (2008)

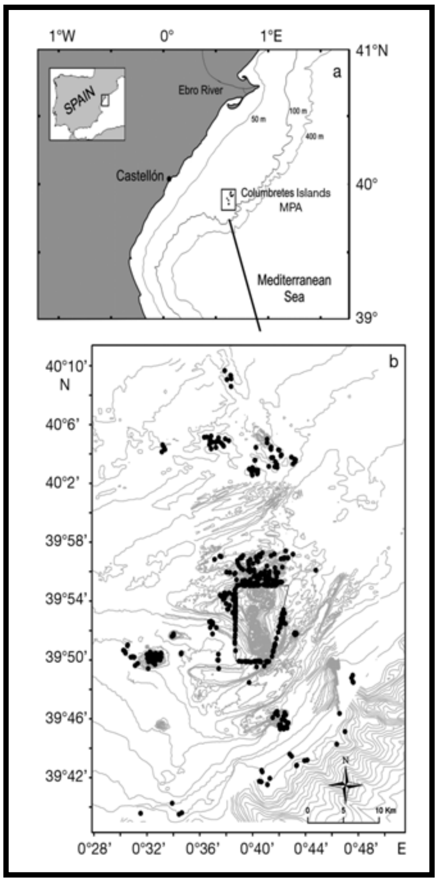
There are other methods to detect spillover. Long-established, well protected marine reserves generally develop gradients in densities of protected species from inside to outside, with higher densities outside but close to reserve boundaries than further away (e.g. Ashworth and Ormond 2005, Harmelin-Vivien *et al.* 2008). In Cuba, an experimental study that reduced densities of groupers outside a marine reserve showed that movements by tagged groupers inside the reserve increased, and that spillover of these fish evened out the densities of groupers between the reserve and fishing grounds, just as predicted by theory (Amargós *et al.* 2010).

Fishery models fitted to data on examples of spillover from eight different marine reserves from seven countries indicated that in most cases spillover played a key role in the sustainability of local fisheries (Halpern *et al.* 2010). Indeed, in most cases, the fishing intensities near reserves were too high for the fisheries to be sustainable without the presence of the reserves.

Box 2: Case study - Columbretes Islands Marine Reserve, Spain

COLUMBRETES ISLANDS MARINE RESERVE, SPAIN
Lobster fishery enhanced by spillover and increased egg production

Columbretes Island Marine Reserves lies 50 km off the Mediterranean coast of eastern Spain. It has protected 44km^2 of sea from all commercial fishing since 1992, expanded to 55km^2 in 2009. There is a traditional tangle net fishery for spiny lobsters, *Palinurus elephas*, around the islands which has been studied in detail since 1997, providing strong evidence that the marine reserve has enhanced the lobster fishery.



Spiny lobsters occur widely throughout the northeast Atlantic and Mediterranean and support valuable fisheries. They are heavily exploited wherever they are common and the Columbretes fishery is especially intensive. Since the marine reserve was established, the fishery has concentrated around the edges, mainly within 1 km of the boundary of the protected area, a phenomenon known as 'fishing the line' (black dots on the map show the location of fishing sets, and the black line shows the boundary of the marine reserve). Such a fishing pattern strongly suggests that spillover of target fishery species is taking place, and a long-term tagging study of protected lobsters confirmed spillover. Over 5000 lobsters were caught, tagged and released in the reserve between 1997 and 2006. Tag returns from lobsters caught by fishermen outside the reserve indicated that 3.7% of female lobsters and 6.7% of male lobsters left the reserve annually. These lobsters were 30% larger on average than lobsters in fishing grounds and emigrating lobsters made up 31-43% of the total catch by weight. Taking into account the 18% reduction in the area of lobster fishing grounds caused by the creation of the reserve, spillover increased annual landings by over 10%.

The marine reserve also contributes to the regional fishery through enhanced egg production by protected lobsters. Between 2000 and 2009 (following 9 to 19 years of protection from fishing) average egg production by protected female lobsters increased by 41%, and at the end of the study was more than double the egg production by unprotected animals. Since lobsters inside the reserve were 20 times more abundant than in the fishing grounds, egg production within the reserve was thirty times greater, area for area, than in fishing grounds. The marine reserve therefore supplied over 80% of regional lobster egg production from only 18% of the area of lobster habitat. This reproductive enhancement is likely to be extremely important to the sustainability of the local fishery, since catch data showed that 80 to nearly 100% of legal-size lobsters were caught within surrounding fishing grounds every year, leaving few mature individuals to reproduce.

Source: Goñi *et al.* (2010) and Díaz *et al.* (2011)

Marine reserves have also been demonstrated to benefit recreational fisheries through spillover. Merritt Island National Wildlife Refuge in Florida is probably one of the best protected, long-standing marine reserves in the world. It lies alongside the Kennedy Space Centre at Cape Canaveral in Florida and has been protected from fishing and human access since 1962. Study of the distribution of record-breaking catches of big fish made by sea anglers in Florida, shows a dense concentration of records around the edge of this reserve (Roberts *et al.* 2001, Bohnsack 2011). Record-sized fish began to be caught only after nearly a decade of protection, indicating recovery of fish stocks and spillover of large fish into the surrounding fishing grounds. There are similar clusters of record-breaking catches by sea anglers around other long-established Florida marine protected areas that demonstrate spillover and clear benefits of protection to recreational fisheries (Bohnsack 2011).

The limited distance over which animals moving out of reserves generally travel before being caught (typically < 1-2 km), suggests that fish stock recovery areas can offer a way of promoting the interests of small-scale fishermen, something that the European Commission and many others have called for under the reform of the Common Fisheries Policy. Most of these fishermen operate close to the coast in territorial waters. Offering small-scale artisanal fishermen preferential access to fishing grounds close to fish stock recovery areas has been highly successful in Spain, France and Italy (Higgins *et al.* 2008, Guidetti and Claudet 2009). Their access has been granted by the creation of buffer zones around core marine reserves in which only certain low-impact, artisanal fishing methods are permitted. This approach makes sense as a way to safeguard the interests of small-scale fishers, promote economic benefits to local communities and enhance supplies of sustainably caught fish. Similar preferential access could be granted to recreational fishers in buffer zones close to fish stock recovery areas. Likewise, such access could promote local economic benefits from the revenues generated by visitors[3].

[3] Many fish stock recovery areas will also foster increased economic opportunities from scuba diving tourism as a result of the increased abundance of marine life within their borders (Roncin *et al.* 2008, Wielgus *et al.* 2008).

6. EVIDENCE FOR EXPORT OF EGGS AND LARVAE

KEY FINDINGS

- Evidence from a wide variety of sources, including genetics, oceanography, geochemistry, rates of spread of invasive species, and direct measurements of larval export, indicate that reserves can supply eggs and/or larvae to surrounding fishing grounds, typically over distances of a few tens to more than 100 km.
- New research using genetic parentage tests has linked parent fish in reserves with their offspring settling into surrounding fishing grounds.
- The most sophisticated research to date showed that reserves on the Great Barrier Reef supplied offspring to fishing grounds in proportion to the fraction of the reproductive stock that was protected, upholding a key theoretical prediction about how reserves can be used to enhance fisheries.

Arguments from theoretical principles suggest that the largest contributions to fisheries made by marine reserves will come from the increased production and export of eggs and larvae by protected animals. The evidence reviewed in Section 4 indicates that reproductive output by protected stocks usually increases several times over, and often by multiples of ten-fold. As this section pointed out, egg production figures probably underestimate the effect of reserves on stock replenishment, because the higher densities of larger, older, more experienced animals they protect could generate potentially much greater increases in reproductive success. It is paradoxical then that export of offspring by marine reserves has to date been the hardest aspect of reserve performance to quantify. Biological common sense indicates that marine reserves must export offspring, but it has been very hard to provide direct evidence. However, in the last ten years there have been repeated and increasingly sophisticated demonstrations of export of eggs and larvae to fishing grounds. This section will discuss theoretical arguments for reserve contributions for fish stock replenishment, indirect evidence for export, and direct demonstrations of this effect.

6.1. Theoretical arguments

The increased egg production observed in protected species can be expected to augment replenishment of a population at least in proportion to the extra eggs that result from that protection. To illustrate, consider that fish stock recovery areas cover 10% of a management area, and that protected animals in the recovery areas produce 10-times more eggs than animals in fishing grounds (a very reasonable assumption based on empirical evidence). In which case, the proportion of total reproduction that recovery areas contribute would amount to 53% (Recovery areas = 10 x 0.1 = 1.0 versus fishing grounds = 1 x 0.90 = 0.9 ; the ratio of recovery area-derived egg production to that from fishing grounds is therefore 1:0.9, or 53% of total egg production).

This simple example demonstrates that because of their much higher reproductive output per unit of habitat, fish stock recovery areas could contribute a much larger fraction of total reproduction by a population than might be expected given a relatively small area that is protected. However, eggs from recovery areas would contribute nothing to the replenishment of fishing grounds if all of them remained within the recovery areas. Because most animals we exploit have a pelagic egg and/or larval dispersal phase in which they drift or swim with the plankton in open water, the chances of all those offspring remaining in fish stock recovery areas is remote. Evidence discussed below in Section 6.2 suggests that egg/larval dispersal distances are typically much larger than the maximum dimensions of marine reserves, so it is likely that much of the production from protected stocks does end up in fishing grounds. To return to the above example, if there was complete mixing of offspring between recovery areas and fishing grounds, protected populations would contribute 53% of population replenishment in fishing grounds.

A theoretical model (Pelc *et al.* 2010) which assumed broad dispersal of eggs and larvae, with a very modest 3-fold lift in reproductive output by protected populations, suggested that export of offspring from marine reserves could compensate for loss of catches due to closures of former fishing grounds, even if up to levels of half of the previous fishing grounds converted to reserves.

6.2. Indirect evidence for export of offspring from reserves

Indirect evidence that marine reserves will export offspring of protected animals can be obtained from measures of typical egg/larval dispersal distances during the open water phase. Such evidence comes in many forms including amount of time spent in the plankton, oceanographic modelling of current flows, patterns of genetic similarity between populations, tracing the geographic origins of fish from geochemical signatures laid down in body structures produced in early life, and rates of spread of invasive species. A recent review (Roberts *et al.* 2010) examined these various sources of evidence in order to make recommendations on separation distances for new Marine Conservation Zones in the UK. Table 1 summarises evidence from this report.

All of these various lines of evidence are in accord in suggesting that many species disperse distances that range from a few tens of kilometres to more than 100 km. Some taxonomic groups disperse less far than others. For example, molluscs spend only around half the time dispersing in the plankton as fish do (Bradbury *et al.* 2008), while some seaweeds and corals spend little or no time in the plankton and disperse distances of metres to a kilometre or two (Shanks *et al.* 2003). From a fisheries perspective, most of the fish and shellfish that we exploit fall into the categories of species that disperse significant distances (Kinlan and Hastings 2005) – tens to a hundred or more kilometres – that would take many of them beyond the boundaries of fish stock recovery areas and into surrounding fishing grounds.

One trend seen in the data for dispersal distances of early life stages of marine species is that animals that live at higher latitudes tend to spend longer dispersing than animals that live at lower latitudes (Bradbury *et al.* 2008). The implications of this difference for the performance of marine reserves as a fisheries enhancement tool have yet to be explored. However, it could mean that reserve augmentation of fish replenishment could extend over larger areas at high latitudes than at lower latitudes. However, high latitude reserves are also likely to augment stock replenishment locally, since an increase in the dispersal period does not imply that all eggs/larvae travel long distances from reserves. Evidence reviewed in the next Section (3.4.3) indicates substantial self-replenishment of marine reserves, even in species which disperse for weeks to more than a month in open water.

Table 1: Evidence for open water dispersal distances of marine species during the egg/larval stage

TYPE OF EVIDENCE	FINDINGS
Dispersal kernel mapping around the UK (Roberts *et al.* 2010)	Short-duration planktonic dispersers could typically travel 5 to 10 km on tidal currents through passive dispersal; long-duration planktonic dispersers could typically travel 15-25 km on tidal currents. Adding wind-driven residual current flows probably at least doubles the distances travelled.
Particle tracking of Irish Sea fish (Van der Molen *et al.* 2007)	Most eggs and larvae generally dispersed less than 160 km, but modal distances of dispersal (i.e. the distances that were reached by most individuals) were usually between 40 and 80 km.
Location of spawning and nursery areas of commercially important fish species around the UK	Distinct spawning and nursery areas are typically a few tens to a few hundreds of kilometres apart. Many overlap suggesting more limited dispersal.
Particle tracking model for Caribbean fish (Cowen *et al.* 2006)	Ecologically relevant dispersal distances typically lie between 10 and 100 km.
Genetics (Palumbi 2003; Kinlan and Gaines 2003; Kinlan *et al.* 2005)	Most species dispersed less than 100 km per generation, although some appear able to disperse several hundreds of kilometres. Large numbers of species sampled had estimated dispersal distances in the range 30 – 80 km.
Invasive species (Shanks *et al.*, 2003; Kinlan and Hastings, 2005)	Invasive species generally spread a few tens of kilometres to less than 200 km per year (but average dispersal is usually at the lower end of this range).
Measured export of larvae from MPAs (Cudney Bueno *et al.* 2009; Pelc *et al.* 2009; Planes *et al.* 2009)	Export of larvae of fish and molluscs detected to distances of a few to a few tens of kilometres.

Source: Roberts *et al.* (2010)

6.3. Direct demonstrations of export of offspring from reserves

Table 2 summarises direct evidence that export of eggs and larvae from marine reserves has contributed to population replenishment of stocks in fishing grounds (Pelc *et al.* 2010). Many of these studies document export of the offspring of commercially important species of mollusc and are based on detection of gradients in the abundance of juveniles newly-settled from the plankton in areas downstream of marine reserves. Such evidence is strongly suggestive that these animals derive from reproduction by protected populations in marine reserves. In some cases these effects occurred rapidly, with one reserve in Mexico increasing fishery replenishment of rock scallops, *Spondylus calcifer*, and black murex, *Hexaplex nigritus*, within two years of establishment (Cudney-Bueno *et al.* 2009).

Surveys of fish eggs and larvae drifting in the waters around Spain's Medes Islands Marine Reserve in the northwestern Mediterranean revealed increasing abundance approaching the reserve boundary for three commercially important species, including the dusky grouper, bream, *Pagellus erythrinus*, and black scorpionfish, *Scorpaena porcus* (López-Sanz *et al.* 2011). This suggests that higher reproductive output by protected fish is being transferred to surrounding fishing grounds by oceanographic processes.

Recently there have been several powerful demonstrations for export of eggs/larvae of fish from marine reserves based on genetic parentage tests. These tests link offspring with their likely parents based on their genotypes in a method similar to that used by police forces to identify criminals from the DNA of relatives held on their databases. In Hawaii, a network of nine marine reserves was created in 1999 along the west coast of the Big Island of Hawaii to support the valuable local aquarium fishery (Christie *et al.* 2010). Together they protect 35% of reef habitat on this coast. These reserves had already produced evidence for spillover of target fishery animals from reserves to fishing grounds (Williams *et al.* 2009). Christie *et al.* (2010) linked four parent-offspring pairs of the surgeonfish *Zebrasoma flavescens* separated by distances of 15–184 km (Table 2). In two of these cases, offspring had been exported from reserves to fishing grounds, while in the other two they had settled into other reserves. This important study broke new ground by showing ecologically meaningful levels of export of young fish from reserves over distances of tens of kilometres. It also showed that reserves established in networks can replenish each other, an important assumption that underpins much of the theory of marine reserve design (Roberts *et al.* 2003).

Another study in Papua New Guinea using similar methods produced essentially the same results for a species of anemonefish *Amphiprion percula* (Planes et al 2009). Although this species is not exploited, it serves as a model for other species which may be. About 40% of larvae settling into a marine reserve from the plankton were derived from production within the reserve, while 5 to 10% of replenishment of populations in proposed protected areas 15–35 km away came from larvae exported from this reserve. The study did not quantify export to fishing grounds as they were not sampled, but it is obvious that the reserve must also have exported larvae to intervening unprotected areas.

The most complete quantification of population replenishment of fishery species by offspring from protected stocks comes from reserve zones in a 1000 km^2 region of the southern Great Barrier Reef Marine Park in Australia (Harrison *et al.* 2012). Like the studies mentioned above, this one used DNA-parentage analysis to link parents of two commercially important reef fishes in reserves with their offspring sampled from both protected reefs and fishing grounds. 55% of sampled juveniles of striped snapper, *Lutjanus carponotatus*, and 83% of coral trout, *Plectropomus maculatus*, could be assigned to known parents. The authors estimated that reserves, which covered 28% of reef habitat in the region, produced half of the replenishment of these species to the whole region (reserves plus fishing grounds). This accorded with the fact that reserves protected roughly double the weight of adult fish per unit area compared to fishing grounds.

Harrison *et al.*'s (2012) findings are important because they underpin a key assumption of theoretical research: that animals protected by reserves replenish fishing grounds in proportion to the fraction of the total fish stocks that they contain (Roberts 2012a). In addition, the study also demonstrated self-replenishment by populations in reserves, exchange of offspring among different reserves, and dispersal of offspring up to 30 km from parents, the maximum distance sampled. It therefore strongly supports the view that marine reserves will replenish fishing grounds over extensive areas.

Table 2: Summary of empirical evidence for larval export from reserves

REGION	SPECIES	OPEN WATER DURATION (DAYS)	RESERVE SIZE (km^2)	CHANGE INSIDE RESERVE	TYPE OF EVIDENCE	SOURCE
Goukamma, South Africa	Brown mussel *Perna perna*	10-20	40	3-fold increase in production	Decline in recruitment with distance	Pelc *et al.* (2009)
Dwesa, South Africa	Brown mussel *Perna perna*	10–20	39	22-fold increase in biomass	Decline in recruitment with distance	Pelc *et al.* (2009)
Dwesa, South Africa	South African eye limpet *Cymbula oculus*	6	39	80-fold increase in production	No evidence of decline with distance	Branch and Odendaal (2003)
Tenerife, Spain	China limpet *Patella aspera*	6	Unknown	Unknown	Decline in recruitment with distance	Hockey and Branch (1994)
Georges Bank, United States	Deep sea scallop *Placopecten magellanicus*	32–56	17,000	14-fold increase in density	5-fold increase in adult abundance downcurrent of reserve	Murawski *et al.* (2000) Fogarty and Botsford (2007)
Fiji	Clam *Anadara* sp.	20–30	0.24	19-fold increase in density	8-fold increase downcurrent of reserve	Tawake *et al.* (2001), Tawake (2002)
Gulf of California, Mexico	Rock scallop *Spondylus calcifer*	<28	18 (all reserves in network)	Unknown for adults. 40% increase in juvenile density	Increase downcurrent of reserve	Cudney-Bueno *et al.* (2009)
Gulf of California, Mexico	Black murex snail *Hexaplex nigritus*	<28	18 (all reserves in network)	Unknown	3-fold increase downcurrent of reserve	Cudney-Bueno *et al.* (2009)
Exuma Cays, Bahamas	Queen conch *Strombus gigas*	25–30	456	30-fold increase in density	2- to 10-fold more early-stage veligers near reserve	Stoner and Ray (1996) Stoner *et al.* (1998)
Isle of Man, United Kingdom	Great scallop *Pecten maximus*	16–33	2	12-fold increase in reproductive output	Higher spat settlement near reserve than far; 5- to 10-fold increase in abundance of 2-yr olds at sites near but not far from reserves	Beukers-Stewart *et al.* (2004, 2005)

REGION	SPECIES	OPEN WATER DURATION (DAYS)	RESERVE SIZE (km^2)	CHANGE INSIDE RESERVE	TYPE OF EVIDENCE	SOURCE
Hawaii, USA	Yellow tang surgeonfish *Zebrasoma flavescens*	50	35% of 150km long coast (all 9 reserves in network)	After 8 years of protection reserves had five times the density of prime target-size fish (5–10 cm), and 48% greater density of adults than fishing grounds	Direct linking of protected parents to their offspring with DNA parentage test	Williams *et al.* (2009), Christie *et al.* (2010)
Great Barrier Reef, Australia	Coral trout *Plectropomus maculatus*	25	6 reserves within $1000km^2$ area protect 28% of reef habitat	83% of offspring assigned to known parents were exported to fishing grounds or other reserves	Direct linking of protected parents to their offspring with DNA parentage test	Harrison *et al.* (2012)
Great Barrier Reef, Australia	Stripey snapper *Lutjanus carponotatus*	33–38	6 reserves within $1000km^2$ area protect 28% of reef habitat	55% of offspring assigned to known parents were exported to fishing grounds or other reserves	Direct linking of protected parents to their offspring with DNA parentage test	Harrison *et al.* (2012)
Medes Islands Marine Reserve, Spain	Dusky grouper *Epinephelus marginatus*, Common Pandora bream *Pagellus erythrinus* and Black scorpionfish *Scorpaena porcus*	22-30, 40-49 and 29 respectively for *Epinephelus marginatus*, *Pagellus erythrinus* and *Scorpaena porcus*	0.9	Gradient of reduced egg and larval abundance with increasing distance from the marine reserve.	Eggs and larvae collected at varying distances from the island.	López-Sanz *et al.* (2011) Macpherson and Raventos (2006)

Source: Pelc *et al.* (2010) and others listed in table

7. EVIDENCE FOR PROTECTION OF HABITAT

KEY FINDINGS

- By protecting areas from the damage caused by fishing gears, marine reserves promote the recovery of diverse, structurally complex, biogenic habitats.
- Over periods of years, habitats in reserves may also change (mainly increase in diversity and complexity) through reorganisation of predator-prey relationships in food webs.
- Improvements in protected habitats will in turn promote population build-up of protected animals.

Probably one of the most obvious and direct benefits of marine reserves stems from the protection of habitats from the damage caused by mobile fishing gears. Such gears include principally otter trawls, beam trawls and various kinds of dredges designed mainly to catch shellfish. These gears are heavy, often weighing 1 to more than 20 tonnes, and while their weight underwater is reduced by water displacement, most still exert tonnes of pressure on seabed life as they are dragged along (Morgan and Chuenpagdee 2003). Their destructive capacity may be enhanced by structures that are designed to deliberately penetrate sediments, or enable use in regions of uneven, rocky or corraline bottoms. For example, scallop dredges often have fixed or spring-loaded downward pointing steel teeth to dig into the sediment; beam trawls have a heavy network of 'tickler' chains toward the front of the net bag to flush fish up off the bottom; otter trawls are often equipped with rollers along the footrope at the front of the net bag, enabling the net to travel over rugged bottoms with less risk of being snagged.

Mobile fishing gears produce a number of effects at the seabed. The most obvious are that they can crush, detach or remove habitat-forming species (Watling and Norse 1998, NRC 2002). Many formerly diverse, three-dimensionally complex and extensive habitats like oyster beds, horse mussel beds, maerl, sabellid reefs and cold water corals have been wiped out or severely degraded over vast areas of European seas as a result of the spread of bottom trawling and dredging over a timescale of centuries (Roberts 2007, Airoldi and Beck 2007, Thurstan 2011). Their destruction often happened so long ago (100 years and more) that they have been long-forgotten. However, the loss of these habitats has changed the structure and functioning of marine ecosystems in profound ways. In retrospect, it seems highly likely that their loss has contributed to the steep declines in some of the fishery target species that were once important in catches, such as common skate, *Dipturus intermedia and D. flossada*, halibut, *Hippoglossus hippoglussus* and cod, *Gadus morhua* (Thurstan *et al.* 2010). Reports by 19th century fishermen consistently noted the positive association between such species and complex, biogenic habitats (Thurstan 2011). Recent studies also indicate that these complex habitats are important to the juveniles of many exploited species as they offer refuges from predators as well as enhanced feeding opportunities (Howarth *et al.* 2011 and references therein).

Even seemingly benign fishing methods that use fixed gears, like bottom-set gillnets, traps or longlines, can cause some damage to seabed life in the form of localised crushing, or damage as gear is hauled at oblique angles to the seabed in the presence of strong currents or where fishing boats are drifting. By preventing damage by fishing gears, marine reserves can begin the process of recovery, and potentially the long-term transformation of marine habitats. It may be that habitats will not return to their pre-exploitation state, for example because there has been region-wide extirpation of some of their component species, such as oysters, *Ostrea edulis*, in Europe. However, reserves are likely to develop ecological communities that differ from surrounding unprotected areas, and are more ecologically complex (Babcock *et al.* 2010). For example, after protection from trawling and dredging, a protected area adjacent to the Isle of Man, UK, developed more varied communities of bottom-living invertebrates, particularly upright species that contribute to structurally complex habitat formation (Bradshaw *et al.* 2001). Personal observations by one of the authors of this report (CMR) within this marine protected area in 2012, after 20 years of protection, showed that it supported highly diverse and complex habitat made up of many invertebrate species living on or attached to the seabed. By comparison, in nearby areas open to dredging and trawling there was a virtual absense of such species and pebbles and rocks supported so few invertebrates they appeared almost polished by regular tumbling in dredges.

There is a second way in which marine reserves can benefit habitats. 'Cascading ecological effects' are those where changes happen in sequence: early changes trigger later changes. Marine reserves in Italy provide strong evidence for such an effect (Guidetti 2006). Much of the area of rocky, subtidal reef habitat in the Mediterranean consists of rock covered by a thin film of algae just millimetres thick (Sala *et al.* 2012). Where such a habitat occurs, sea urchins which graze on this algae are abundant. From a distance the rocks appear bare and largely devoid of life, which is why they are known as 'urchin barrens'. However, inside well-enforced marine reserves in Italy, the habitat looks different. In the Torre Guaceto marine reserve, for example, half of the rock area is covered in thickets of dense seaweed (Guidetti 2006). The difference is due to recovery of fish, mainly seabreams, which prey on urchins. Inside the reserve there are ten times more predatory breams than outside and ten times fewer sea urchins. Recovery of predators following protection reduced the abundance of urchin grazers and allowed the re-formation of dense seaweed beds, which in turn support a much wider variety of marine life than urchin barrens do. Europe has vast areas of urchin barrens from the Mediterranean to its northern seas. When well-protected marine reserves are established in these areas, similar effects can be expected.

Recovery of complex, biologically diverse habitats in reserves must certainly be responsible for the ability of reserves to continue to build up populations of commercially important species over many decades.

8. ARE MARINE RESERVES EFFECTIVE IN TEMPERATE WATERS?

KEY FINDINGS

- Marine reserves work just as well in temperate waters as they do in tropical seas.
- Even apparently very mobile species have benefited strongly from protection.

Marine reserves are often dismissed as a management tool for use in temperate water fisheries for two reasons: (1) a lack of research on their performance in temperate habitats, and (2) that temperate species are too mobile to benefit from protection in anything other than impractically large marine reserves.

The first reason no longer applies. In the last 15 years there has been a surge of research effort into the effects of temperate water marine reserves, especially in Europe, as studies cited in this report show. There is now abundant, high quality evidence that such reserves produce very similar effects to those in warmer waters. In their review of reserve effects on protected species, Lester *et al.* (2009) found no significant difference in performance of temperate versus tropical reserves. Protected areas in both warm and cool seas showed a rapid rebound in abundance, biomass, diversity and body size of protected animals.

While critics still maintain that temperate reserve research has been concentrated on hard-bottom habitats in warm-temperate regions (Caveen *et al.* 2012), research on colder water reserves in soft-bottom habitats has also produced strong evidence of reserve benefits (e.g. Beukers-Stewart *et al.* 2005, Howarth *et al.* 2011). Setting this evidence aside, the fact is that much of the nearshore habitat in European territorial waters where fish stock recovery areas would be established is of exactly the kind in which strong reserve benefits to protected stocks and fisheries have been demonstrated.

The second criticism of reserves as a management tool in temperate seas, i.e. the perceived greater mobility of fish species compared to warmer water regions, is seen as a problem because of too much movement of animals in and out of marine reserves. To gain protection from a marine reserve, animals must spend time within it. Species whose movements are entirely enclosed by a reserve will be protected full time, while those that move in and out of it will only gain partial protection. Other things being equal, the less species move around, the greater the protection they will get from a marine reserve. Movements that take animals outside reserves form the basis for spillover to fishing grounds and are therefore one of the key reasons that reserves can deliver benefits to fisheries (Grüss *et al.* 2011).

The argument levelled against cool-temperate marine reserves is that animals will spend too much time outside reserves for their stocks to benefit very much from protection, so such reserves will not work very well. Is there any evidence to support this contention? Roberts *et al.* (2010) reviewed movements of fish and other animals typical of northern European Seas like the North Sea, in order to make recommendations as to how large marine reserves should be to provide benefits to protected species there. The report examined movement distances of mature adults of 72 different species, including a wide range of taxa of commercial importance such as fish, crustaceans and molluscs. Thirty-one species (43% of the sample) did not move at all after settlement from the plankton, while a further 27 species (38% of the sample) typically moved less than 10 km after reaching maturity (Table 3). On this basis, the authors recommended that for an English network the median size of reserves in territorial waters should be no less than 5 km in their minimum dimension, and that the average size should lie between 10 and 20 km in their minimum dimension. Such a network would offer good protection to a wide variety of the species common in northern European seas. More mobile species, the report concluded, which included animals important in fisheries such as plaice, whiting and hake, would gain less protection from marine reserves of this size. However, their mobility should not be taken to mean they would receive no benefit from reserves as there are many ways in which mobile and migratory species can benefit from protection. These are discussed in the next section.

Before moving on, however, it is apparent from recent research using satellite or archival electronic tags to track animal movements, that many species viewed as highly mobile move less far than believed or spend significant amounts of time in one place. Perhaps the quintessential case is that of cod. For much of the 20th century, this fish was thought of as nomadic, undertaking long distance migrations between feeding and breeding grounds throughout the year. However, tagging has revealed much more finely structured behaviour, and shows the existence of more site-attached inshore cod populations, as well as the familiar long-distance migratory fish (Wright *et al.* 2006).

Table 3: Typical movements of a selection of different species found in northern European waters

DISTANCE MOVED					
0 km	0-1 km	1-10 km	10-100 km	100-1000 km	1000-10000 km
Bryozoans Seafans Corals Sponges Sea squirts Oysters Mussels Seaweeds Barnacles	Starfish Sea urchins Brittle stars Scallops Dog whelks Polychaete worms *Nephrops*	Lobster Brown shrimp Shore crab Sandeel	Cuttlefish Edible crab Spider crab Cod Sole Lemon sole Anglerfish Sprat Thornback ray Sardine	Plaice Herring Whiting Hake Sea bass Spurdog Scad	Mackerel Basking shark Blue shark

Source: Roberts *et al.* (2010)

There is a fascinating example of how protection can benefit cod from the Öresund, the narrow strait that separates Denmark and Sweden and connects the Kattegat to the Baltic Sea (Svedäng 2010). This strait varies from 5 to 45 km wide and is the primary route for ships travelling between the North Sea and Baltic. Because of the danger to shipping, mobile fishing gears like bottom trawls have been banned from the Öresund since the 1930s. However, hooks, nets and traps have been used throughout this time outside the shipping lanes. Although not fully protected from fishing and despite the small size of this *de facto* protected area, cod have clearly benefitted greatly from the exclusion of bottom trawling. Research catches showed that cod were 15–40 times more abundant in the Öresund than in the Kattegat. Trawl catches in the Kattegat declined from 15–20 thousand tonnes in the 1970s to 450 tonnes in 2008, whereas catches in the Öresund (which covers ten times less area) remained stable at around 2000 tonnes. Cod in the Öresund reached much larger sizes than those in the Kattegat, with some rivalling the size of the huge fish seen in century-old photographs. Other kinds of fish are also larger there than in the Kattegat, including lemon sole, haddock, plaice and whiting. Despite the fact that it covers only 2000 km^2 (equivalent to a square 44 km on each side), and the coasts that border the strait are densely populated, these species and fisheries for them have benefitted. All are species for which there has previously been widespread skepticism as to the value of reserves as a fisheries management tool.

A wide-ranging analysis of the effects of marine reserve protection in 12 European marine reserves provided strong support for the view that even apparently very mobile species benefited from protection (Claudet *et al.* 2010). The authors stated, ”Our most compelling finding is that protection benefited very vagile [= mobile]...commercial exploited species, whatever their home range size and yearly displacement, and irrespective of the size of reserves.”

9. CAN HIGHLY MOBILE OR MIGRATORY SPECIES BENEFIT FROM MARINE RESERVES?

KEY FINDING

- Protected areas have long been used to protect highly mobile and migratory animals from fishing at vulnerable times and places, such as in nursery areas or spawning aggregations. Fish stock recovery areas could very usefully take on this role.

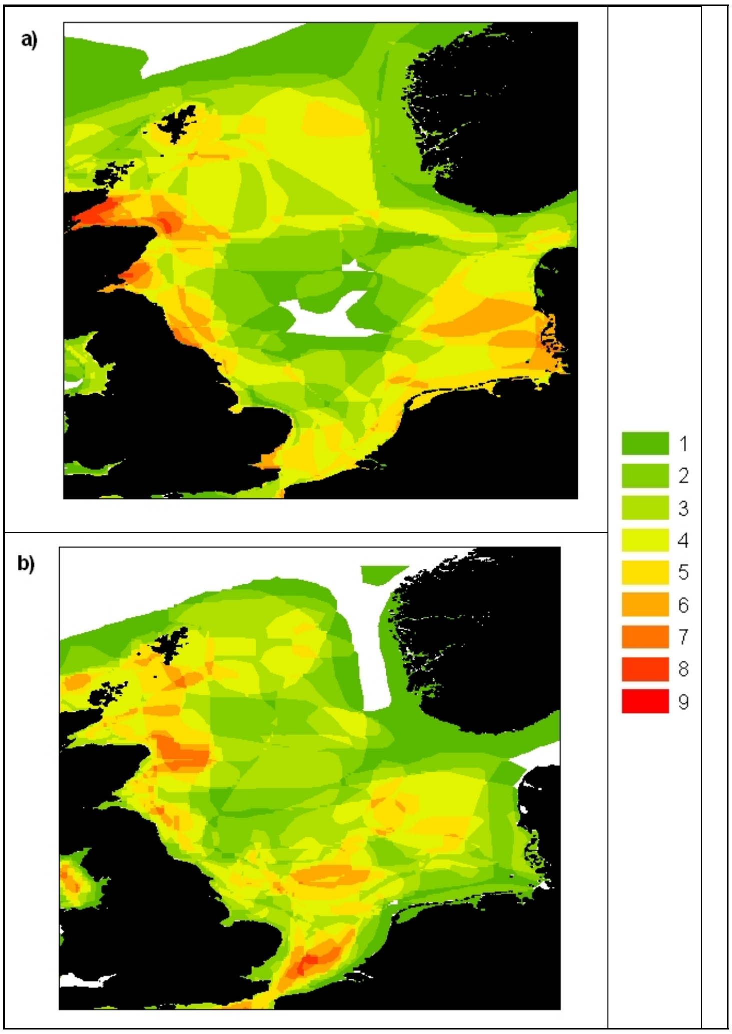
In order to answer this question, it is useful to distinguish three kinds of mobility: home range, ontogenetic movements and migrations. Home range movements involve the typical movements that a species makes around the place in which it lives in the course of day to day life. Ontogenetic movements refer to the shifts in habitat and location that an animal makes over the course of its life. Migrations are repeated movements made from place to place. They can be annual movements or may be more frequent, such as in the case of movements between feeding grounds and spawning areas.

Since the earliest days of fisheries management, people have protected exploited animals at certain places and times in their life cycle. The most common form of protection is that given to nursery grounds, where young animals congregate early in life. Fishermen have long recognised that it makes no sense to remove animals from the sea before they have grown to a marketable size. Protecting animals from premature capture is a proven method of increasing fishery yield. This kind of protection takes advantage of ontogenetic movements. Because they are smaller, young fish usually eat different diets from adults and use different habitats where there are fewer predators, or more physical protection from them. To gain a fishery benefit, it is only necessary to protect animals when they are small. Where nursery areas are geographically separate from places occupied by exploited adults, they form obvious targets for spatial protection. Such regions are usually located inshore (Figure 2), and a network of fish stock recovery areas in territorial seas could be designed to include many such places.

Several fishery closures are already in place in Europe to protect young fish, including the Plaice Box in the southeastern North Sea, the Mackerel Box off the southwestern UK and the Norway Pout box off the north of Scotland. Smaller protected areas that offer a higher degree of protection, as fish stock recovery areas would, can be expected to work well for a variety of other bottom-living fish species.

Marine reserves can also offer substantial benefits to migratory species by offering animals protection at times of increased vulnerability to fishing. Many species migrate either annually or more frequently to particular places to spawn. At peak spawning times, aggregation sites can become filled with high densities of adult fish in prime condition and are therefore highly attractive to fishermen. Concentrated fishing on spawning aggregation sites can cause high levels of mortality to the reproductively mature fraction of a population, and has been the cause of many instances of overexploitation. Computer simulation models of migratory fish stocks show that protection of places where stocks are concentrated and therefore catch rates are high can provide substantial benefits to fishery yield and sustainability in the long-term (e.g. Apostolaki *et al.* 2002, Roberts and Sargant 2002). Again, it is not necessary to protect animals all of the time for them to benefit from such reserves. In the US Virgin Islands, protection of spawning aggregation sites for the red hind grouper, *Epinephelus guttatus*, produced rapid increases in average size of fish and the proportion of males (which are larger than females), despite covering only 1.5% of the area of fishing grounds (Beets and Friedlander 1999). In the Solomon Islands, very small marine reserves placed over spawning aggregation sites of groupers produced up to ten-fold increases in the abundance of adult fish in less than ten years (Hamilton *et al.* 2011).

Figure 2: Composite maps of (a) nursery areas for blue whiting, cod, haddock, herring, lemon sole, mackerel, *Nephrops*, Norway pout, plaice, saithe, sandeel, sole, sprat and whiting; (b) spawning areas for cod, haddock, herring, lemon sole, mackerel, *Nephrops*, Norway pout, plaice, saithe, sandeel, sole, sprat and whiting. Numbers 1-9 and the corresponding colours refer to the number of species using an area as a spawning or nursery ground.



Source: Roberts and Mason (2008)

Although stocks of many migratory species would likely be increased in size by targeted protection, in Section 2 we noted that migratory species need not actually increase in abundance for there still to be a benefit from protection. Species at spawning aggregations that are intensively fished may be subject to high levels of disturbance which could interfere with reproductive behaviour and success. One remarkable example involved northern cod gathered to spawn off the coast of Newfoundland (Morgan *et al.* 1997). Trawlers passed through aggregations 600 to 1880 times a year before the fishery was closed. After each passage of a trawler, it took shoals up to an hour to regroup. In such circumstances, protection from disturbance is likely to increase reproductive success, not least because it would prevent animals from being caught before they have spawned.

Seasonal protection has long been given to herring, *Clupea harengus*, in Europe, which lay their eggs on the seabed. Concerns were raised as early as 1837 that bottom trawlers were damaging the seabed habitat in places used by herring to deposit their spawn and were destroying newly-laid eggs (Reports from the Commissioners, 1837). As a result of such concerns, protected areas were established in the late 19^{th} century and many have remained protected ever since (Thurstan and Roberts 2010).

Mobile and migratory species can also benefit in other ways from marine reserves. Mobile predators will likely find enriched feeding opportunities within well-established marine reserves as a result of the build-up of populations of protected animals. The much higher biomasses of fish and benthic marine life found in marine reserves could therefore boost body growth and reproductive outputs of transient species. The existence of enhanced prey availability might also induce mobile species to spend more time within marine reserves. Research into this possible effect of reserves has been very limited to date. However, in a recent study, mobile reef sharks in Belize, for example, were more abundant in no fishing zones of the Glovers Reef Marine Reserve than in fished sites, and exhibited higher site fidelity to protected reefs (Bond *et al.* 2012). Claudet *et al.* (2010) attributed their finding that stocks of even very mobile species built up in reserves to enhanced habitat quality inside reserves.

10. TIMESCALES OF MARINE RESERVE BENEFITS

KEY FINDINGS

- Evidence indicates that marine reserves produce rapid and long-lasting increases in populations of previously exploited species. Increases become detectable for many species within a year or two of protection.
- Some species respond quickly, others more slowly. Long-term studies of reserves show that benefits to long-lived and slow growing species, and to habitats, can continue to increase over periods of decades.
- Marine reserves will typically begin to produce fishery benefits within 5 to 10 years of protection and benefits will continue to increase for decades thereafter. It could take half a century or more to see the full extent of benefits from protection.
- Because of the extended timescales of stock and habitat recovery, and the speed with which benefits can be dissipated on resumption of fishing, the establishment of fish stock recovery areas must be seen effectively as a permanent commitment if they are to contribute meaningfully to fish stock recovery and habitat conservation.
- The only exception to this would be where particular reserves were demonstrably failing to achieve much in the way of stock or habitat recovery. Such an outcome would need to be determined on a case by case basis through fishery independent survey methods, but the five year suggested timescale for such a review is too short. 10 years would be more appropriate based on available evidence of the timescales of reserve benefit.

Marine reserves begin to have effects on fish stocks, wildlife and habitats as soon as protection is instigated. However, it may take decades for some effects to become apparent.

The first species to respond to protection tend to be those that are common at the time of reserve establishment. In intensively exploited areas they are usually small to medium-sized species that have been able to persist in the face of the high levels of fishing mortality that prevailed before protection. Examples in Europe include species like the white seabream, *Diplodus sargus* (Guidetti 2006), black scorpionfish, *Scorpaena porcus* (López-Sanz 2011) in the Mediterranean, and king scallop, *Pecten maximus* (Beukers-Stewart *et al.* 2005), and European lobster *Homarus gammarus* (Hoskin *et al.* 2011) in northern European waters. Although their presence in the absence of protection shows they can cope better with fishing mortality than more vulnerable species, the fact that they often increase rapidly in abundance and biomass, often doubling or tripling within 3 to 5 years of protection (Claudet *et al.* 2010), shows that they too can benefit from reserves. It is these species that provide the first tangible benefits to fishers who have given up some of their grounds. A growing number of studies, some of them mentioned above, have demonstrated improvements to nearby fisheries within 5 to 10 years of the establishment of marine reserves (e.g. Roberts *et al.* 2001, Pérez-Ruzafa *et al.* 2008 and references therein). Fishery benefits have arisen from rapid increases in biomass, combined with increased abundance of larger, more fecund animals, that have translated into fisheries benefits through spillover and export of offspring.

As noted above, the first species to respond are those small to medium-sized species already common at the time of protection. It follows that effects will take longer to emerge for species that are rare, slow to colonise and grow, or reach reproductive maturity later in life. In the Philippines, populations of large predatory fish like snappers and groupers have continued to increase rapidly within marine reserves protected for up to 26 years (Russ and Alcala 2010). Regression models fitted to the trajectories of population increase suggest that full recovery could take 40 years. Similarly, protected areas off the African coast have shown extended recovery periods for fish like surgeonfish with increases continuing for decades (McClanahan *et al.* 2007).

Extended recovery periods for large and long-lived fish species were apparent from the studies of the effects of protection on the number of world-record sized fish caught by sea anglers around marine reserves in Florida mentioned in Section 5 in relation to spillover of fish from reserves. Angling records show that Merritt Island National Wildlife Refuge, which was fully protected in 1962, began to deliver large fish into surrounding fishing grounds after 9 years of protection for the shortest-lived of three species (spotted seatrout, *Cynoscion nebulosus*, which lives up to 15 years), after 27 years of protection for red drum (*Sciaenops ocellatus*, which reaches 35 years old) and after 31 years of protection for black drum (*Pogonias cromis*, which reaches 70 years old), and is the largest of the three. World records could only be broken by anglers once fish had been protected long-enough by the refuge for some of them to exceed previous record sizes. Evidently, the restoration of extended population age-structures is a prolonged process.

Some species are very rare at the time of marine reserve establishment, having seen their abundance decline to extremely low levels within fishing grounds, often over a period of centuries. These species cannot be expected to recover rapidly. For example, large predatory groupers failed to respond in two Caribbean reserves even after 13 years of protection for the simple reason that there were virtually none left to begin with (Roberts 2000). Here in Europe, the common skate (*Dipturus intermedia* and the closely related species *Dipturus flossada*, Griffiths *et al.* 2010) were abundant throughout northern waters in the 19th century and were a mainstay of commercial catches in ports from France to Norway. The spread of bottom trawling in the first half of the 19th century led to swift declines in catches as abundance of these species fell (Report of the Commissioners 1866). Today, common skate have been eliminated from much of their former range and now persist only in areas of rocky habitat that are too rough to be trawled. In the majority of newly created marine reserves, recovery will depend on recolonisation from these refuge populations, which could take many years in the absence of human intervention.

Experience from several regions of the world show that the habitat transformative effects of marine reserves also take decades to emerge (Babcock *et al.* 2010). There are two simple reasons for this. The first is that some of the species involved in creating structural habitats are slow growing and therefore take time to recover, such as corals. The second reason is the phenomenon of ‘cascading ecological effects’ described in Section 7. A well-known example from the Leigh Marine Reserve in North Island, New Zealand, which was established in 1975, sheds light on the extended timescales over which such effects develop. The reserve includes the kind of temperate rocky reef habitat that is common around the coasts of Europe. At the time of reserve creation much of the habitat was composed of ‘urchin barrens’ dominated by abundant sea urchins, like those prevalent in the Mediterranean and northern European seas. Because the urchins eat seaweed, their high abundance prevented the formation of anything other than a thin film of algae over the rocks.

The first species to respond to protection in the Leigh Marine Reserve by increasing in abundance and size were snappers, *Pagrus auratus*, and rock lobsters, *Jasus edwardsii*, both of them predators of sea urchins (Babcock *et al.* 2010). After 5-7 years predator numbers had rebounded sufficiently that they began to cause a decline in urchin numbers. After a further 10 years, urchins were reduced by more than three-quarters, taking them below the level necessary to control kelp. Three years later, in 1993, kelp forest cover in the reserve had risen to 60%. A recent survey of habitats within the reserve, 30-years after it was established, show the almost complete replacement of urchin barrens with kelp forest and dense seaweed turfs. Similar examples of long-term habitat recovery have been documented in Australia and California (Babcock *et al.* 2010). Although Guidetti (2006) did not determine timescales of recovery of seaweed dominated habitats in the Italian protected areas he studied, it is likely that they would have followed a similar trajectory to those in the Leigh Marine Reserve.

How long should fish stock recovery areas be protected for? This answer to question must be informed by several considerations: the timescales of marine reserve benefits discussed above, the rate with which these benefits would be dissipated on reopening a reserve to fishing, and the performance of specific reserves. Clearly, the extended timescales of population and habitat recovery in marine reserves suggest that protection will be a long-term commitment if marine life and the people who depend on it for their livelihoods are to extract the maximum benefits from reserves. When this consideration is allied to the timescales over which benefits would be dissipated, the argument for long-term protection becomes even more compelling. Research on experimental 'fishing down' of previously protected populations indicates that they can be depleted extremely quickly by the intensive, targetted fishing that is certain to accompany the reopening of a marine reserve (Roberts and Polunin 1991, and references therein). Populations of large predatory fish and some other types of animal can often be reduced by 50 to 70% or more within weeks of reopening, underlining their vulnerability to fishing. Effects of fishing resumption on habitats could be equally dramatic. Many marine reserves are small, perhaps only a few to a few tens of square kilometres in area. Considering that a single boat towing a dredge or bottom trawl can sweep an area of one to several square kilometres in a day, and the majority of damage to the seabed is done on the first pass of the gear (Watling and Norse 1998), the effects of decades of habitat protection could be undone within weeks, or even days, of reopening.

Article 7a of Amendment 68 states "3. The location of fish stock recovery areas shall not be modified within the first five years of their establishment. If a modification is needed, this shall only occur after the establishment of another area or areas of the same dimensions;". In terms of determining whether a fish stock recovery is succeeding or failing on biological grounds, the period of 5-years is too brief. Studies of marine reserves across the world consistently show rapid effects of protection becoming detectable in surveys within 2 to 5 years of the onset of protection. However, it will take longer periods for such effects to feed into fisheries as stocks must build up sufficiently for spillover to begin (often 10 years or more) and spawning potential must increase sufficiently through colonisation, growth and maturation, for protected stocks to contribute significantly to replenishment of fished populations. We therefore recommend that a 10-year review period be substituted for the 5-year review indicated in Amendment 68.

11. WHAT MARINE RESERVES CAN DO THAT CONVENTIONAL FISHERY MANAGEMENT CANNOT

KEY FINDINGS

- Incorporation of fish stock recovery areas into management practice in European fisheries would deliver benefits that conventional fishery management tools cannot, including recovery of depleted, vulnerable species and habitats without the need to shut down productive fisheries.
- Fish stock recovery areas would make an important contribution toward the adoption of 'ecosystem-based fishery management' and precautionary management.
- Marine reserve networks – including the proposed fish stock recovery areas – will be essential to achieving good environmental status under the Marine Strategy Framework Directive.

There are a number of things that marine reserves can do that will enhance the success of fisheries management, over and above what conventional tools can achieve (such as limits on fishing effort, landings, or gear used)(Roberts *et al.* 2005). This role has been brought into sharp focus by recent evidence that conventional fisheries management measures are not very good at delivering sustainability within multispecies fisheries, even in places like the European Union where management investment is high (e.g. Froese *et al.* 2010, Froese and Proelß 2010, O'Leary *et al.* 2011). There are many reasons for this failure, some technical, some institutional.

Fishery managers face major technical problems in multispecies fisheries, either where many species are caught using the same fishing gear, or where different fisheries using different methods operate over the same grounds and impact upon one another. Bottom trawl fisheries are a prime example of poor selectivity. Although designers are working hard to reduce unwanted bycatch, the problem cannot be eliminated by design alone. Problems with sustainability arise where species differ in their vulnerability to depletion. Some animals, by virtue of rapid growth and prolific reproduction at an early age, are able to sustain high levels of fishing without suffering overfishing (Hawkins and Roberts 2004). Others are much more vulnerable, typically animals that mature late in life, grow more slowly and attain large body sizes. Optimising catches of highly productive species will cause depletion of more vulnerable animals, in extreme cases to the point of regional extirpation. There are many examples in European waters. For example, animals like halibut, common skate and angel sharks, *Squatina squatina*, once supported productive fisheries in areas like the North Sea, but are now largely absent due to intensive overfishing by trawlers (Roberts 2007). For the most vulnerable, depletion has gone farther than being a problem merely for fishery managers. Their loss has become a concern for conservationists who are now demanding steps are taken to achieve recovery.

More serious problems arise when fishermen switch to more unselective or destructive fishing methods as stocks of traditional target species decline. Throughout much of the northeast Atlantic, this has taken the form of a shift toward exploitation of shellfish, such as scallops and prawns (e.g *Nephrops norvegicus*). The methods used to catch them involve fine mesh trawls and heavy dredges that are more damaging than the methods they have replaced. In regions like Scotland's Firth of Clyde and the Irish Sea, the majority of bottom living fish have been reduced so far in abundance that they have become almost commercially extinct (Thurstan and Roberts 2010). The dilemma for managers is that, because of the high bycatch of juvenile fish in prawn trawls and the habitat loss caused by dredgers, these fisheries cannot be recovered without prohibition of prawn trawling and dredging over extensive areas. Likewise, for vulnerable species like skate and halibut to recover, fishing effort would have to be reduced so far that you would need to sacrifice the productivity of resilient fish and shellfish species.

Marine reserves – i.e. fish stock recovery areas – can offer a way forward. They provide refuges within which vulnerable species and habitats can recover without having to shut down productive fisheries around them. From the perspective of habitat protection, they can also deliver long-term recovery of seabed habitats altered by trawling and dredging. Many of the animals that form biogenic habitats are long-lived and slow growing. Even draconian reductions in the intensity of trawling or dredging may not be enough to foster their re-establishment. By providing total refuges from mobile fishing gears, marine reserves can provide the benefits of protection without the sacrifice of productive fisheries.

Marine reserves have also been predicted to increase resilience of marine life to environmental fluctuations and extreme events (Roberts *et al.* 2005, Roberts 2012b). They can do this by sustaining larger, more productive populations with extended age structures. Because the starting levels of abundance are greater it is likely that stocks in reserves will be depleted less by extreme events than the smaller populations in fishing grounds, so they can potentially bounce back more quickly. Furthermore, dominance of protected populations by large, reproductively active animals can buffer replenishment against the ups and downs of environmental fluctuations (Hsieh *et al.* 2006).

A recent study has upheld the expectation that reserves can boost recovery rates after environmental disturbances. Off the west coast of Mexico's Baja Peninsula, a climatic event produced serious hypoxia which led to mass mortality of marine life. However, pink abalone *Haliotis corrugata*, a valuable fishery species, survived better in a reserve, recovered more quickly through greater reproduction, and spread the benefit to surrounding fishing grounds via larval spillover (Micheli *et al.* 2012).

The use of marine reserves in these roles is fundamental to the delivery of ecosystem-based fishery management (Pikitch *et al.* 2004), which is called for in the proposed reform of the Common Fisheries Policy. The conservation role of reserves is also indispensable for achieving targets of good environmental status under the Marine Strategy Framework Directive. The incorporation of fish stock recovery areas into fishery management practice within the EU is therefore essential.

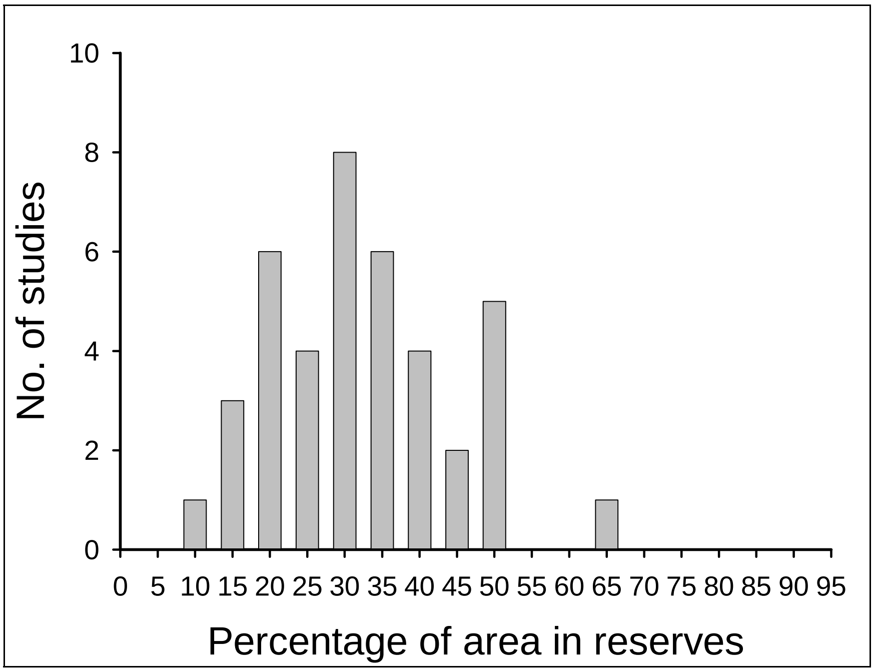
12. HOW MUCH AREA SHOULD BE PROTECTED?

KEY FINDING

- The proposed coverage for fish stock recovery areas of 10-20% of territorial seas places them within the range that present research predicts will produce strong fishery benefits.

Amendment 68, Article 7a, calls for fish stock recovery areas to be established over between 10% and 20% of territorial waters, phased in over a period of years. Will such a coverage produce the desired effects? Dozens of studies have examined the question of how much of the sea should be protected in order to deliver fisheries and conservation benefits, looking at the question from many different angles. For example, researchers have explored the area needed to maximise yields within single or multispecies fisheries, to minimise the risk of stock collapse, to prevent the adverse evolutionary effects of fishing on features such as age at maturity or growth rates of fish, among many others. Some studies have looked at cases where reserves are the only form of management for a fishery, while others have examined cases where reserves are complemented with other measures. Not surprisingly, the answers vary from study to study. However, there is much consistency in the overall conclusions from this research (Gell and Roberts2003). If reserves are to provide significant benefits, they must cover a significant fraction of the sea. Figure 3 summarises much of the research on the coverage of reserves that maximises, optimises or achieves the goals set in the studies included.

Figure 3: Synthesis of research from 40 studies on how much of the sea should be protected to maximise, optimise or achieve goals (depending on the nature of the question asked in each particular study).



Source: Gell *et al.* (2003)

A few percent coverage of marine protected areas, as we have now (and especially where those MPAs generally afford little real protection, see next section), will not be sufficient to generate substantial, region-wide fishery benefits. This doesn't mean that small and isolated marine reserves don't work. We have learned a great deal about the benefits they can deliver to fisheries from studies of small reserves. However, the localised benefits they provide are usually shared narrowly with local fishing communities. To gain wider benefits of a greater magnitude, fish stock recovery areas (in combination with other well-protected MPAs) will have to grow to cover tens of percent of the sea.

The question of how much area should be protected has also been asked in relation to the size and spacing of marine reserves necessary to deliver protection of relatively mobile species and ensure that adjacent reserves are able to supply each other (and fishing grounds) with the offspring of protected animals. Roberts *et al.* (2010) synthesised research on mobility and egg/larval dispersal to recommend that Marine Conservation Zones in an English network should average 10-20 km in their minimum dimension and be spaced 40-80 km apart. Such size and spacing would produce a total coverage ranging from 11% (10 km reserves, 80 km apart) to 33% (20 km reserves, 40 km apart) of territorial seas.

The UN Law of the Sea recognises the right of innocent passage by boats, no matter whose jurisdiction the area of sea falls under. Such a right should not be violated by fish stock recovery areas and boats should be permitted to transit such areas without hindrance. However, in order to facilitate effective enforcement of regulations within such areas, Amendment 68 states that, '6. If a fishing vessel is transiting through a fish stock recovery area, it shall ensure that all gears carried on board that are used for fishing are lashed and stowed, during the transit;'. This is a sensible approach that has proven effective in other instances, such as vessels transiting marine reserve zones in the Florida Keys National Marine Sanctuary in the USA.

13. STATUS AND EFFECTIVENESS OF EXISTING EUROPEAN MARINE PROTECTED AREAS

KEY FINDINGS

- Existing MPAs cover only a few percent of European seas, cover a narrow range of habitats, and are mostly concentrated in territorial waters.
- Marine reserves that are protected from all fishing are small, scattered and cover less than 0.01% of European seas. Larger MPAs tend to be weakly protected and/or poorly managed.
- The introduction of fish stock recovery areas at the scale proposed would dramatically improve the state of the European marine environment.
- There is an opportunity for fish stock recovery areas to be implemented in places with MPAs by upgrading levels of protection.

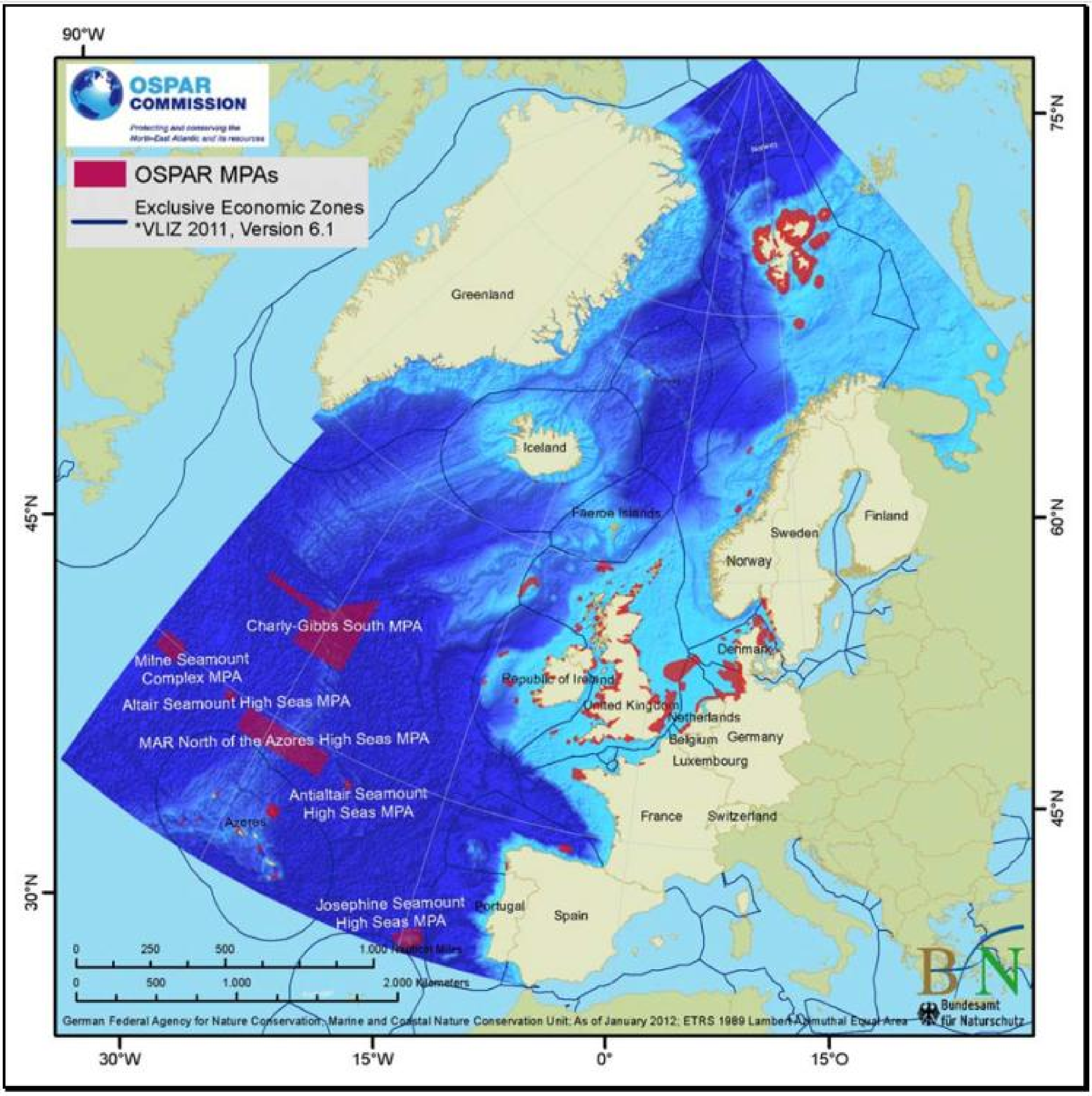
There are currently hundreds of marine protected areas established in nearly every coastal country throughout the European Union. In 2003, European nations that are party to OSPAR, which covers much of the northeast Atlantic, but not the Mediterranean, agreed to establish an 'ecologically coherent' network of marine protected areas by 2010. OSPAR published a report on the status of this network in 2011 (OSPAR Commission 2011)(Figure 4). Most of these protected areas were established under the Habitats Directive (Special Areas of Conservation, SACs) and Birds Directive (Special Protection Areas, SPAs), as well as under various national laws and international agreements (e.g. RAMSAR wetlands of international importance).

At first glance, this network looks impressive. By 2011, it consisted of 282 MPAs that collectively covered 3.5% of the area of OSPAR seas. As the vast majority of sites were in coastal waters, this network covered 16% of territorial seas. But closer scrutiny reveals some fundamental weaknesses. The network is very patchy; the waters of some countries, like the UK, Denmark and Germany, are well-covered, but coverage is sparse in places like Belgium and territorial seas of mainland Portugal. In some cases this reflects a real absence of protected areas, but in others, like Belgium (Bogaert *et al.* 2009), it is because the country has not yet declared its MPAs as a contribution to the OSPAR network.

A second weakness lies in the representation of different habitat types. The Habitats and Birds Directives are very narrowly focussed on small segments of biodiversity. Only a few marine habitats have been listed under the Habitats Directive, including sea caves, shallow subtidal sandbanks and rocky reefs. The great majority of marine habitats are excluded from consideration for protection. The Birds Directive is of course only interested in birds.

Setting aside issues of coverage and representativity, the most fundamental weakness of the OSPAR network is that protection is very weak. Most SACs and SPAs afford very little protection from exploitation to marine life, and routinely permit many activities that can damage or destroy habitats, such as trawling and dredging. In the Mediterranean, fewer than 100 marine protected areas were listed in a comprehensive 2008 assessment (Abdulla *et al.* 2008)(Figure 5).

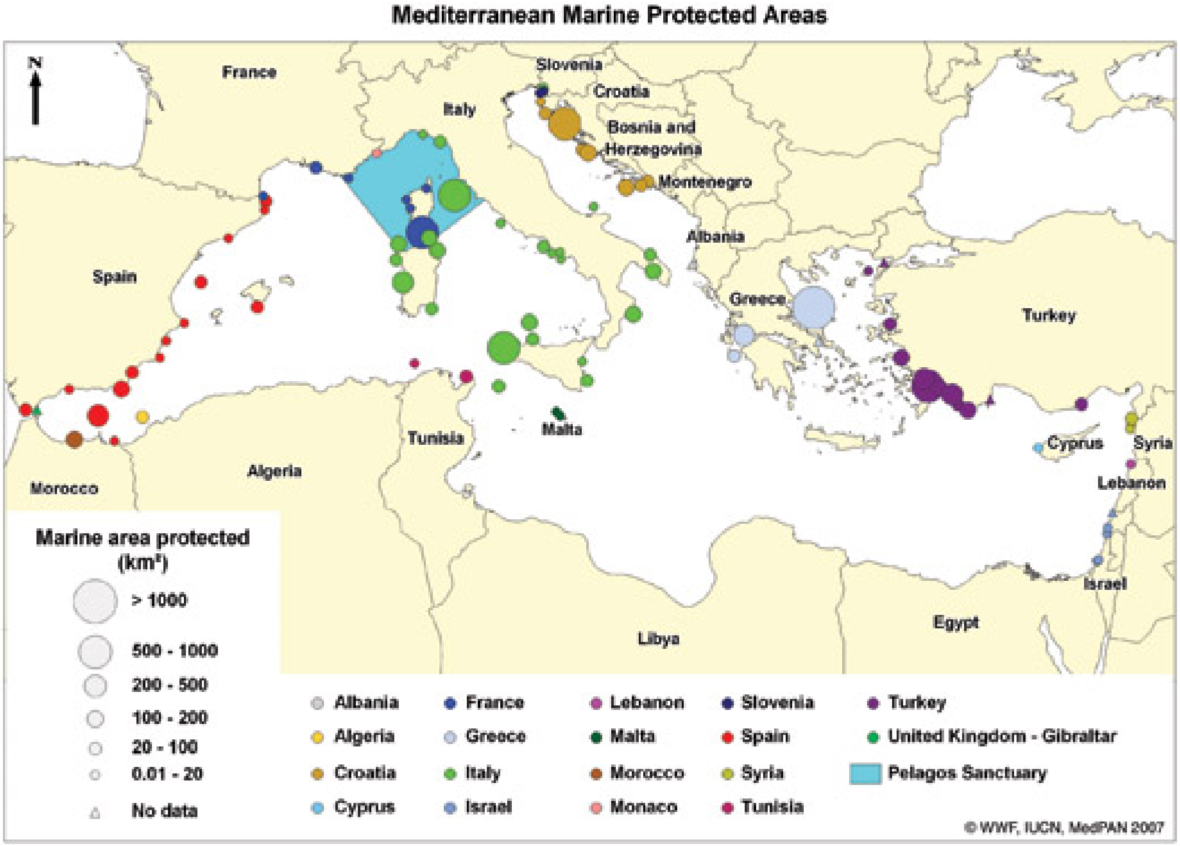
Figure 4: OSPAR marine protected areas (as of 2011)



Source: OSPAR Commission (2011)

Like the OSPAR network, these areas were not representative of the range of wildlife and habitats found in the Mediterranean. Nor were they very extensive: taken together (including non-EU countries), MPAs covered just 4% of the area of the Mediterranean, similar to the coverage of MPAs in OSPAR waters. However, when the coverage of the largest MPA was excluded (the weakly protected Pelagos Marine Sanctuary in the Ligurian Sea, which was established to protect cetaceans), only 0.4% of Mediterranean coastal seas was protected. As in OSPAR waters, marine reserves that are protected from all fishing are very small. Taken together, just over 200km^2 of the Mediterranean has been protected from all fishing, just one ten thousandth of its total area. Although small, these areas have recently contributed enormously to our understanding of the functioning of marine reserves as the many studies quoted in this report testify.

Figure 5: Mediterranean marine protected areas (as of 2008)



Source: Abdulla *et al.* (2008)

It is easy to summarise marine protection in European waters. The present network of MPAs is small and not representative of the range of habitats and species found in European seas. Marine reserves, where they exist, are very small and widely scattered and cover far less than one tenth of one percent of Europe's waters, even within territorial seas. Most protected areas permit activities with very little regulation that could potentially damage or destroy habitats or deplete species.

Several countries have taken steps to improve their networks of MPAs. For example, Germany commissioned a report from ICES (EMPAS: Environmentally Sound Fishery Management in Protected Areas, ICES 2009) to explore the compatibility of various kinds of fishing with the objectives of SACs, with a view to increasing the level of protection given to their SACs. France has begun work to expand the coverage of its marine protected areas to 20% of its seas by 2020, half of which will be protected from all fishing. The UK is well advanced in a proposed expansion of its marine protected area network under domestic legislation (the UK Marine and Coastal Access Act 2009) which will increase coverage, representativity and protection levels.

Although this assessment of current protection looks rather bleak, there is a clear opportunity for a policy to create fish stock recovery areas to enhance protection of marine habitats and biodiversity in Europe. Such areas could either add to the coverage of MPAs in the network or existing MPAs could double as fish stock recovery areas by upgrading protection within them. The latter option is attractive because protected areas do not work without stakeholder support. Given the huge effort already undertaken in terms of stakeholder consultation to create existing MPAs, upgrading protection could be a rapid and effective way of rolling out a network of fish stock recovery areas.

14. EXPERIENCE FROM OTHER COUNTRIES

KEY FINDINGS

- Establishing networks of MPAs can take many years and requires long-term, legally binding, non-partisan commitment from governments and sufficient financial support.
- Widespread stakeholder involvement is necessary to see through the process, but not all stakeholders will be happy with the outcome, and the process of engagement will have to be tailored to local conditions.
- Good science, transparency, fairness, a willingness to compromise and firm deadlines help to keep progress on track.

14.1. USA : California Marine Life Protection Act

California is nearing completion (expected in 2013) of a state-wide network of marine protected areas within state waters (up to 3 nautical miles offshore). There are three kinds of protected areas in the network that offer complete or high levels of protection from fishing. By the time it is complete, a total of 124 MPAs will cover 16% of state waters (Gleason *et al.* 2012, Griffiths *et al.* in press).

The Marine Life Protection Act, which mandated marine protection, was passed in 1999. After two false starts in which failures of funding, process and participation led to deadlock, the process was redesigned and given greater financial support (it has cost $18.5 million in public and $19.5 million in private funds)(Fox *et al.* 2012). The ultimately successful process was split into three planning phases covering central, northern and finally southern waters. Fox *et al.* (2012) listed the keys to success as a strong legal mandate for protected areas coupled with unwavering political support, a tight timeline with firm deadlines, adequate funding, a willingness of civil society to engage in the process, and an effective and transparent process that balanced science with stakeholder input (Gleason *et al.* 2010).

14.2. New Zealand : The first national policy for marine reserves

New Zealand has the distinction of being the first nation in the world to pass legislation for the creation of marine reserves that are protected from all fishing, doing so in 1971. However, it was not until 1975 that the first marine reserve was established. Although New Zealand is often seen a world leader in marine reserves, in truth it was overtaken by other countries long ago (such as Australia and the USA, this section). For most of the time since the law was passed reserves have been implemented in a piecemeal way (Banks and Skilleter 2010). Since 2005 there has been a more coordinated policy and an accompanying surge in designation. Even so, 37 years after its first reserve only 0.2% of New Zealand's mainland territorial waters had been protected. Part of the problem for slow progress has been a perceived conflict between marine reserves, which have been viewed as a conservation tool, and fisheries policy. Since the department that governs fisheries policy is required to sign off on new marine reserves, progress has stalled.

14.3. Australia : State of Victoria

Australia has been building a national network of marine protected areas for several decades. In 2002, Australia's State of Victoria completed its part of this network in a process intended to result in an 'adequate, comprehensive and representative' network of marine reserves (Wescott 2006). Twenty-four marine reserves were designated, covering 5.3% of state waters and reaching from the shoreline to the deep sea beyond the edge of the continental shelf. It was the outcome of a process that took over 20 years and involved stakeholders from industry, NGOs, government and the general public. The road to establishment was fraught with difficulty and recreational fishing groups opposed the reserves from start to finish. Fishing industry opposition eventually dissipated in the face of the legal inevitability of the network being established and through concessions made on the placement of reserves to avoid key fishing areas. The outcome of the process was criticised by some conservationists who felt that fishing industry involvement had led to the inclusion of too much deep sea habitat of low conservation value at the expense of nearshore habitats that were more threatened and richer in wildlife. However, most people agree that the network is an important step on the path towards good marine management. Australia has since made significant further progress towards establishing its countrywide network of marine protected areas, including a large area in the Coral Sea, much of which is expected to be protected from all fishing (Nature News: http://blogs.nature.com/news/2012/06/extended-protection-for-australian-seas-in-world-first-reserve-network.html).

15. PITFALLS AND ROADBLOCKS

KEY FINDINGS

- Fishers will need to be fully involved in the process of establishing fish stock recovery areas. Since the process will need to vary from region to region, reflecting variation in social and ecological conditions, the Regional Advisory Councils would be well-placed to advise on site selection and implementation.
- While compromises are essential in processes to establish marine protected areas, reducing the level of protection afforded by fish stock recovery areas would not be a sensible compromise, given that benefits are rapidly reduced by even low levels of fishing.
- The process of establishing fish stock recovery areas will be expensive and will impose transitional costs on fishermen as they adapt to the new management regime. Financial support from the European Maritime and Fisheries Fund could facilitate an effective and equitable roll out of the policy.

Almost wherever marine reserves are proposed, they attract vigorous and sometimes fierce debate, especially between those interested in wildlife conservation and those who make a living from fishing. The debates often rapidly become polarized and progress can be painfully slow, if it is possible at all. Fishers often see reserves (and therefore those who promote them) as taking away from their livelihoods. Conservationists often see fishers as irresponsible and destructive to wildlife. There are many reasons for mistrust and mutual lack of understanding which must be overcome if progress is to be made.

In reality the interests of fishers and conservationists overlap a great deal. Fishers need healthy fish stocks and high quality habitat to support productive fisheries. Given the difficulties in achieving such a goal across multiple fish stocks and fisheries under imperfect management (and even under 'perfect' management) fishers need networks of reserves to deliver this foundation for their fishery sustainability and profitability.

The question is how to engage in a productive debate about setting up fish stock recovery areas ? The international experiences described in Section 14 show a number of ways forward, all of which require intensive and sensitive effort to engage stakeholders. This is a fast moving field. Scientific understanding of the effects of marine reserves is increasing much faster than most stakeholders appreciate. It is important not to let the debate about fish stock recovery areas become mired in old arguments about whether or not they will benefit fisheries based on outdated views of the state of the science. As this report shows, there is abundant, high quality evidence to demonstrate that marine reserves will deliver many benefits to fisheries. So one priority at the outset is to update the knowledge of those who will take part in the process.

Experience shows that the establishment of MPAs is most successful when they have broad stakeholder support. They will not be effective if simply imposed top down, which means that in each region local fishers with local experience will need to be engaged in the process to produce designs for networks of fish stock recovery areas that are suited to local conditions. Probably the most effective means to do this will be by closely involving the Regional Advisory Councils (RACs), which have already established good working relationships among fishers and with conservationists. While the roll out of fish stock recovery areas can be expected to differ from region to region, the RACs will have to agree common criteria for selection and placement at the outset.

While it is essential that fishers have most of the say over where fish stock recovery areas will be placed, there are certain pitfalls to stakeholder participation. In the UK, a stakeholder process to propose sites for Marine Conservation Zones has attracted criticism. Commercial interests within stakeholder groups led to some of the areas considered most valuable for conservation being overruled as candidates for protection because they were also valuable to fisheries. A similar outcome from stakeholder participation in site selection was seen in Australia (Edgar *et al.* 2009). There some sites established as marine reserves had less good fish stocks in the early years after protection than nearby fished sites, indicating that poorer quality sites were chosen as reserves. This does not mean that those sites and adjacent fisheries will not benefit in the long-run, but the benefits may be slower to accrue.

There are clearly costs as well as benefits from establishment of fish stock recovery areas. Some people may be displaced from their favourite fishing sites and others may have to travel farther to reach fishing grounds. Balanced against this, others may have to travel less far to fish as spillover benefits from local fish stock recovery areas begin to flow. Even so, close involvement of fishers in the process of siting fish stock recovery areas will enable some of these costs to be minimised (Higgins *et al.* 2008), and experience from other parts of the world (e.g. Northern Australia, Manson and Die 2001) shows possible ways forward.

It can be very tempting, when negotiating to establish marine protected areas or fishery closures, to compromise not on whether to establish them but on the level of protection they receive. The perception is that such compromises will deliver the benefits of protection while reducing costs. Unfortunately, this is a false premise. For example, permitting prawn trawling to continue in cod recovery areas has condemned them to fail in Europe (Roberts and Mason 2008). In the same way, leaving fish stock recovery areas open to some kinds of fishing would greatly reduce their benefits. The science is crystal clear on this – partial protection produces far less stock recovery than full protection (Edgar *et al.* 2011, Sala *et al.* 2012). Given the projected limited extent of fish stock recovery areas, it is essential that they are given the highest level of protection in order to generate significant and widespread fishery benefits. Otherwise the creation of fishery recovery areas will produce many of the costs but few of the benefits.

On the matter of costs, the adoption of this policy would incur substantial up-front costs before benefits began to flow. As the implementation of the California Marine Life Protection Act demonstrated, the set up costs can be high (Gleason *et al.* in press). While implementing a fishery management tool like this can be expected to be less expensive, it will still be costly. Fishers may also incur costs adapting to the new management regime and transitional finance will be necessary to help offset these costs in the first few years. The European Maritime and Fisheries Fund would be an obvious source of this support.

16. RECOMMENDATIONS

Incorporation of fish stock recovery areas into management practice in European fisheries, at the scale proposed, could deliver major benefits for fish stock recovery and habitat protection. They could produce benefits of a form that conventional fishery management tools cannot, such as recovery of depleted, vulnerable species and habitats without the need to shut down productive fisheries. Fish stock recovery areas could make an important contribution toward the adoption of ‘ecosystem-based fishery management’ and precautionary management. Marine reserve networks – including the proposed fish stock recovery areas – will be essential to achieving good environmental status under the Marine Strategy Framework Directive.

It is recommended that fish stock protection areas be established to cover 20% of fishing grounds.

It is recommended that buffer zones be created around fish stock recovery areas, in which low impact fishing methods are employed by small scale fishers, and recreational fishing is allowed.

Because of the extended timescales of stock and habitat recovery, and the speed with which benefits can be dissipated on resumption of fishing, the establishment of fish stock recovery areas must be seen effectively as a permanent commitment if they are to contribute meaningfully to fish stock recovery and habitat conservation.

The only exception to this would be where particular reserves were demonstrably failing to achieve much in the way of stock or habitat recovery. Such an outcome would need to be determined on a case by case basis through fishery independent survey methods, but the five year suggested timescale in Amendment 68 for such a review is too short. 10 years would be more appropriate based on available evidence of the timescales of reserve benefit.

Fishers will need to be fully involved in the process of establishing fish stock recovery areas. Since the process will need to vary from region to region, reflecting variation in social and ecological conditions, the Regional Advisory Councils would be well-placed to advise on site selection and implementation.

While compromises are essential in processes to establish marine protected areas, reducing the level of protection afforded by fish stock recovery areas would not be a sensible compromise, given that benefits are rapidly reduced by even low levels of fishing.

The process of establishing fish stock recovery areas will be expensive and will impose transitional costs on fishermen as they adapt to the new management regime. Financial support from the European Maritime and Fisheries Fund could facilitate an effective and equitable roll out of the policy.

In accordance with the UN Law of the Sea right of innocent passage, fishing vessels should be permitted to transit fish stock recovery areas, provided that all gears carried on board that are used for fishing are lashed and stowed, during the transit.

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