The Arran Marine Regeneration Trial: the mechanisms and evidence of fisheries benefits to Marine Protected Areas.

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Preface

Experience from around the world has shown that opposition from fishermen is a common problem facing the implementation of Marine Protected Areas (MPAs) (Gell & Roberts 2003a, Hutchings 2000, Roberts & Hawkins 2000). Diani Marine National Reserve, Kenya, gazetted in 1994 for example, remained unmanaged due largely to strong objections by fishermen (McClanahan et al. 1997), while more recently, park facilities of the Galapagos Marine Reserve were seized by fishermen unhappy with fishing regulations governing the reserve [(1)]. The lack of perceived benefits of MPAs in the face of economic hardships encountered due to fishery closures are a common thread to such objections. Evidence from New Zealand and Australia suggests that fishermen would accept MPAs more readily if they were provided with firmer evidence of the fisheries benefits (Hoskin P. 2001). This is supported by Gell & Roberts (2003b) who note that, 'fishers are most often convinced of the usefulness of reserves through the experience of other fishers'.

A useful dialogue often seems to be hindered however by a negative 'knee-jerk' reaction whenever conservation related measures are mentioned to fishermen. This is quite understandable as fishermen often, and with some justification, see conservation measures to be in conflict with fishing practices. Gear restrictions, and/or area closures, involved in MPA management are a clearly tangible threat to the size of fishing patches. Negative or sensationalist press from both fishery and conservation camps have often fuelled this conflict; a good example of this being Watling & Norse's (1998) article comparing the use of mobile fishing gear to forest clear cutting and the misinformed use of this by an American based fisherman's forum [(2)].

Representing and incorporating the needs of fishermen into management plans is of vital importance if reserves are to be successful. Experience from Soufriere Marine Management Area, St. Lucia, for example, has shown that where fishermen felt that they had not been properly/appropriately considered, they would continue to fish in protected zones, compromising the success of management plans (Roberts & Hawkins 2000). In America, recreational anglers have initiated the Freedom to Fish Act [(3)] in response to what they see as heavy handed MPA implementation without proper consultation. MPA management involving all stakeholder groups, especially fishermen, is clearly a priority and is commonly advocated [(4,5)].

As the examples given above demonstrate, fisheries conflicts with MPAs are a world-wide issue. MPA initiatives in the UK have typically met with opposition from fishermen. The St. Agnes Shell-Fisheries Voluntary No-Take Zone in Cornwall, for example, had its integrity compromised through continued fishing pressure from just a few individuals (Hoskin M, 2001). In Scotland, proposals for a MPA on the east coast of Arran – The Arran Marine Regeneration Trial – have met with stiff resistance from particular quarters of the Clyde Fisherman's Association. As a result, the trail has been refused support from the inshore fisheries division of the Scottish Executive until 100% consensus across all stakeholders is achieved (Tom Vella-Boyle, Community of Arran Seabed Trust. pers comm.).

Resolving fishery-based conflict to MPAs is clearly a key factor in their success. Although financial incentives have been used as compensation for fishing restrictions inevitably involved in MPAs, such as in Australia (Hoskin P 2001,MPA News[6]) and St Lucia (Roberts and Hawkins 2000), Gell & Roberts (2003a) suggest that this can only be a short-term fix. With gathering evidence demonstrating the benefits of MPAs to fisheries, this study aims to provide a synthesis of this information particularly in relation to the UK and The Arran Marine Regeneration Trial. The aim of this is to demonstrate that The Arran Marine Regeneration Trial is a valuable tool in fisheries management with the hope that its implementation is more readily accepted and supported by fishermen.

Covering the background to the Arran initiative, the mechanisms and evidence for MPA function and fisheries benefit, it is hoped that those attempting to set up the Arran Marine Regeneration Trial will use the information contained in this study to support their efforts in winning the approval all stakeholders.

Summary

The use of Marine Protected Areas (MPAs) as tools for conservation has often met with conflict from fishermen. An increasing body of evidence, however, shows that MPAs can also be used as fisheries management tools. Traditional methods of fisheries management have relied on stock estimates that have been shown to be unreliable due to the huge variations in recruitment to the fishery. Failure of these management practices, as indicated by declining fish stocks and fishing fleets, suggests that new methods to manage fisheries are urgently required. MPAs offer a simpler and more robust method to manage fisheries as well as meeting marine conservation objectives that are being increasingly called for.

Proposals for a MPA in Lamlash Bay on the east coast of Arran, Scotland, are facing objections from fishermen concerned about the loss of fishing grounds. Using examples from around the world, this study aims to assess the fisheries function of the trial based on evidence from MPAs around the world. Previous studies have often faced criticism for using tropical reef based examples to advocate temperate reserves. Where possible, this study aims to draw on experience from temperate reserves to illustrate the case for MPAs as tools for fisheries management.

Fisheries benefits are derived from the 'reserve effect'; the build up of stocks inside reserves that delivers benefits beyond its boundaries. Numerous studies have shown increased abundance, size, recovery of population age structure, and increased reproductive potential of a wide variety of species including fish, shellfish and

crustaceans (defined as a group by 'fish' or fish stock'). Reserves are also predicted to assist habitat recovery, which in turn delivers further benefits to these stocks. Mechanisms that benefit the fishery include increased fishery stability derived from a more natural population structure within the MPA, and restocking of the fishery through egg and larval export, and spillover of juveniles and adults from the protected area. Numerous studies around the world illustrate these mechanisms and provide evidence for their operation. These examples illustrate that MPAs on a range of scales provide fishery benefits for a variety of species with widely contrasting biology and behaviour. Furthermore, for many of the examples used the age of the reserves means that fisheries benefits are still in their early stages and therefore represent minimum benefits that can be expected to increase over time.

The Arran Marine Regeneration Trial is expected to succeed as a conservation tool. Based on present evidence, particularly from the Isle of Man, it is also expected to benefit the local scallop fishery. Its contribution to other fisheries around Arran is however, uncertain due to the lack of evidence from other UK examples. Nevertheless, the trial will provide a much-needed platform for further scientific investigation into the conservation and fisheries benefits of MPAs around the UK, and contribute heavily to present knowledge in this area.

1.0 Introduction

Initially implemented as conservation measures, principally designed to protect areas of sea from excess fishing pressures, Marine Protected Areas (MPAs) are showing increasing evidence of their success as tools for both conservation and fishery management. Kelleher (1999) defines a MPA as 'any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical or cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment'. Other terms such as reserves, closed areas and MPAs have also been used to describe such areas. For simplicity, the use of these terms in this study is inclusive, i.e. they all refer to areas that are closed to fishing and other extractive uses unless otherwise stated.

The use of the term 'MPA' in its simplistic sense does however hide the varying degree of protection afforded by MPAs in response to a broad range of management objectives. A good example of this is in the management of the Great Barrier Reef, Australia, where separate zones have been established along the reef, representing different allowable uses from multi-use to no-take zones. No-take zones are considered especially valuable in providing support for fish stocks. Improvements in fishing gears and technology, commonly referred to as 'technology creep' (Ward & Hegerl 2003) has opened up previously unknown or unexploitable areas that served as *de facto* refuges to marine animals; no-take zones effectively replace these refuges.

In the UK, while various initiatives by the Sea Fisheries Committees to manage stocks have proved successful in many areas, conflict within the fishing industry based on interference among different fishing practices often undermines such measures. Commercial trawling for brown shrimp, for example, results in significant bycatch of flat fish (Tasker et al. 2000), while in the Fladen ground off the north-east coast of Scotland Nethrops is common bycatch for whitefish trawlers [(8)]. Even the use of species specific fishery closures has in many cases proved insufficient. Closure has taken place on a large scale, e.g. the Plaice Box (38,000km2), but open access to other types of fishing has reduced potential benefits. In the Plaice Box for example, total closure would be expected to provide greater fisheries benefits by reducing the significant mortality rates of juvenile plaice caused through fishing targeted at other species such as shrimps. Furthermore, it is expected that other species that suffer from high discard rates such as sole would also benefit (FSBI 2001).

MPAs can help negate this interference, complementing existing fishery management measures, with regulations that do not shift according to changing policies and providing protection for all species. Through simplifying fishery management practices, MPAs have been identified as among the least difficult ways to manage fisheries (Roberts & Polunin 1993). Furthermore, the permanence of these areas, especially no-take zones, increases their integrity in protecting fish stocks, and can greatly assist fisheries managers in meeting both ecological and economical sustainability goals. This is perhaps critical for an industry that is under intense pressure to adopt conservation measures while still remaining economically viable.

Until more recently, much of the work on MPAs focused on their value as tools for conservation and as such there is a large body of evidence supporting MPAs in this role. Protection from fishing predictably results in increased abundance, size and age structure of exploited species (Alcala 1988, Babcock et al. 1999, Buxton & Smale 1989, Jennings et al. 1996) with a resultant increase in reproductive output. The delivery of fisheries benefits are derived from the 'reserve effect' and come as a result of increased fishery stability, with 'spillover', egg and larval dispersal acting as the export mechanisms from the protected area into the fished area.
Spillover, from reserve stocks into fishing areas, has been noted for various species in different parts of the world, including spiny lobster in New Zealand (Kelly et al 2001) and species of coral reef fish in Kenya (McClanahan & Mangi 2000). Larval recruitment of exploited shellfish into fished areas has also been demonstrated across a wide geographical range.

In Lamlash Bay on the Isle of Arran, traditional methods to maintain fish stocks have obviously failed. Local diver observations in Lamlash Bay suggest that both the Queen (*Aequipecten opercularis*) and Great scallops (*Pecten maximus*) have shown a significant decline in numbers, while data from the angling festival shows a massive reduction in various fish species in the bay, including cod and haddock. In response to this decline locals are attempting to gazette Lamlash Bay as a MPA; The Arran Marine Regeneration Trial. Understandable concerns by fishermen regarding the impingement of their fishing rights has inevitably led to conflict over the implementation of this MPA.

Present evidence, from a large body of literature, suggests that the trial will be a successful conservation tool. In light of the existing conflict however, this study aims to show that the Arran Marine Regeneration Trial can also be a successful fisheries management tool. It is hoped that the initiative will complement other fisheries management measures already in place, providing a solid foundation for the enhancement of fish and shellfish stocks that offsets any loss of fishing inherent in the area protection involved.

It must be noted however that a great deal of the evidence supporting MPAs concerns studies based in tropical regions – typically around coral reefs. Considering that ecosystem function will differ significantly between tropical and temperate regions, using tropical, coral reef based studies as examples of MPA benefits may seem inappropriate. While a great deal of MPA science has been based on these studies, examples of MPA performance given in this appraisal will largely be confined to temperate regions so that comparison to the Arran Marine Regeneration Trial can be made more readily. Where case studies or examples do not stick within these guidelines, their use is to demonstrate a particular point relevant to the Arran initiative.

2.0 Background

The result of intensive fishing practices around Arran, the largest of the Firth of Clyde Islands in Scotland, has, locals argue, had a huge impact on fish stocks and other marine life. Of particular concern is the area of Lamlash Bay on the south-eastern shore of Arran, approximately 5km long and location to the second largest settlement on the island. With a noticeable reduction in marine life since the 1970's the Community of Arran Seabed Trust (COAST) was set up in an attempt to address the problem.

2.1 The Arran Marine Regeneration trial

Following consultation with UK scientists, the trust proposed 'The Arran Marine Regeneration Trial' involving the establishment of a Marine Protected Area (MPA) in Lamlash Bay.

Fig 1. Large scale map showing Arran in relation to Scottish mainland

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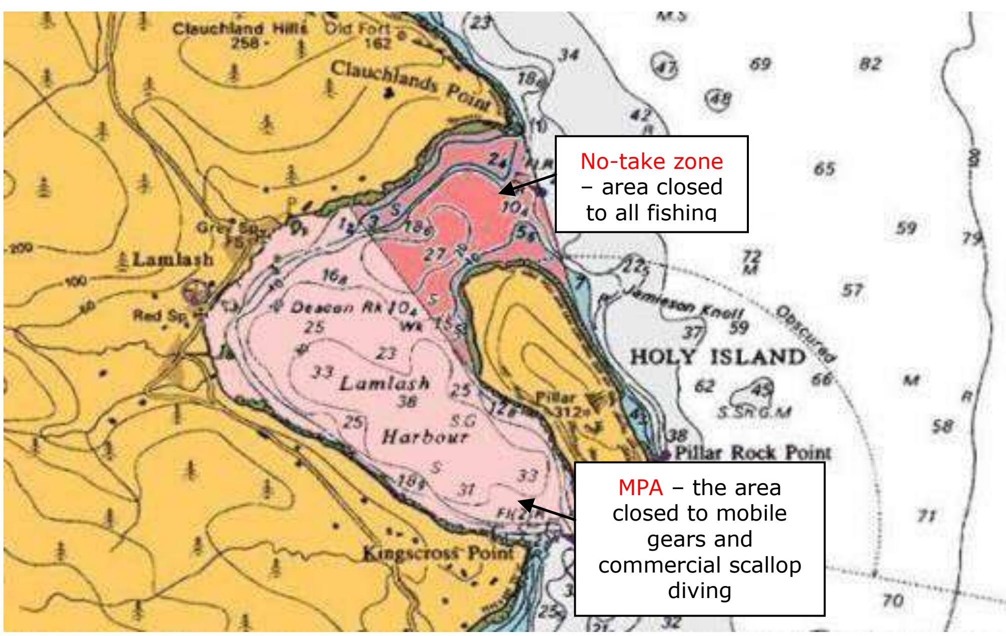
Operating for a trial period of 10 years, the MPA will cover a total area of approximately 7.9km^2 of which 2.4km^2 will be a no-take zone while the remaining area is closed to mobile fishing gear and commercial scallop diving.

Fig 2. Lamlash Bay on the east coast of Arran

Fig 3. The proposed zones making up the protected area within Lamlash Bay



Images from COAST: www.arrancoast.co.uk

While the trial is largely conservation driven, COAST recognises the need to sustain the livelihoods of those dependent on fishing and it is hoped that while the trial demonstrates the use of MPAs, it will also improve the long term viability of fishing around Arran. The differential regulations between areas is an important part of this: restriction of mobile gears over part of the MPA is intended to halt the habitat damage and associated impacts on fish stocks, while complete closure of the north end of the bay to all types of fishing is expected to result in a rapid build up of fish that may then contribute to the fishery in open access areas. It is hoped that this segregation will 'demonstrate the comparative difference between the regeneration of marine life within the no-take zone, to that of the MPA and the status quo which will be the area immediately outside Lamlash Bay' (8).

With only one statutory fully protected MPA in the UK (a 3.3km^2 zone off the east coast of Lundy Island) and few examples of voluntary MPAs, this initiative forms a landmark point for both marine conservation and fisheries management around the British Isles. As such, it is intended that the trial provides data to the fishing industry and marine resource managers to assist them in setting up other such initiatives.

2.2 Seabed within Lamlash Bay

Assessment by the Marine Biological Station, Millport, concluded that the area has significant potential for regeneration (8). Boat survey and diver observation show the bay exhibits a range of habitats, which under natural conditions suggests high species diversity and abundance (Tait & Dipper 1998, Barnes & Hughes 1999).
The seabed of Lamlash Bay is typically composed of soft sediments, with patches of sublittoral rock and associated kelp communities, with seagrass and maerl beds also present. Supporting a highly diverse flora and fauna (Birkett et al. 1999) and productive scallop fishing grounds (Hall-Spencer & Moore, 2000a), the maerl beds are of specific interest, but there is concern about the sensitivity of these beds to towed bottom gear, especially scallop dredges (Hall-Spencer & Moore, 2000b).

> Maerl beds are composed of various species of calcified red seaweed growing as nodules or attached branches on the seabed. Maerl is very slow-growing and fragile, but over long periods may form structurally complex habitats composed of both dead and living maerl that accumulate into deep deposits. Maerl beds are an important habitat for a wide variety of marine animals and plants and are therefore high in biodiversity. Recognised as a habitat of importance under intertidal SSSI site selection guidelines, exploitation of two of the main maerl forming species in Europe *Lithothamnion corallioides* and *Phymatolithon calcareum*, is managed under the EC directive on the Conservation of Natural Habitats and Wild Fauna and Flora (1992) (Hall-Spencer & Moore, 2000a, 2000b)
> For further information see: UK Marine Special Areas of Conservation
> http://www.ukmarinesac.org.uk/maerl.htm

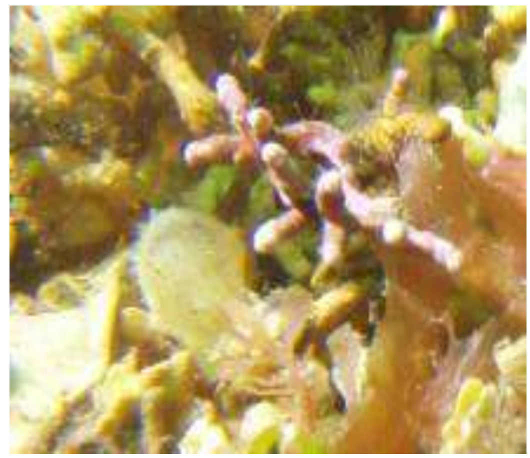
2.3 Fishing within Lamlash Bay

Data from the Sea angling festival shows a 1000 fold decline in weight of catch from the 1960's, when the festival was at its height, to the 1990's. Like other areas, while there is no direct evidence linking this decline to fishing it is widely acknowledged that this has been the primary cause.

While the recreational fishing effort may have been large within Lamlash Bay during the annual sea angling festival, most of the effort today is by commercial fishermen. It is estimated that 2-3 boats operate fixed nets (typically for whitefish) while approximately the same number operate scallop dredges for the Queen and Great scallop.

Fig 4. Great scallop *(Pecten maximus)*

Fig 5. Juvenile scallops on maerl bed



3.0 Underpinning MPA function: protection of habitat

Figures from The United Nations Food and Agriculture Organisation (FAO), show that 70% of marine fisheries are fully exploited, overfished, depleted or recovering from depletion, with 13 of the planet's 15 major oceanic fishing areas presently fished at or beyond capacity [(9)]. One of the major factors recognised to underpin such declines is the effect of fishing on non-target species and habitats (Alverson et al. 1994, Jennings & Kaiser 1998, Rodwell et al 2003). A comprehensive analysis of the effect of fishing on non-target species and habitats is not within the scope of this study, but it does need to be addressed as such impacts are of direct relevance to the function of MPAs. For fuller reviews on these extensive subjects see Alverson et al (1994) and Kaiser & de Groot (2000).

Habitat complexity is known to influence the diversity of fish and other marine life (Tait & Dipper 1998, Barnes & Hughes 1999) and is also viewed as vitally important to production. With widespread recognition that MPAs allow degraded habitat to recover (Lindeboom 2000, Roberts & Hawkins 2000), protection of habitats by MPAs should be seen as a vital part of their function in maintaining the integrity of fish stocks both within and outside reserves.

3.1 The impacts of fishing upon habitats and non-target species

The effect of various types of bottom gear on seafloor habitat has been a well-documented and controversial area of study. Impacts include reduced habitat heterogeneity, benthic diversity, and abundance of species sensitive to disturbance. Opportunistic species such as scavengers, on the other hand, have often shown short term increases. Bergman & Van Santbrink (1994), for example found that due to trawling activities in the southern North Sea, several benthic species had decreased while others had disappeared altogether. Kaiser & Spencer (1996), who studied the effects of beam trawl disturbance at a site 27-40m deep in the Irish Sea found a similar pattern. The site encompassed stable sediments composed of coarse sand, gravel and shell debris, supporting a rich epifaunal filter-feeding community of soft corals and hydroids, and mobile sediments characterised by megaripples (large sand waves) with few sessile epifaunal species. The effects of disturbance were undetectable in the mobile sediments, largely due to the high levels of natural disturbance and because animals living in the troughs of megaripples were less likely to be disturbed by fishing since the gears rode over the crest of each sand wave. However, the authors found that the number of species and individuals in the stable sediment community was reduced by two and three-fold respectively. Their study also revealed that less common species were most severely depleted by trawling.

With a scallop fishery operating in Lamlash Bay, a look at the effects of scallop dredging is particularly relevant here. The effects of this fishery on seabed communities have, like other fishing methods, shown varying degrees of impact. Studies by Bradshaw et al (2000) on gravelly seabed habitat around the Isle of Man showed that scallop dredging was a significant factor in structuring of the benthic community. Areas where dredging took place were shown to be more homogenous with slightly fewer species than areas closed to dredging. However, abundance of species was found to vary between dredged and undredged sites with various polychaete worms and crabs being more abundant at undredged sites while the brittlestar _Ophiura albida_, the bivalve _Dosinia exoleta_ and the polychaete worm _Owenia fusiformis_ were more abundant on the dredged plots. Aggregation of scavengers around the dredged areas only occurred in the short term as it was found that the periodic nature of dredging and the degree of damage sustained by these animals in the long term outweighed food benefits. Annual mortality was not more than 1% of the population for most benthic invertebrates but was as high as 14% for the edible crab; a situation that would have implications for the fishery of this species. The study suggested that habitat homogenization, together with direct mortality, were the main factors causing the observed reduction in diversity in areas that were heavily dredged.

Fig 6. A Bedford-style scallop dredge being brought on board

A full benthic survey of Lamlash Bay has yet to be conducted, but analysis so far suggests that the bay is typically composed of patches of sublittoral rock and associated kelp communities, seagrass and maerl beds with a dominance of soft sediments. The natural communities of these sediments are expected to be diverse, including deep burrowing animals and fragile epifauna (Ball et al. 2000). Forming highly stable communities in sheltered conditions such as Lamlash Bay, impacts even from low levels of disturbance are likely to be high (Macdonald et al. 1996). Of even greater concern however is the impact of scallop dredging on the maerl beds which are particularly vulnerable to disturbance (Macdonald et al. 1996). These beds are often productive scallop fishing grounds but due to the high biodiversity of these habitats, bycatch makes up a significant proportion of total catch (Hall-Spencer & Moore 2000a). Examining the effects of scallop dredging over maerl beds in the Clyde area, Scotland, Hall-Spencer & Moore found that for every 1kg of scallops caught, 8–15kg of other organisms were captured. This ratio of bycatch to target species ranks scallop dredging over maerl beds at the top end of fisheries with the highest discard ratios (Alverson et al. 1994). Furthermore, it was found that the dredges were significantly more efficient at removing marketable sized *Pecten maximus* from maerl beds compared with other substrata, which, coupled with the destruction of valuable scallop habitat, has important implications for the maintenance of a spawning stock of scallops. Further analysis (Hall-Spencer & Moore 2000b), found that scallop dredging led to a >70% reduction in live maerl cover with no sign of recovery over the following 4 years. This was also associated in a loss of habitat complexity as a result of both live and dead maerl being buried and crushed.

As can be seen, the effects of bottom gear on differing substrata are varied and complex. Analysing the impacts of fishing gear over seabed sediment based communities is further complicated by natural disturbance in shallower water. Furthermore, before-after effects analysis is often set against a historical background of disturbance that has meant that comparisons can often only be made between heavily and lesser-impacted communities (Bradshaw et al. 2000). Using maerl as an example, comparisons between non-impacted and impacted sites are more robust as the slow growing nature of maerl beds allows disturbance history to be more easily recognised.
Fishing effects on epifauna are likely to be greater on hard substrata where a diverse epifaunal community relies on a stable physical habitat structure.

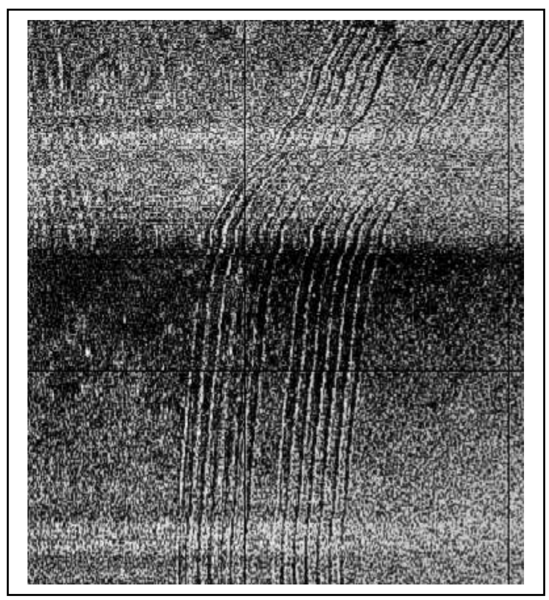


Fig 7. Dredge tracks clearly visible across the seabed of Lamlash Bay. Sonar image from RV Aora, Marine Biological Station, Millport.

While the effect of fishing practices over sediment based infaunal and epifaunal communities has been demonstrated, the knock on effect to fish populations has been harder to quantify. It is reasonable to suggest, however, that heavy disturbance of habitat that may be critical for feeding or juvenile stages of fish will be detrimental. Auster et al. (1996), for example, showed that when target fish species are under pressure, the removal of epifauna and microhabitats is likely push species beyond their population threshold.

MPAs can clearly play an important role in protecting habitats and the associated communities of marine organisms that depend on them for food and shelter. Although the effects of mobile gears, such as scallop dredges, in Lamlash Bay have yet to be quantified for either habitat or fish stocks, evidence strongly suggests that such practices will contribute towards habitat deterioration and reduction in food items for various species. Depressed populations of fish and other marine life, such as lobsters and crabs are therefore likely. Plans for a zone restricting the use of mobile gears in Lamlash Bay can be seen as a necessary requirement and are increasingly being advocated in MPAs on a wider scale (MPA News [(10)]). As will be discussed in the following section this has important implications for the stability of the fishery.

3.2 Habitat improvements enhance fishery stability

The question as to whether MPAs act to import or export fish stocks has often been raised by fishermen concerned that instead of acting as sources to fished areas, MPAs will act as sinks, reducing targeted species in the fishing grounds. Edgar & Barrett (1999) suggested that increases within MPAs might be as a result of both recruitment and movement of species into the reserve from other areas, potentially attracted by improvements in habitat associated with protection. In Leigh Marine Reserve for example, Babcock et al (1999) found that kelp beds were more extensive compared to areas outside, and thus, may be a more ‘attractive’ habitat to fish and lobsters. It is widely acknowledged that utilisation of habitat has an important density-dependent factor, meaning that at low densities fish and other species will occupy areas of highest quality. As density increases, resources become limited so species move to areas of lower quality where relative availability of resources is higher due to a lower population density. For a variety of species the reverse is true when population size falls; movement back into areas of high quality occurs where reduced density means that resources are once again available (MacCall 1990).

The implication of this for fisheries is that even as stocks fall catch may still remain high as effort shifts to cover denser aggregations of fish typically occurring in areas of highest habitat quality and/or resource availability. Decline of the northern cod stock for example (Hutchings 1996), meant that between 1989 and 1991, 50–60% of the estimated biomass was concentrated in high density areas that could sustain high catches even though the overall pattern of population abundance was in decline. High densities of cod were maintained in favoured habitats by relocation from other areas; large catches were therefore maintained as long as abundance remained high enough to form dense aggregations. Fishing continued until this could no longer be supported and the stock collapsed at a time when total biomass was very low. While continued fishing may have been implicated in the collapse of the stock this was also supported by the failure of research to pick up on overall population decline as estimates of stock abundance were averaged out across all areas (Hutchings 1996).

A MPA, assumed to have high habitat quality and resource availability, could theoretically have prevented stock collapse as movement of fish into this area as the population declined would have resulted in cessation of all fishing mortality. This is supported by recent evidence showing that for a number of temperate species, including cod, haddock and lemon sole, a high degree of site fidelity is shown where habitat quality is high. Where this could be considered essential fish habitat, location of a MPA to cover such an area means that density-dependent relocation will concentrate the fish into protected areas (Hinz et al. 2003). This highlights the practicality of permanent MPAs, in that protection does not rely on potentially flawed estimates of stock biomass or on regulations that need to be rapidly implemented in response to declining stocks.

4.0 Recovery and build up of fish stocks within reserves

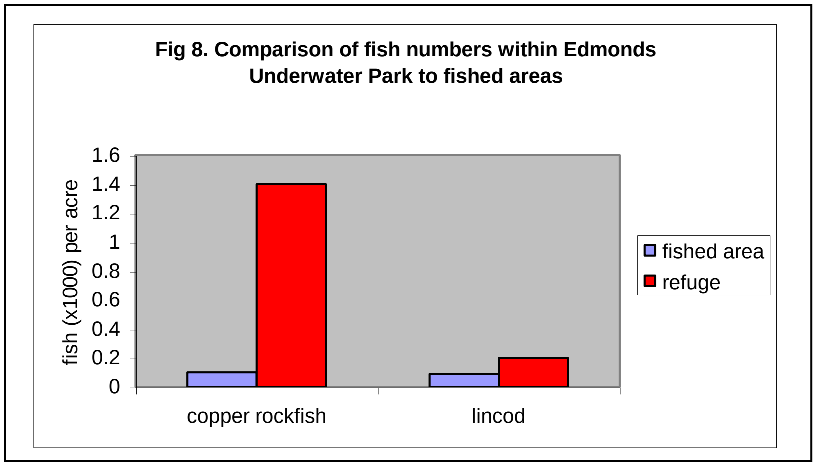
The previous section suggested that protection of habitats was a key part in the recovery and stability of fish stocks. While it was acknowledged that the fisheries effects resulting from habitat improvements have been hard to quantify, there should be no doubt, based on evidence presented here, that populations of fish, shell-fish and crustaceans (referred to as fish stocks) do build up within reserves. This build up effectively forms the basis for benefits outside the reserve, i.e. to the fishery, and underpins the mechanisms supporting this, commonly termed 'the reserve effect'.

4.1 Evidence for recovery and build up of fish stocks within reserves

There is a large and fast growing body of evidence from around the world showing the effects of MPAs on the abundance, size, biomass and diversity of species. Gell & Roberts (2003a) and Roberts & Hawkins (2000) provide an excellent review of MPA studies from temperate and tropical regions on a case by case basis while Halpern (2003) analysed the aggregate effects of 89 reserves across a range of protection and level of management. While this analysis used both temperate and tropical examples, it is a general illustration of reserve benefits. Suggesting that any marine habitat could benefit from implementation of a reserve, Halpern showed that, with the exception of invertebrate biomass and size, values for size, abundance, biomass and diversity of species were significantly higher inside reserves compared to outside, or after reserve establishment versus before. On average, species within reserves were twice as abundant, a third larger, had a three-fold biomass increase and showed an increase in diversity by a third. While these figures may not seem particularly significant, Hawkins and Roberts (2000) pointed out that the analysis included reserves that varied in their level of protection, from full closure to restrictions on particular groups such as spear fishermen. Furthermore the actual level of protection varied across the reserves with some areas achieving good compliance to regulations while others showed poor compliance. Because of these variables it was considered that Halpern's analysis 'should be considered as minimum levels of performance for fully protected, well-respected reserves' Hawkins and Roberts (2000).

Individual examples provide a better picture of the performance of MPAs and show that where a high degree of protection is provided and/or the duration of protection is on a longer term, far greater increases across the four parameters of species biomass, abundance, size and diversity can be achieved. Edmonds Underwater Park in Puget Sound for example at only 0.1 km^2 has had a long history of protection since its establishment in 1970. Work by Palsson and Pacunski (1995) showed that more and larger copper rockfish (*Sebastes caurinus*) and lingcod (*Ophiodon elongatus*) occurred at the Edmonds refuge than at any of the comparable fished areas in central Puget Sound. Copper rockfish numbers at Edmonds were 15 times greater than at the fished sites. Large copper rockfish exceeding 40cm in length were uncommon at the fished sites but were the most common sizes at Edmonds. Lingcod were more than twice as abundant at the long-term refuge where they averaged 91cm in length compared to only 60cm at the fished sites in Puget Sound.

While the benefits of long term protection cannot be ignored here, it is clear that even protection of a small area may exhibit significant recovery. This bodes extremely well for the Arran initiative with a total area of 7.9km^2. Furthermore, situated next to a busy ferry terminal and established principally for recreational diving through the creation of artificial habitat such as sunken boats and cars, Edmonds is certainly not a site specifically chosen for its naturalness or as a critical area for fish.



Redrawn from Palsson & Pacunski (1995)

Long term protection is clearly beneficial as experience from New Zealand also shows. At a similar size to the proposed Arran MPA, the Leigh Marine Reserve established in 1975 has exhibited significant recovery of both fish and lobster populations and has gained the support of local fishermen in the process. Short term recovery of fish populations documented by Cole et al (1990), showed minimal changes in abundance of fish populations with only one species, the red moki (*Cheilodactylus spectabilis*) increasing in abundance over the initial six years of management. Further survey in 1988 however, thirteen years after establishment of the reserve, showed an increased abundance of snapper, blue cod, red moki and rock lobsters. Studies by Babcock et al (1999) in both the Leigh Marine Reserve and Tawharanui Marine Park (Est: 1981, Area: 5.8km^2) showed that the most common demersal predatory fish, the snapper *Pagrus auratus,* were at least 5.8 and 8.7 times more abundant inside reserves than in adjacent unprotected areas. Individuals were also much larger inside reserves with mean total lengths of 316 mm compared with 186 mm in fished areas.

The effects of both short and long term protection were shown by Kelly et al (2000), across four MPAs on the eastern coast of North Island, New Zealand. These sites varied in age from 3 years (Cathedral Cove and Tahua Marine reserves, 9 and 7.8km^2 respectively) to 14 years (Tawharanui Marine Park) to 21 years (Leigh Marine Reserve). This study compared the abundance, size and reproductive output of spiny lobsters, *Jasus edwardsii*, between reserves and similar non-reserve locations. It was shown that the mean density of the total lobster population increased by 3.9% and 9.5% in sallow (<10m) and deep sites (>10m) respectively for each year in which the reserves were established. For recently established reserves this meant an overall increase of 40% across all depths while for Leigh Marine Reserve this meant an increase of 280% across all depth ranges. Mean size of lobsters (given by carapace length) was estimated to increase by 1.14mm per year of protection and as a consequence, lobster biomass (kg/500m^{-2}) was conservatively estimated to increase by 5.4% and 10.9% in shallow and deep sites respectively per year of protection. Based on comparisons to other studies in Leigh Reserve that showed rapid population increases in spiny lobsters in the 8 years after protection, the authors noted that their estimates of abundance were probably very conservative.

Away from New Zealand, Edgar & Barrett (1999) examined the effects of marine reserves on Tasmanian reef fishes, invertebrates and plants. Of the four reserves studied, the largest reserve at Maria Island (approximately equal in size to the proposed Arran trial at 7km^2) exhibited the greatest impact with the number, size and biomass of a range of species all increasing significantly within the reserve relative to reference areas outside the reserve. Over a six year period for example, a 240% rise in the numbers of large fish (>33cm) was noted, relating to an average increase of 2.6 to 9.2/500m^{-2}. Outside the reserve, densities remained constant at approximately 1/500m^{-2}. A massive increase in the abundance of the bastard trumpeter, *Latridopsis forsteri*, was a part of this, with the density of trumpeter within the reserve increasing 100 fold, from an average of 0.04 to 4.9/500m^{-2}. Outside the reserve no trumpeter were recorded at fished sites in either 1992 or 1997. Similar to the New Zealand reserves, rock lobster (*Jasus edwardsii*) numbers showed a 260% increase in the Maria Island reserve, relating to an average of 0.8 /50m^{-2} in 1992 to 2.8/50m^{-2} in 1997. Over the same period, numbers outside the reserve increased by only 12% (from 1.3 to 1.5 / 50m^{-2}).

Evidence also shows that MPAs are beneficial to more sedentary species such as scallops. The Georges Bank fishery closures, USA, are often cited as a classic example. In this case, protection of heavily depleted scallop (*Placopecten magellanicus)* stocks over a 5-year period resulted in scallop biomass increasing 14-fold within the closed areas from 1994-1998 compared to adjacent open areas (Murawski et al 2000). At 17000km^2 however, the Georges Bank closures are often deemed an inappropriate measure to judge the effects of small scale MPAs. Moving closer to home therefore, restrictions on dredging and trawling off the Isle of Man and the resultant changes exhibited by scallops (*Pecten maximus*) can be looked at. At 2km^2 the protected area is more readily comparable to the Arran initiative and the period of closure prior to analysis of effects is also comparable to the trial period for Arran. Bradshaw et al (2001) found that scallop populations increased significantly in the closed area from less than 2/200m^{-2} in 1989 to nearly 15/200m^{-2} in 2000. Scallops in the protected area were also larger and older than those in the fished sites; an important point which will be discussed in following sections.

Having established that various sized temperate MPAs, providing proper protection over a range of time periods can offer significant benefits for both mobile and more sedentary species, it is important to look at the mechanisms behind this as they have direct relevance to the fishery.

4.2 Increased reproductive output

Changes in population structure caused by fishing have been linked to reduced reproductive output as a result of the selective removal of larger and/or older individuals. Rice & Gisalson (1996) showed that fishing in the North Sea has significantly reduced the size diversity of large fish while increasing the size diversity of smaller fish. Catches of cod, *Gadus morhua,* for example, are often comprised of fish below the minimum recommended size that have not even reached sexual maturity [11]. Protection of stock therefore suggests that as fish get older and grow larger, their reproductive output will increase. Importantly this is one of the preconditions to fishery benefits. Studies on North Sea cod, by Marteinsdottir & Steinarsson (1998) for example, established a positive relationship between size of females (related to age) and the number of eggs they produce together with their viability. Such a relationship was also shown for larval viability and size of spawning females.

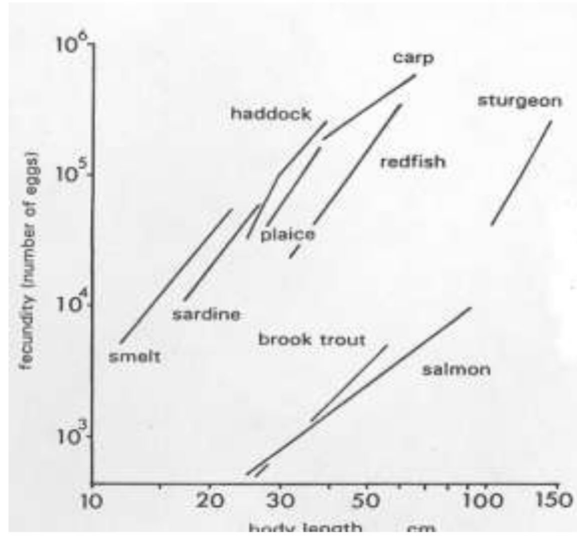


Fig 9. The fecundity of various fish species dependent on length (Bone et al. 1997)

This is consistent with work on haddock (*Melanogrammus aeglefinus*) by Blanchard et al. (2003) who demonstrated that for five different stocks, fecundity increased with length.

In the previous section it was shown that MPAs allowed exploited stocks to live longer, grow larger and increase in abundance. The result of this has been an increase in reproductive output, dramatically demonstrated, for example, by Palsson and Pacunski (1995) at Edmonds Underwater Park, USA, where the egg output is estimated to be equivalent to 50 km of fished coast. Here the greater abundance and size of fish (see section 3.1) has resulted in increased reproductive output for both lingcod and copper rockfish. It was calculated that lingcod in the park produced 20 times more young than those in the fished areas, while copper rockfish produced 100 times more young.

Similar responses in increased reproductive output were reported by Willis et al (2003) at three Marine Reserves in New Zealand. It was demonstrated that snapper, *Pagrus auratus*, larger than the minimum legal size, were estimated to be 14 times denser in protected areas than in fished areas, with the relative egg production estimated to be 18 times higher. Furthermore, a conservative estimate suggested that egg production from a reserve the size of Leigh (approx. 5km of coastline) might produce a quantity of snapper eggs equivalent to that produced by approximately 90 km of unprotected coastline.

Edgar & Barrett (1999) showed that in the Maria Island Reserve Tasmania, the abundance of rock lobsters, *Jasus edwardsii*, increased by 260% over 6 years compared to only 12% outside the reserve. The size of lobsters (measured by carapace length) was also shown to increase with the largest animals encountered inside the reserve increasing in size by approximately 15 mm during each year of monitoring. In 1992 the largest animal observed in the reserve was 110 mm while by 1997 the largest lobster found was 198mm. Numerous individuals between 110 and 200 mm were found within the reserve in 1997, whereas outside the reserve very few individuals exceeded the minimum legal size for the fishery (110 mm for males and 105 mm for females). As a result of this increased size range the estimated reproductive output of rock lobsters in the Maria Island reserve was calculated to have increased by 10 times, with egg production estimated to have risen from 34200 to 343000/50m^{-2} within the reserve. Kelly et al. (2000) reported similar findings for *Jasus edwardsii* in four New Zealand reserves as a result in growth of protected individuals. An overall increase in egg production of 6.7% per year was calculated, meaning a 140% increase in egg production for the Leigh Reserve since its establishment.

Data from the Isle of Man shows that despite a significant drop in numbers of scallops in 2002 due to illegal fishing in the closed area, they were still more abundant than in the fished area. Furthermore there was a significant difference in age structure, size and reproductive potential between the fished and unfished areas. Diver surveys showed that only 5.4 % of scallops collected in the fished area in 2002 were older than 5 years, compared to 40.0 % of those collected from the closed area (Brand et al 2003). Scallops in the closed area were also significantly larger with 55.8% exceeding 13cm compared to only 10.7% in the fished areas. Changes in age and size structure have had important implications for reproductive potential (measured by gonad weight) which in 2002 was nearly 6 times higher per 100m^2 than in the fished area (Brand et al 2003). Figures for 2003 show that the difference in reproductive potential between closed and fished areas were the highest recorded yet, with a 12-fold (12.52) difference (Beukers-Stewart et al., in review). Since fertilisation success is highly dependent on the proximity of spawners, high scallop densities in the closed area could mean that the actual reproductive output was considerably more than12 times greater than `from the closed area(Beukers-Stewart, pers comm). Reduced fishing pressure and the resultant higher survivorship and growth of juvenile scallops in the closed area has also been identified by Brand et al (2003) as being a key factor in increased recruitment to the population. It has been estimated that up to 70% of the total catch consists of undersized scallops that are subsequently discarded. It has been suggested that these discards, and even those scallops left on the seabed that may have been damaged, face reduced survival due to a higher risk of predation (Jenkins et al. 2001).

Like the recovery or maintenance of quality habitat, the recovery of a natural population age structure, with the resulting increase in reproductive potential, has important implications for the stability of fish populations both within and outside protected areas. This is vitally important, as stock stability is often considered to act as the primary factor underlying fisheries benefits. Furthermore, supporting increased stability at the ecosystem level has been widely acknowledged to enable faster recovery following intense disturbance events such as storms or oil spills (Lindeboom 2000, Roberts & Hawkins 2000).

4.3 Do all species benefit?

MPAs have often been seen as appropriate only for reef based species that are relatively sedentary, disperse their young over a wide area and are vulnerable to over-exploitation (Horwood 2000). More mobile species on the other hand are not expected to respond to protection unless significant areas (>70 000km2) are closed to fishing (FSBI 2001). Martell et al (2000) for example, suggest that fish with high exchange rates, large home ranges, or seasonal migrations for spawning require large marine reserves. Their studies into the use of MPAs for lingcod (a species that seasonally migrates to spawn) suggest that small reserves will not offer year round protection from anglers. However, they also note that densities of large spawning animals are higher in the MPAs than on surrounding reefs, which is consistent with increased densities of lingcod in Edmonds Underwater Park (Palsson & Pacunski

1995). Willis et al. (2003) show that the snapper *Pagrus auratus,* another seasonally mobile species, is much more abundant within reserves than in fished areas. While this may be due in part to short term residency in areas of better habitat, Willis et al (2001) have shown that some individuals exhibit a longer term site fidelity, with residency throughout the year.

Fig 10. Lingcod (*Ophiodon elongatus*)

In the North Sea, highly mobile species such as cod and herring are generally not expected to benefit from MPAs unless significant proportions of their ranges are closed (FSBI 2001). The potential of closing large areas of the North Sea to protect cod for example was investigated by the EU in 1993 through the International Council for Exploration of the Sea. At the time, based on current understanding of fish behaviour, it was concluded that closing areas, even as large as one quarter of the North Sea, would do nothing to protect the cod whose mobility would leave it open to exploitation elsewhere (Horwood 2000). Recent investigations (Righton et al. 2001) into behaviour of cod in the North and Irish Sea, however, found substantial differences between the two stocks. Of particular significance were findings that seasonal patterns of activity vary between stocks, with the North Sea cod reducing their foraging movements over the summer months. Like the findings by Willis et al. (2001 & 2003), this challenges generally accepted species behaviour patterns and has serious implications for the management of these fish species. Small reserves have been shown to benefit lingcod and snapper and may also be found to benefit other temperate species, considered to be wide ranging such as cod and haddock. These species may show behavioural shifts in response to factors influenced by MPAs such as increased food abundance and habitat quality. As illustrated in section 3.2, recent evidence (Hinz et al. 2003) showing that such species may exhibit a high degree of site fidelity supports this.

The demands of fisheries mean that in coastal regions it is unlikely that a reserve can be made large enough to provide full protection for all but the most sedentary species. Partial protection is, however, intrinsic to delivery of fishery benefits; the key to maximising these benefits is providing protection when species are most vulnerable to capture such as at critical stages in their lifecycle – breeding and spawning for instance. Protection of spawning aggregations has for example been fundamental in designing a network of MPAs in the Gulf of California (Sala et al.2002).

5.0 The 'reserve effect': mechanisms underlying fisheries benefits

Mechanisms benefiting MPAs, such as increased stock stability due to improved habitat quality and recovery of a natural population age structure, clearly have implications for fisheries too. It is often difficult therefore to separate initial benefits to the MPA, which could be seen as conservation objectives, to those of the fishery.

The inclusion of increased fishery stability due to protection of habitat in the previous section testifies to this.

Aside from increased fishery stability due to improved habitat, benefits to the fishery will also accrue as a result of the 'reserve effect'. This has typically been defined as the movement of fish stocks, from protected areas, at different stages of their life cycles into adjacent fished areas. Evidence from section 4.1 and 4.2 shows that the conditions for fisheries benefits have been met: translating these into actual benefits depends on export of fish biomass into the fished areas.

5.1 Mechanisms of export to the fishery

Theory predicts that as stocks within a MPA increase, spillover of individuals into the fished areas will occur, either passively - based on natural movements - or through density dependent mechanisms such as resource limitation (Kramer & Chapman 1999). Although it has been suggested that highly mobile species in UK waters, such as cod, may benefit from small-scale MPAs (section 4.3), benefits to the fishery via spillover may only be apparent if protection allows build up of stocks to a level above that outside the protected area. The degree of fishery enhancement will of course be dependent on the difference between populations within and outside the MPA and the level of spillover. As a result of this, it is expected that those species of intermediate mobility will contribute most to the fishery via spillover. For species with high movement rates, potential build up within the reserve is offset by a high degree of movement into the fished area and subsequent capture. For species with low movement rates, individuals rarely move out of the reserve area while for species with moderate movement rates, the rate of movement outside the reserve would not negate increased abundance within the reserve (Gerber et al. 200)

Sedentary species, such as oysters and mussels, and species that can be effectively considered sedentary, such as scallops, are expected to show the greatest recovery within reserves (Horwood 2000, Kramer & Chapman 1999). Benefits to the fishery will not be met through spillover, but rather through larval export, as a result of increased abundance coupled with recovery of the population age structure and associated gain in reproductive potential. It becomes clear therefore that for a variety of species, fishery benefits will be derived from both spillover and recruitment from MPAs.

For Lamlash Bay the efficacy of the mechanisms leading to fisheries benefits will vary across the range of species that presently inhabit the bay or recolonise it in the future. For the scallop population, an analysis of current patterns along the east coast of Arran and into and out of Lamlash Bay (Alan Hills, SEPA. Pers comm) indicates that a proportion of scallop larvae would inevitably be transported to areas outside the bay and potentially enhance recruitment. It is clearly evident that the transport mechanism exists, but as discussed earlier, the potential for enhanced recruitment depends on the level of increased reproductive output. Evidence from elsewhere indicates that cessation of scallop fishing in Lamlash Bay will result in such an increase, due to recovery of a more mature population and build up of stocks. Export of larvae from the bay is then expected to result in increased recruitment to the fished areas.

5.2 Evidence for recruitment to fished areas.

Many studies have demonstrated that full protection can lead to increased abundance of previously exploited species with the associated recovery of an extended population age structure and resultant increases in reproductive output. Increased reproductive output however, does not translate directly into increased recruitment, which has been shown to vary considerably due to numerous biological, physical and environmental factors (Borja et al. 1998, Williams & Quinn 2000). Of these, temperature often has a critical part to play. The variability of recruitment from year to year has meant that it has often been difficult to separate reserve-derived benefits from natural variation. Beukers-Stewart et al (in review), for example, found increased recruitment of scallops outside areas closed to scallop dredging relative to increases in reproductive potential of scallops within the closed area. While the general increase in recruitment may have partly been due to higher than average sea temperatures, it was noted that the greatest increases occurred in the areas immediately surrounding the closed area. This suggests that scallop reproduction in the closed area was contributing to scallop populations in the fished areas to at least some extent; a view also supported by the fishermen (Beukers-Stewart. pers comm.)

Evidence from changed fishing patterns was also used to infer increased recruitment due to large-scale closures on the Georges Bank. In this case, a 14-fold increase in scallop biomass over a five-year period, resulted in scallop biomass densities reaching 9 and 14 times the level in fished areas (Muraswki et al. 2000). A resultant shift in fishing was noted with scallop fishers preferentially targeting sites immediately around the closed area (Rago & McSherry 2001[(12)]).

Although it has been acknowledged that it is often difficult to separate reserve benefits from natural variation in recruitment due to various factors, it is important not to ignore increased recruitment where environmental data or evidence for spatial shifts in fishing effort is lacking. In Fiji, closure of a $0.24 km^2$ mudflat area to clam (*Anadara* spp) harvesting was implemented as a management strategy in response to the decline of this species as a food source over the preceding years. After four years of management a 1353% increase in numbers was seen in the closed area and a 523% increase in the fished area. A year later this increased to 1796% and 719% respectively (Tawake et al. 2001). While the effects of other factors apart from fishery closure need to be acknowledged, they cannot account for all possible variation, especially considering the timing of recovery. Consequently, this evidence cannot be ignored and even while a tropical example has been drawn on, it is done to specifically highlight evidence for recruitment to fished areas from sedentary species.

The need to use a tropical example draws attention to the general lack of definitive evidence for increased recruitment to the fishery from closed/protected areas. Shellfish are used as the primary evidence as their sedentary nature enables spillover to be separated from recruitment via transport of eggs and larvae. Studies on more mobile species have shown a dramatic increase in reproductive potential for individuals within closed areas. Palsson and Pacunski (1995) calculated that copper rockfish in Edmonds Underwater Park produced 100 times more eggs than in adjacent fished areas while lingcod produced 20 times more eggs. Overall it was estimated that the area produced as many young copper rockfish as 50 km of fished shoreline in Puget Sound. While the actual level of recruitment to the fishery could not be assessed, the small size of the park certainly means that export to fished areas will be ensured, so it cannot be denied that such an increase in reproductive output will have some significance. For stocks of spiny lobster in New Zealand marine reserves, Kelly et al (2000) noted that even where recruitment to fished areas could not be established, the use of marine reserves to ensure adequate spawner stocks would be prudent.


Fig 11. Copper rockfish (*Sebastes caurinus*)

The general view is that even where increased recruitment cannot be proven, it has yet to be disproved, and that MPAs will enhance recruitment to fishing grounds (Gell & Roberts 2003a). Although the effects of recruitment to the fishery will be dependent on the size of the spawning population protected, compared to the fished population and the level of recruitment, the success of a MPA could be measured on its ability to compensate for loss of fishing grounds. In other words, a MPA need not necessarily provide benefits for the entire stock as is commonly advocated, but if increased recruitment from the MPA can compensate for loss of catch from within its boundaries, then conservation needs have been met without compromising the fishery. Anything above this only enhances the fishery; a case which is true for spillover as well.

5.3 Spillover to the fishery

One of the main conditions for spillover is that densities of fish build up inside reserves to levels higher than outside reserves. It is then predicted that fisheries benefits will accrue due to natural movement across reserve boundaries. The evidence for build up of biomass inside reserves has already been proven for a variety of species, but separating fisheries benefits derived from increased recruitment or spillover has often proved difficult (Roberts & Hawkins 2000). For fish species, increased abundance outside reserves may be due to both recruitment and spillover of adults.

If any support is needed for the assumption that fish will inevitably move out of reserves, it comes from tagging studies of fish and crustaceans in particular, showing movement across reserve boundaries or of sufficient distance that individuals could potentially move into fished areas. Dispersal of the surf-zone fish, galijoen (*Coracinus capensis*) from the De Hoop Marine reserve, South Africa, for example, was investigated in order to asses reserve benefits for this species. Tagging (11,022 fish) and subsequent recovery (1,108 fish) over a five-year period, showed that while 72% of the fish recovered had not moved further than 5km from their release site, 18% had moved a minimum of 25km (and up to 1044km) away. These fish were found spread fairly evenly across the range of the southern population (Attwood & Bennett 1994). This showed that dispersal behaviour varied widely within the population, with some fish showing a degree of site fidelity while others dispersed widely. In view of earlier evidence (Bennett & Attwood 1991) that the reserve exhibited significant recovery of the galjoen following prohibition of all fishing activities, it was concluded that the reserve was contributing to the fishery through provision of fish to both nearby and distant grounds.

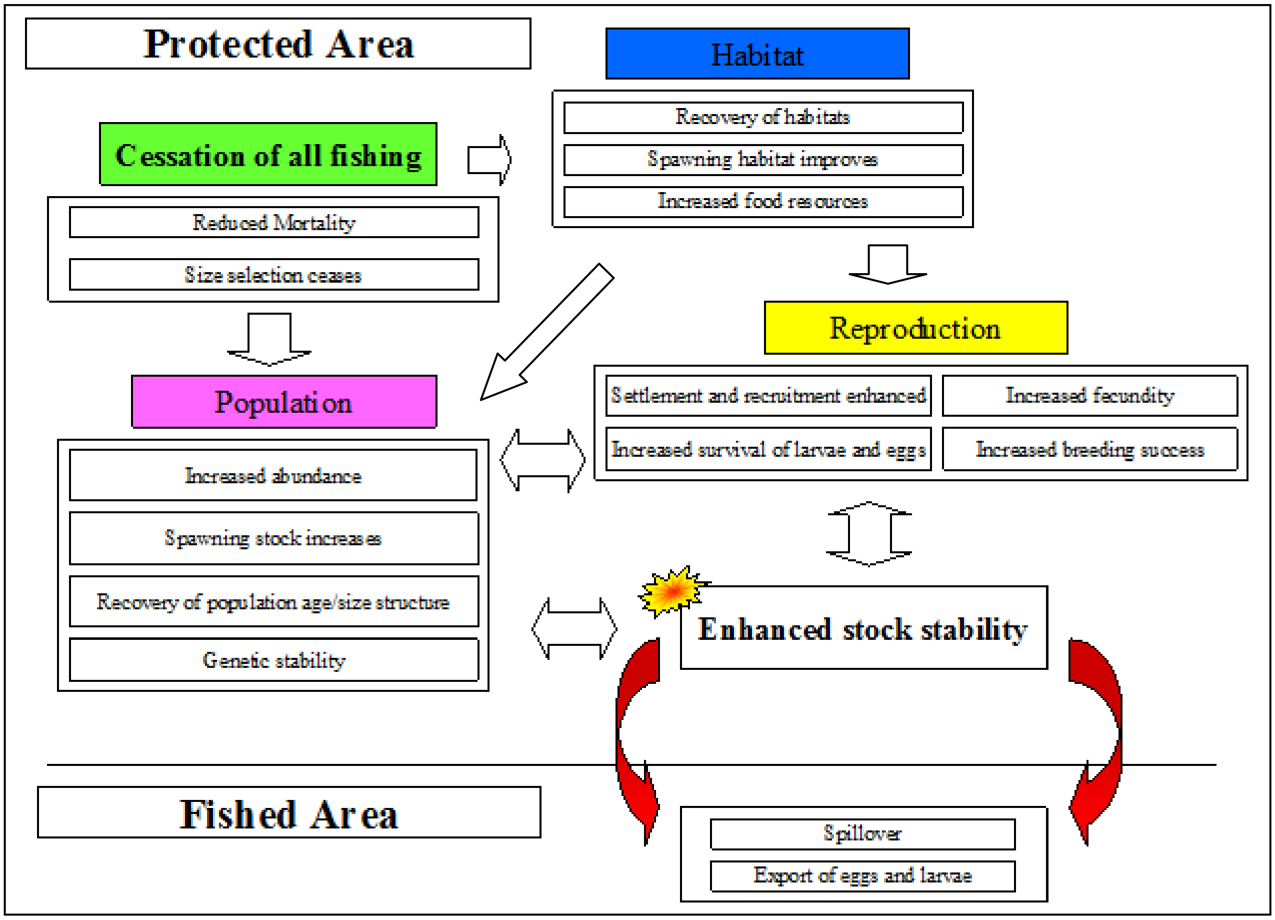
For other fish species, the value of adult spillover may be minimal. Willis et al. (2001), for example, demonstrated that snapper, *Pagrus auratus*, in Leigh Marine Reserve, showed long term site fidelity across a range of sizes. This contradicted earlier beliefs that only large snapper established long-term residency on reefs. More recent studies (Willis et al. 2003) suggested that if any fish were displaced from the reserve it was more likely to be younger individuals that would be of little benefit to the fishery. It was suggested, however, that high densities of large older snapper could mitigate against the loss of genetic diversity. Furthermore, the reduction in spillover as a result of high site fidelity could potentially be offset by increased reproductive output from protection of an older, larger population.

Studies on the spiny lobster (*Jasus edwardsii*), in Leigh Marine Reserve, have shown that while the reserve decreases spatial access to fishing grounds, a significant proportion of the population does become available to fishermen. Tagging studies (Kelly & MacDiarmid 2003) revealed that seasonal fluctuations in the abundance of legal sized lobsters in the reserve could be explained through movements (approx 20% of lobsters) across reserve boundaries. The range of movements, (between 0.25 and 6.0 km) is consistent with other studies (Booth 1997) on the movements of *Jasus* spp which indicate that such dispersal and migration is crucial to recruitment along coasts.

Elsewhere, the differential dispersal and migration of other lobster species has also been shown. On the south coast of England, for example, juvenile European lobsters, *Homarus gammarus*, have been shown to move distances up to 3.8km. Movements over 5km were generally shown by larger, mature lobsters (Smith et al. 2001).Tagging studies on the American lobster, *Homarus americanus* (Estrella & Morrissey 1997), off the eastern shore of Cape Cod, Massachusetts, revealed that 39% of the recaptured lobsters moved less than 10 km from point of release. 45.5% were recaptured within 10 to 40 km from their points of release and 15.5% were found 40km or more away. The implications for a MPA are clear; differential movements will result in part of the population remaining within the MPA, while another proportion moves outside the boundaries, becoming available to fishermen. Outside migration times, a build up of biomass and increasing reproductive output of lobsters inside the MPA will support nearby fisheries, through spillover upon migration and dispersal and increased recruitment through export of larvae.

It has often proved difficult to show increased densities of fish outside reserves and even more so to link any differences to the reserve effect. A lack of change over time may be attributable to fishermen taking any spillover before it can be observed through study. There is compelling evidence for this through changes in fishing behaviour around reserves, where fishermen have been observed 'fishing the line', i.e. fishing along or close to the reserve boundary. Observational evidence from reserves in Tasmania (Edgar & Barrett 1999) and New Zealand (Kelly et al. 2000) shows that fishermen preferentially set nets and pots on reserve boundaries This suggests that catches of both fish and lobsters are higher in these areas. While this may be judged to represent only perceived benefits, the perception is supported by commercial catch data, which shows that economic value of lobster catches around the boundaries of Leigh Reserve, New Zealand, is equal to or higher than areas remote from the reserve (Kelly et al. 2002). The expected variability in catches around the reserve due to temporal migrations was exhibited, with catches far more variable than in areas with unrestricted access to lobsters. Overall, however, fishermen believed that they did benefit from the reserve and generally commented that they would report illegal fishing (Hoskin P 2001).

5.4 Summary of the mechanisms supporting fisheries



6.0 Conservation and fisheries management

It is important to note that for the majority of examples throughout this study, MPAs were implemented primarily for conservation purposes. Any fisheries benefits that did accumulate helped to offset the loss of fishing grounds inherent in the designation of MPAs. It is important to highlight this point, as failure to exhibit fisheries benefits need not signify that the MPA is falling short of its goals. Set up for conservation purposes, these reserves are meeting their objectives and criticism over failures to meet any objectives belatedly imposed upon them should take account of this.

The use of MPAs for conservation has been well recognised to rest on the strength and quality of design (Halpern & Warner 2002) and failure of MPAs has often been the result of design not being commensurate with objectives (Gell & Roberts 2003a). The success of MPAs for fisheries management alone is also dependent on a set of robust design criteria (Gerber et al. 2002) that may, in some respects, be significantly different from those used for conservation purposes. The extent to which a MPA will function as both a fishery and conservation tool will therefore depend on the integration of criteria designed to meet both these objectives [(5)].

Traditional fisheries management measures have typically taken the form of protecting spawning grounds, nursery areas and breeding sites. If MPAs are to be used specifically as both conservation and fisheries management tools, they too need to take into account critical life cycle stages to optimise benefits to a given level of protection. With increasing recognition about the need to integrate conservation and fisheries into an ecosystem-based approach (Jennings & Kaiser 1998) such optimisation approaches are increasingly being considered e.g. Sala et al (2002).

7.0 Conclusions

Having discussed the various mechanisms to the delivery of fishery benefits from MPAs and looked at the evidence for this, the question over whether The Arran Marine Regeneration Trial can deliver fisheries benefits still remains. Departing from the ease of considering the whole of Lamlash Bay area as a no-take zone in comparisons to other MPAs, the objectives of the trial need to be considered against its design. The objectives highlighted in 2.1 can be placed broadly into conservation and fishery categories. It must be noted, however, that fisheries related benefits are expected as an offshoot of conservation objectives and should not be considered as primary objectives themselves. Fishery benefits are 'hoped' for and 'expected', as the scope of the trial is to 'demonstrate the comparative difference between the regeneration of marine life within the no-take zone, to that of the MPA* and the status quo which will be the area immediately outside Lamlash Bay' [(8)]. The category we are mainly interested in here is that of fisheries related benefits, but as these are dependent on conservation success (i.e. habitat improvements and increased abundance/diversity etc of marine life without considering fisheries), a cross over will inevitably exist in discussion.

Based on present evidence, cessation of scallop dredging within the MPA is likely to result in a significant increase in numbers of scallops and the recovery of a natural population age structure. A resultant increase in reproductive output will further support population growth within the MPA and also lead to increased recruitment in the fished areas through larval dispersal. Benefits to the fishery are expected to build over time as the size and reproductive output of the stock within Lamlash Bay increases. Early on (5-10 years) recruitment to the fished areas may be expected to balance the loss of fishing grounds and later, actively enhance the fishery above the level of simply balancing loss. A large stock of scallops within Lamlash Bay will also enhance the stability of the fishery against declining reproductive output where populations have been reduced through natural or man-made disturbance.

It is clear from examples used throughout this study that species will respond differently to cessation of fishing depending on a variety of factors. For many species, particularly those of low or intermediate mobility, protection within the no-take zone will lead to increased abundance and biomass, a recovery of population age structure and increased reproductive output. Habitat improvements (measured by complexity through indices of species abundance and diversity) as a result of cessation of the use of mobile gears, especially scallop dredging, will support this.

* i.e the area closed to mobile gears and scallop diving.

Based on weight of evidence, and considering the importance of Lamlash Bay as an area of high productivity it is likely that protection of targeted species is likely to result in their rapid recovery leading to increased recruitment to the fished area. Sala et al. (2002) highlighted the importance of including critical habitats within reserves if they are to prove successful. The presence of Maerl beds within Lamlash Bay therefore strengthens the case for expected conservation and fishery benefits.

It is clear that for wider fishery benefits to occur the scale and design of the MPA needs to be assessed. Amongst the factors affecting the fishery benefits of a protected area, one is the relative size of the area to that of the fishery (Gell & Roberts 2003b, Kelleher 1999). It must be accepted that because of the small size of the proposed MPA, fishery benefits will be restricted. The plan for the Arran Marine Regeneration Trial already proposes closure of the bay to scallop fishing to achieve maximum benefits; extending the no-take zone over a similar area should be therefore be considered to maximise fishery benefits. This move may be especially significant as it readdresses the difference between size of closures to mobile gear compared to fixed gears which, in other areas, have been identified as a source of considerable conflict (Hoskin 2001). However because of the advanced stage of stakeholder negotiations and the strong community support this project has in practice a far greater chance of success than any imposed MPA without local support.

Considering MPAs in general, evidence from a variety of studies shows that small scale, temperate MPAs have the potential to achieve both conservation and fisheries benefits for a number of species e.g. Beukers-Stewart et al. (in review), Edgar & Barrett (1999), Kelly & MacDiarmid (2003), Palsson & Pacunski (1995). Where designed correctly, MPAs may actively support and benefit the fishery above the level of simply balancing the loss of fishing grounds. This is especially important for fishermen who potentially face the loss of these grounds, often without recompense.

In the UK the use of MPAs is still in its infancy and projects such as the Arran Marine Regeneration Trial and The Lyme Bay Reefs Project [(13)] afford a valuable base for the scientific assessment of the potential for MPAs as fishery management tools. The case for the Arran Marine Regeneration Trial is a good one, supported by the success of MPAs in other temperate regions of the world for a variety of species and over a range of sizes. With growing environmental awareness and demand for food, an approach to resource use needs to tackle both fisheries and conservation objectives. It is clear from various fisheries management measures already in place, such as protection of breeding and nursery areas, that in the UK, fishermen have long recognised that for fisheries to be economically sustainable they must also be ecologically sustainable. Furthermore, fisheries are coming under increasing pressure from both government and public bodies to adopt various management procedures for conservation objectives. While the statutory mechanism has existed for the imposition of an MPA under the Inshore Fisheries (Scotland) Act 1984, the implementation of the Water Framework Directive sets a wider context for the maintenance of good ecological condition for all coastal waters, and may well initiate further national and European policy on marine and coastal protection [(14)].

The Arran Marine Regeneration Trial provides the opportunity to meet economic and ecological objectives through the adoption a whole ecosystem approach. Evidence indicates that the trial should significantly benefit the local scallop fishery and while the fishery effects for other species still need to be determined, the trial provides the opportunity for a small-scale study that may set up precedents to a novel approach to UK fisheries management in the future. Judging by the decommissioning of 63 vessels in Scotland in 2003 [15], and more recent calls to cut the UK whitefish fleet by 13% [16], new fisheries management practices are clearly in order.

Glossary

Benthos/Benthic: the *benthic* zone defines the seabed and so those organisms attached to, or living on, in or near, the seabed, including that part which is exposed by tides are referred to as the *benthos.*

Biodiversity: the variability among all species. Considering an ecosystem, *biodiversity* refers to the variety of flora and fauna present.

Biomass: the overall mass of organisms in an environment. An important parameter as, of two populations with the same number of individuals, the population with the highest *biomass* will be of more value to a fishery.

By-catch: species caught unintentionally. In a fisheries context it is often used to define unintentional catch of fish. From a conservation perspective may include birds, *benthic* fauna etc.

Closed area: area closed to particular fishing practices or species.

Community: a group of organisms occurring in a particular environment. May be subdivided into more specific types such as a fish community and, like *ecosystems* defined on a variety of different scales.

Ecosystem: the complete biological *community* of an area including the physical environment. May be defined on a variety of scales from 'The North Sea Ecosystem' down to smaller units such as inlets. An *ecosystem* approach to management therefore looks at an area and the interactions between all species within it, as opposed to single species.

Epifauna: animals living on and generally attached to, the surface of the seabed, making up part of the *benthos.*

Fecundity: the reproductive output of an organism. May often be measured in the number of eggs produced or for those species that do not bear eggs, the number of live young produced. Fecundity may often be balanced against survivorship, so although some species may have low fecundity, this is offset against increased survivorship of their young.

Infauna: animals living within the seabed such as burrowing molluscs and polychaete worms such as the lugworm. Like the *epifauna* they make up part of the *benthos.*

Intertidal: the zone between spring high and low waters i.e. the area between maximum and minimum tides.

No-take zone: area closed to all fishing and other extractive uses. For management purposes may impose other criteria such as anchoring regulations to limit damage.

Recruitment: often takes on a broad meaning. For fisheries scientist's, recruitment is when fish/shellfish/crustaceans etc become available to the fishery. In this study, where defined, it has been used in the fisheries context but also to describe the replenishment from protected areas to fished populations at any life cycle stage.

Spawning stock: the amount of reproductively active fish present in a population. Expressed in terms of *biomass* or abundance.

Sublittoral: the zone exposed to air only at its upper limit by the lowest spring tides**.** Often used to define a type of biological community rather than the area and so practically speaking often refers to rocky shorelines from the upper limit of the large kelps.

Subtidal: areas below the spring low water mark i.e. permanently covered by water.

Target species: those species that are specifically targeted by fishermen.

References

Alcala AC (1988) Effects of protective management of marine reserves on fish abundance and fish yields in the Philippines. *Ambio* **17**: 194-199

Alverson DI, Freeberg MH, Pope JG & Murawski SA (1994) a global assessment of fisheries bycatch and discards. FAO Fisheries Technical Paper No. 339. 233pp.

Attwood CG & Bennett BA (1994) Variation in dispersal of galjoen (Coracinus capensis) (Teleostei: Coracinidae) from a marine reserve. *Canadian Journal of Fisheries and Aquatic Science* **51**:1247-1257.

Auster PJ, Malatesta RJ, Langton RW, watling L,Valentine PC, Donaldson CLS, Langton EW, Shepard AN & Babb IG (1996) the impacts of mobile fishing gear on seafloor habitats in the Gulf of Maine (Northwest Atlantic): implications for conservation of fish populations. *Reviews in Fisheries Science* **4**:185-202.

Babcock RC, Kelley S, Shears NT, Walker JW, Willis TJ (1999) Changes in community structure in temperate marine reserves. *Marine Ecology Progress* **189**: 125-134.

Ball B, Munday B, Tuck I (2000) Effects of otter Trawling on the benthos and environment in muddy sediments. In: Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp69-82. Blackwell Science, Oxford, England. 399pp.

Barnes RSK & Hughes RN. 1999. An Introduction to Marine Ecology 3rd ed. Blackwell Science, Oxford. 285pp.

Bennett BA & Attwood CG (1991) Evidence for recovery of a surf-zone fish assemblage following establishment of a marine reserve on the south coast of South Africa. *Marine Ecology Progress Series* **75**:173-181

Bergman MJN & Van Santbrink JW (1994) Fishing mortality of populations of megafauna in sandy sediments. In: Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp49-68. Blackwell Science, Oxford, England. 399pp.

Beukers-Stewart BD, Vause BJ, Mosley MWJ, Rossetti HL and Brand AR. Benefits of closed area protection for a population of scallops. *Marine Ecology Progress Series*. In Review.

Birkett DA, Maggs C & Dring MJ (1998) Maerl: an overview of dynamic and sensitivity characteristics for conservation management of marine SAC's. Prepared for the Scottich Association of Marine Science (SAMS) for the UK Marine SAC's Project. 117pp.

Blanchard JL, Frank KT, Simon JE (2003) Effects of condition on fecundity of total egg production of eastern Scotian Shelf haddock (*Melanogrammus aeglefinus*). *Canadian Journal of Fisheries and Aquatic Science* **60**: 321-332.

Booth JD (1997) Long-distance movements in *Jasus* spp. and their role in larval recruitment. *Bulletin Of Marine Science* **61**:111-128.

Bone Q, marshall NB & Blaxter JHS. 1997. Biology of Fishes. Chapman & Hall. London. 332pp.

Borja A, Uriarte AS, Egaña J, Motos I & Valencia V (1998) Relationships between anchovy (*Engraulis encrasicolus*) recruitment and environment in the Bay of Biscay (1967-1996) *Fisheries Oceanography* **7**(3): 375-380.

Bradshaw C, Veale LO, Hill AS & Brand AR (2001) The effect of scallop dredging on Irish Sea benthos: experiments using a closed area. *Hydrobiologia* **465**:129-138.

Brand AR, Beukers-Stewart BD, Vause BJ and Mosley MWJ. (2003) Shellfish Research Report to the Isle of Man Government, Department of Agriculture, Fisheries and Forestry. 50pp.

Buxton CD & Smale MJ (1989) Abundance and distribution patterns of three temperate marine reef fish (Teleosteii: Sparidae) in exploited and unexploited areas off the southern cape coast. *Journal of Applied Ecology* **26**: 441-451.

Cole RG, Ayling TM & Creese RG (1990) Effects of marine reserve protection at Goat Island, northern New Zealand. *New Zealand Journal of Marine and Freshwater Research* **24**: 197-210.

Edgar GJ & Barrett NS (1999) Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. *Journal of Experimental Marine Biology and Ecology* **242**: 107-144.

Eleftheriou A, & Robertson MR (1992) The effects of experimental scallop dredging on the fauna and physical environment of a shallow sandy community. *Netherlands Journal of Sea Research* **30**:289-299.

Estrella BT & Morrissey TD (1997) Seasonal movement of offshore American lobster, Homarus americanus tagged along the eastern shore of Cape Cod, Massachusetts *Fishery Bulletin* **95** (3): 466-476.

FSBI (2001) Marine Protected Areas in the North Sea,. Briefing Paper 1. Fisheries Society of the British Isles, grant information systems, Cambridge UK.

Gell FR & Roberts CM. 2003a. The Fishery Effects of Marine Reserves and Fishery Closures. WWF-US, 1250 24th Street, NW, Washington, DC 20037, USA.

Gell FR & Roberts CM (2003b) Benefits beyond boundaries: the fishery benefits of marine reserves. *Trends in Ecology and Evolution* **18**: 448-455.

Gerber LR, Kareiva PM & Bascompte J (2002) The influence of life history attributes and fishing pressure on the efficacy of marine reserves. *Biological Conservation* **106** (1):11-18.

Halpern BS (2003) the impact of marine reserves: do reserves work and does size matter? *Ecological Applications* **13**(1): 117-137.

Halpern BS & Warner (2002) Marine reserves have rapid and lasting effects. *Ecology Letters* **5**:361-366.

Hall-Spencer JM & Moore PG (2000a) Impact of scallop dredging on maerl grounds. In: Kaiser MJ & de Groot eds. 2000.Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp105-117. Blackwell Science, Oxford, England. 399pp.

Hall-Spencer JM & Moore PG (2000b) Scallop Dredging has profound, long-term impacts on maerl habitats. *ICES Journal of Marine Science* **57**: 1407-1415.

Hinz H, Kaiser MJ, Bergmann M, Rogers SI, Armstrong MJ (2003) Ecological relevance of temporal stability in regional fish catches. *Journal of Fish Biology* **63**: 1219-1234.

Horwood JW (2000) No-take zones: a management context. In: Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp105-117. Blackwell Science, Oxford, England. 399pp.

Hoskin M (2001) St Agnes Shell-Fisheries Voluntary No-take Zone:Interim Report 2001. Unpublished report for Cornwall County Council, Objective One Fisheries Fund, English Nature, Cornwall Sea-Fisheries Committee & The Cornish Fish Producers Organisation.

Hoskin P (2001) No Take Zones: working towards sustainable local fisheries. Unpublished report for the Winston Churchill Memorial Trust.

Hutchings JA (1996) Spatial and temporal variation in the density of northern cod and a review of hypotheses for the stock's collapse. *Canadian Journal of fisheries and Aquatic Science* **53**: 943-962.

Hutchings JA (2000) Collapse and recovery of marine fishes. *Nature* **406**: 882-885.

Jennings S, Marshall SS, Polunin NVC (1996) Seychelles' marine protected areas:comparitive structure and status of reef fish communities. *Biological Conservation* **75**: 201-209.

Jennings S & Kaiser MJ (1998) The effects of fishing on marine ecosystems. *Advances in Marine Biology* **34**:201-352.

Kaiser MJ & Spencer BE (1996). The effects of beam-trawl disturbance on infaunal communities in different habitats. Journal of Animal Ecology **65**:348-358.

Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp105-117. Blackwell Science, Oxford, England. 399pp.

Kaiser MJ, Spencer FE & Hart PJ (2000) Fishing-gear restrictions and conservation of benthic habitat complexity. *Conservation Biology* **14**(5): 1512-1525.

Kelleher G (1999) Guidelines for Marine Protected Areas. IUCN Gland, Switzerland and Cambridge, UK. xxiv +107pp. *

Kelly S, Scott D, Mac Diarmid AB & Babcock RC (2000) Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. *Biological Conservation* **92**: 359-369.

Kelly S, Scott D & MacDiarmid AB (2001) The value of a spillover fishery for spiny lobsters around a marine reserve in northern New Zealand. *Coastal Management* **30**:153-166.

Kelly S & MacDiarmid AB (2003) Movement patterns of mature spiny lobsters, *Jasus edwardsii*, from a marine reserve. *New Zealand Journal of Marine and Freshwater Research* **37**:149-158.

Kramer DL & Chapman MR (1999) Implications of fish home range size and relocation for marine reserve function. *Environmental Biology of Fishes* **55**:65-79.

Lindeboom J (2000) the need for closed areas as conservation tools. In: Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp290-302. Blackwell Science, Oxford, England. 399pp.

MacCall AD. 1990. Dynamic Geography of Marine Fish Populations. University of Washington Press. Seattle. 153pp.

Marteinsdottir G & Steinarsson A (1998) Maternal influence on the size and viability of cod (*Gadus morhua*) eggs and larva. *Jounal of Fish Biology* **52**:1241-1258.

Martell, SJD, Walters CJ, Wallace CC (2000) The use of marine protected areas for conservation of lingcod (Ophiodon elongatus). *Bulletin of Marine Science* **66**(3):729-743.

McClanahan TR, Glaesel H, Rubens J, Kiambo R (1997) The effects of traditional fisheries management on fisheries yields and the coral reef ecosystems of southern Kenya. *Environmental Conservation* **24**: 1-16.

McClanahan TR, Mangi S (2001) Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecological Applications* **10**:1792-1805.

Murawski SA, Brown R, Lai H-L, Rago PJ, Hendrickson L (2000) Large Scale closed areas as a fisheries management tool in temperate marine ecosystems: the Georges Bank experience. *Bulletin of Marine Science* **66**: 775-798.

Palsson WA & Pacunski RE (1995)** The Response of Rocky Reef Fishes to Harvest Refugia in Puget Sound. Proceedings Vol 1: Puget Sound Research ’95. Puget Sound Water Quality Authority, Olympia, Washington.

Rice J & Gisalson H (1996) Patterns of change in the size spectra of numbers and diversity of the North Sea Fish assemblage, as reflected in surveys and models. *ICES Journal of Marine Science* **53**:1214-1225.

Roberts CM & Hawkins JP. 2000. Fully-protected marine reserves: a guide. WWF Endangered Seas Campaign, 1250 24th Street, NW, Washington, DC 20037, USA and Environment Department, University of York, York, YO10 5DD, UK.

Roberts CM & Polunin NVC (1993) Marine Reserves: simple solutions to managing complex fisheries? *Ambio* **22**: 363-368.

Rodwell LD, Barbier EB, Roberts CM & McClanahan TR (2003) The importance of habitat quality for marine reserve – fishery linkages. *Canadian Journal of Fisheries and Aquatic Science* **60**: 171-181.

Sala E, Aburto-Oropeza O, Paredes G, Parra I, Barrera JC & Dayton PK (2002) A general model for designing networks of marine reserves. *Science* **298**(5600): 1991-1993.

Smith IP, Jensen AC, Collins KJ, Mattey EL (2001) Movement of wild European lobsters, *Homarus gammarus*, in natural habitat. *Marine Ecology-Progress Series* **222**: 177-186.

Tasker ML, Knapman PA, Laffoley D (2000) Effects of fishing on non-target species and habitats: identifying key nature conservation issues. In: Kaiser MJ & de Groot eds. 2000. Effects of Fishing on Non-Target Species and Habitats: Biological, conservation and socio-economic issues.pp281-289. Blackwell Science, Oxford, England. 399pp.

Tait RV & Dipper FA. 1998. Elements of Marine Ecology 4th ed. Butterworth-Heinemann, Oxford. 437pp.

Tawake A, Parks JE, Radikedike P, Aalbersberg B, Vuki V & Salafsky N (2001) Harvesting clams and data:involving local communities in monitoring: A case in Fiji. *Conservation Biology in Practice* **2**(4): 32-35.

Ward T & Hegerl E (2003)*** Marine Protected Areas in Ecosystem-based Management of Fisheries. A report for the Department of Environment and Heritage, Australia.

Watling L & Norse EA (1998) Disturbance of the seabed by mobile fishing gear: A comparison to forest clearcutting. *Conservation Biology* **12**(6): 1180-1197.

Williams EH & Quinn TJ (2000) Pacific herring, Clupea pallasi, recruitment in the Bering Sea and north-east Pacific Ocean, II: relationships to environmental variables and implications for forecasting. *Fisheries oceanography* **9**(4): 300-315.

Willis TJ, Parsons DM, Babcock RC (2001) Evidence for long-term site fidelity of snapper (Pagrus auratus) within a marine reserve. *New Zealand Journal of Marine and Freshwater Research* **35**: 581-590

Willis TJ, Millar RB, Babcock RC (2003) Protection of exploited fish in temperate regions:high density and biomass of snapper Pagrus auratus (Sparidae) in northern New Zealand marine reserves. *Journal of Applied Ecology* **40**(2): 214-227.

*Available at:
Guidelines for Marine Protected Areas. IUCN Gland, Switzerland and Cambridge, UK. xxiv +107pp.

**Available at:
Marine Refuges offer a haven for Puget Sound Fish.
http://wdfw.wa.gov/science/articles/marine_sanctuary/index.html

***Available at:
Marine Protected Areas in Ecosystem-based Management of Fisheries. A report for the Department of Environment and Heritage, Australia.
http://www.deh.gov.au/coasts/mpa/wpc/pubs/mpas-management-fisheries.pdf

(1) MPA News 5(8) 2004: Ecuadorian Government agrees to review Galapagos fisheries regulations following seizure of park facilities by fishermen.
http://depts.washington.edu/mpanews/MPA50.pdf

(2) FishNet USA (6) 1999 – Anatomy of an Anti fishing Campaign
http://www.fishingnj.org/netusa6.htm

(3) Coastal Conservation Organisation- Freedom to fish Campaign
http://www.joincca.org/con%20columns/2002/FTF%20cc1.htm

(4) Maine Fisherman's Forum – Using Marine Protected Areas for fisheries management in the Gulf of Maine
http://www.seagrant.umaine.edu/Extension/Fisheries/mpa03/mpa03.pdf

(5) MPA News 1 (2) 1999: International workshop gives recommendations for MPA planning process
http://depts.washington.edu/mpanews/MPA2.htm

(6) MPA News 5 (7) 2004. Australia to compensate fishers impacted by MPAs
http://depts.washington.edu/mpanews/MPA50.pdf

(7) Fisheries research services
http://www.marlab.ac.uk/FRS.Web/Uploads/Documents/SS-Nephrop%20North%20Sea.pdf

(8) The Arran Marine Regeneration Trial - Business Plan
www.arrancoast.co.uk/busplan.htm

(9) UN Food and Agriculture Organisation –World Review of Fisheries and Aquaculture
http://www.fao.org/docrep/005/y7300e/y7300e04.htm#P746_35154

(10) MPA News 5(7) 2004. No-take zones are not the only way to achieve benefits for biodiversity and fisheries.
http://depts.washington.edu/mpanews/MPA49.htm

(11) Cod Stock in the North Sea Hit by Triple Whammy
http://192.171.163.165/PDF_files/Nature_article_press.pdf

(12) Rago P & McSherry M (2001) Spatial Distribution of Fishing Effort for Sea Scallops: 1998-2000.
http://www.nefsc.noaa.gov/nefsc/publications/crd/crd0201/0201appg.htm#f7

(13) Lyme Bay Reefs Project
http://www.devonwildlifetrust.org/?section=places:lymebay

(14) The Water Framework Directive and Conservation
http://www.bef.lv/core_bef/pdf/bg_paper/WFD_links_nat.pdf

(15) Scottich Executive: The fishing vessel decommissioning scheme 2003
http://www.scotland.gov.uk/library4/ERADSF/JSF/00017732.aspx

(16) Guardian Unlimited, March 25th 2004. Government Proposes Major Fishing Cuts.
http://politics.guardian.co.uk/scotland/story/0,9061,1177768,00.html

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