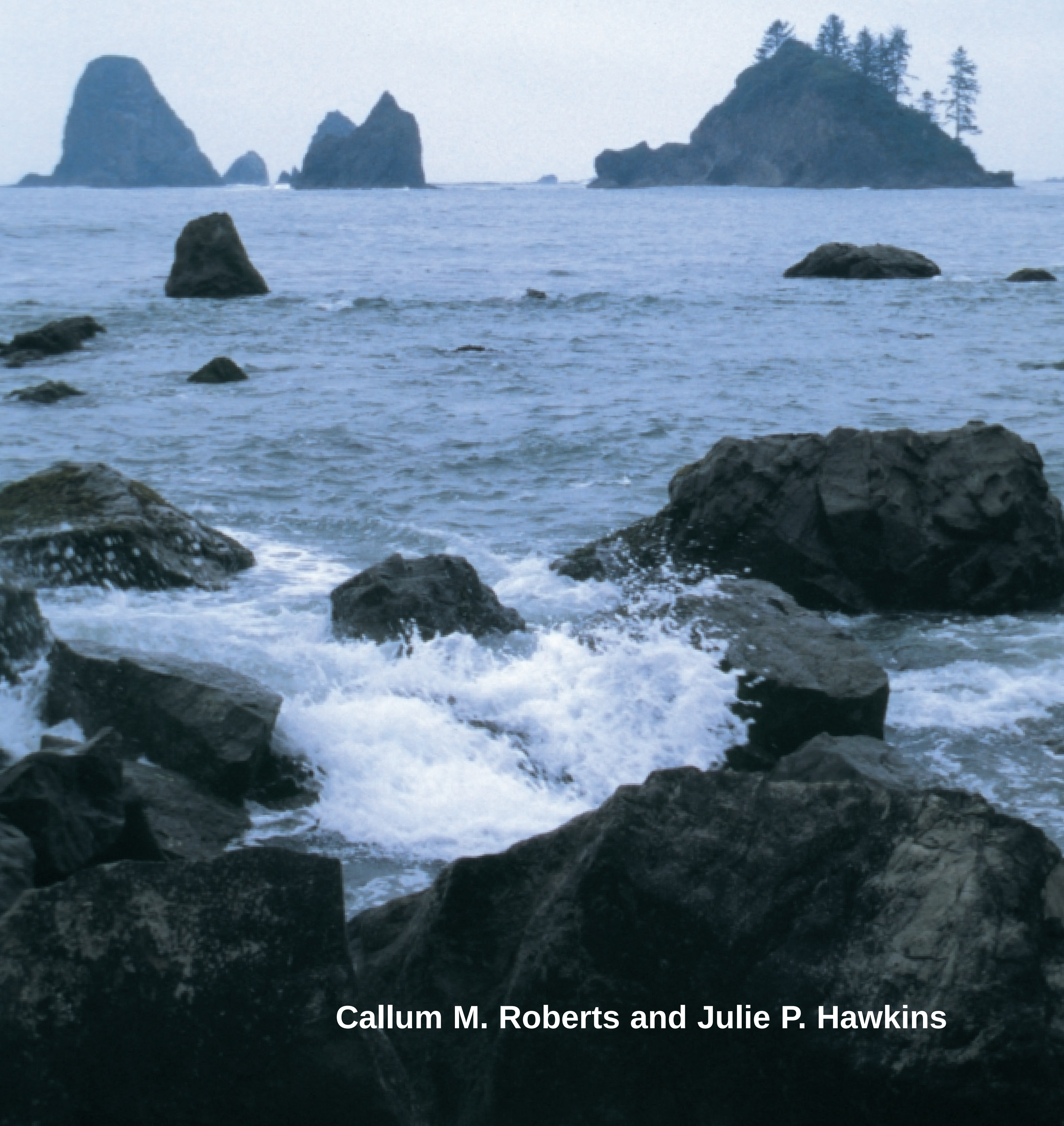
Fully-protected marine reserves: a guide



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Front cover: View across the Olympic Coast National Marine Sanctuary in Washington State, USA. Many marine protected areas, like this one, do not yet offer full-protection from fishing within any of their waters.

Back cover: School of Galápagos grunts (*Orthopristis forbesi*) at Corona del Diablo, Galápagos Islands. This species is found only in the Galápagos and will benefit from the newly agreed zoring plan that will protect nearly 20% of the coast from fishing within the Galápagos Marine Reserve. The marine reserve encompasses the entire archipelago.

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1. Preface

Fully-protected marine reserves[1] are areas of the sea completely protected from fishing and other extractive or harmful human uses. Since the first fully-protected reserves were established, more than two decades ago, they have stimulated a wealth of research and intense interest. Recent scientific evidence indicates that reserves are not only powerful tools for conservation, but can also provide much needed support for fisheries. There is an urgent need for more reserves in order to address the developing crisis in the oceans. Worldwide, fisheries are in trouble, and **habitats** and species are being lost at an alarming rate. However, decision makers need good scientific information on how to make reserves work successfully. Questions such as 'how do reserves function?', 'how many should we have?', and 'where should we put them?' are challenging the minds of scientists, conservationists and managers everywhere. The case for marine reserve establishment gets stronger with every new study published and scientists are making good headway in developing a detailed theoretical basis for fully-protected reserves, supported by good quality data.

People responsible for establishing marine reserves are rarely scientists. Few of those who lobby hardest will have a doctorate in fisheries biology or ecology, nor will the people who decide whether or not to implement protection. People who fish and whose livelihoods will be directly affected by reserves, are educated by the sea itself. Yet all of them, be they fishers, conservationists or government ministers, need clear answers to basic questions and concerns about reserves. For any non-specialist, whatever their level of education, this can be problematic. Scientific papers are difficult to read and can be hard to acquire. Scientific research can also take years from completion to publication as it grinds through peer review, then joins the queue for a journal slot. The most recent research, while much talked about among scientists, is thus generally inaccessible to those who need it most. The aim of this information pack is to summarize the scientific case for fully-protected reserves in a way that is easily understood by everyone. Our objective in producing it is to speed up the process of translating scientific research into action. The pack is particularly aimed towards people who need information to inform and persuade others of the benefits of reserves. They include, for example, those working to set up community-based management of marine resources, park or fishery managers, and policy makers. Since people who will be affected by reserves must be willing to place their faith, and possibly risk their livelihoods, on conclusions drawn by scientists, they should be in no doubt about why they are doing so.

In addition to explaining the theory behind fully-protected reserves this book is also intended as a practical guide. The main text of the book provides much of the background to reserves. This is supplemented by a series of case studies showing some of the most interesting reserves from around the world. Each of them highlights key findings and identifies lessons from those cases. Two other features of this pack are designed to help people trying to establish reserves in the field. A collection of 30 slides and accompanying descriptions showcase marine reserves and their benefits. They can be used as the basis for a presentation on reserves, either in their entirety, or split into shorter presentations highlighting particular uses of reserves for different audiences. A series of 12 overhead transparencies, with accompanying text, can also be used as the basis for one or more tailored presentations, and could be used to accompany a slide-based presentation.

As new information is constantly emerging, we intend this book to be a living text that we update regularly, adding new case studies and sections. These updates can be downloaded from the website that will accompany the book (which can be accessed via a link from www.panda.org/endangeredseas/). We welcome your suggestions for new sections, or case studies that you would like to see covered. You can email them to us at cr10@york.ac.uk.

[1]Terms in the text that are in **bold** are defined in the glossary at the end of this book.

2. Introduction

Life in the sea is diverse, exciting, good to eat and provides a myriad of services to humanity, many of which we barely even comprehend. However, human activities now pose serious threats to the oceans' **biodiversity** and their capacity to support productive fisheries, recreation, water purification and other services we take for granted. These threats come at a time when we still know little about the life that exists in the sea. Even species we have been catching and eating for hundreds of years such as cod, tuna or halibut, have unknown secrets. We think we know enough to catch plenty today and still have enough left over for tomorrow. Then a fishery collapses, proving that in the sea, just as on land, humans can decimate animals which once had hugely abundant populations. If we do this to species we are supposed to be managing for our own benefit, what are the prospects for small, or deep-sea living creatures that have yet to be discovered? How safe is anything from the pollution, over-fishing and habitat destruction we inflict on the sea?

We desperately need new approaches to better manage the oceans. A growing number of people now believe there is a way to conserve marine biodiversity, restore dwindling **fish** stocks, promote sustainable tourism and safeguard **ecosystem** integrity. All of this can be achieved using fully-protected reserves, that is, areas completely closed to fishing and all other types of exploitation or harmful use. Such reserves would offer much greater protection than is currently afforded by most **marine protected areas (MPAs).** At the moment MPAs cover less than half a percent of the world's oceans, few protect very much and 71% appear to have no active management (Kelleher et al. 1995). In an assessment made in 1997, Susan Wallace pointed out that of Canada's 110 MPAs, 72 provided no protection to species or habitats (Wallace 1997), and most marine parks in the United States seem to positively encourage fishing. For example, although California has more than 100 MPAs, less than one fifth of one percent of their combined area is protected from fishing, and little of that is effectively enforced (McArdle 1997)!

Few MPAs, and little protection for those that do exist - this characterizes the situation worldwide, in countries rich and poor, in waters warm and cold. It cannot continue. The disappearance of species from fishers' nets stands witness to the oceans' loss in biodiversity. Today we eat fish that were once thrown away as unfit for consumption. Many of the prized species of the last century have all but disappeared. With the development of scuba diving equipment in the middle of the 20th century, it has been possible to witness such losses first hand. For example, a few decades ago the kelp forests of California were filled with giant fishes and lobsters, but no longer. Coral reefs throughout much of the Caribbean stand stripped of the large predators that once captivated divers. For fishers, these disappearances translate into loss of livelihoods and the end of a way of life. The situation for both fishers and biodiversity has become so serious that reserves are no longer an option - they have become a necessity.

Wherever reserves have been properly established, and have existed for a number of years with full protection, they have been successful. Not only have they achieved conservation goals, like maintaining marine biodiversity and protecting marine habitats, they have also brought social and economic benefits. Examples include increased lobster catches in New Zealand and growth of ecotourism in Belize. One common effect that pilot reserves have had across the world has been that fishers who once opposed them have turned into their supporters. Tourists flock to dive and snorkel in fully-protected reserves, attracted by the prospect of seeing marine life at its best. People who fear that "fully-protected reserves" mean "no-people zones" are wrong. The purpose is not to exclude people, but to provide a much needed refuge from harm for marine life.

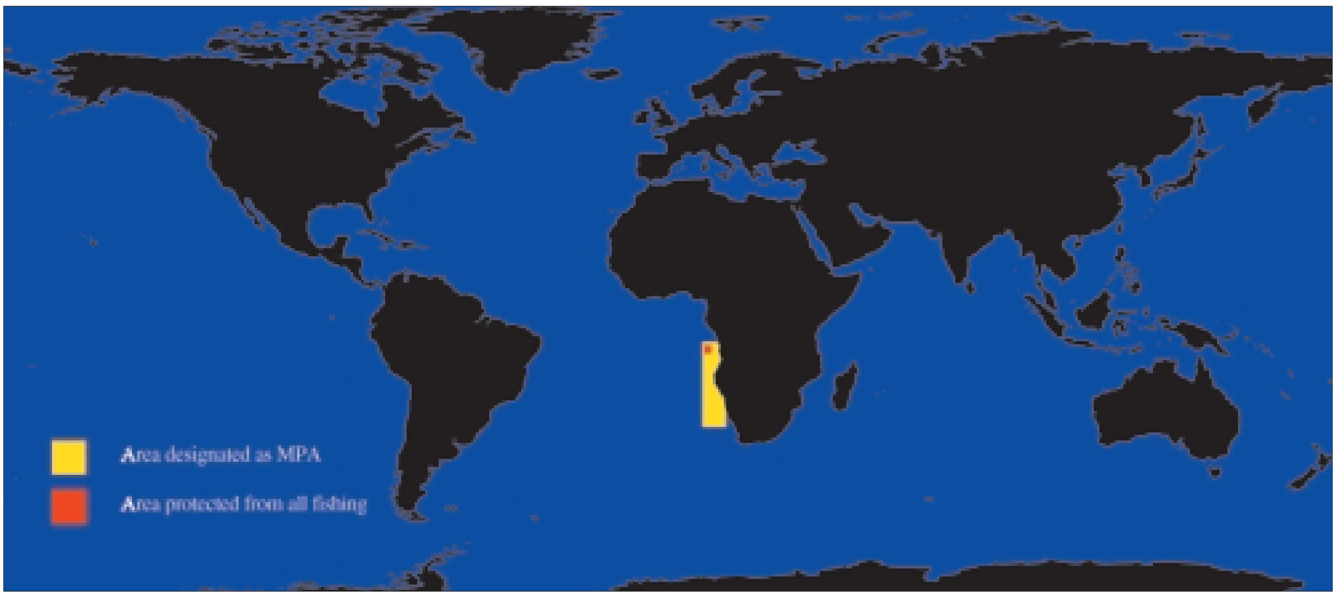
Although fully-protected reserves might seem like a new approach, they are as old as fishing itself. In the past there were always places that could not be fished because they were too deep, too dangerous, too hard to get to, or the bottom was too rough. Modern technology gives us access to these areas and the amount of sea that is not fished has dwindled. Likewise, more and more of the sea has come within reach of pollution and habitat destruction. Unfished areas once played a critical role in supporting fisheries. Reserves simply put back these vital refuges for fish breeding stocks.

Reserves also address a perennial problem with ocean and fishery management, but one we have only recently begun to appreciate. Marine ecosystems, like their terrestrial counterparts, are complex. They consist of a myriad of species that interact with each other, with people, and with their environment. Strangely, we have tended to ignore these complexities in our relations with marine life. Fishery managers, for example, have treated species as isolated targets that have no important links to other species or the habitats they live in. In their mathematical models, fish have become particles within homogeneous seas that are fished randomly by unthinking fishers. Environmental influences on fish populations are also conveniently tidied out of the way. Fishing is considered the only thing that matters. The folly of this approach has become more painfully obvious as fishery after fishery has succumbed to overexploitation. For years, many failures were put down to inadequate models. Over time we have built more and more complex mathematical edifices - but still they fail. The problem is that marine ecosystems and the species that live in them are inherently unpredictable. We can never eliminate uncertainty altogether, and a reliance on models that pretend we can is a flawed strategy.

To deal with uncertainty we have to adopt a more cautious approach to exploitation. There is also a growing wave of opinion that we must put the ecosystem into fishery management. Fully-protected reserves represent one of the simplest ways to do this, by simultaneously protecting **target species,** their habitats, and the ecological processes that underpin fish production. They are precautionary because they do not expose an entire fish population to exploitation at once. If things go wrong, all will not be lost.

Fishing is not the only cause of concern in the sea. Land-based pollutants are entering the oceans faster than ever before. Soil washed from denuded forests is smothering coral reefs, and toxic chemicals are building up in marine ecosystems, poisoning animals or preventing them from reproducing. Nutrients washed from land are dramatically changing marine habitats, especially in shallow, enclosed seas like the Baltic. These problems concern fishers just as much as conservationists. Marine reserves cannot directly protect habitats from sources of harm like these, but they can help promote better management at much larger scales. They signal that here are things we consider worth protecting and galvanize us toward achieving that end.

***Figure 1:* Only a tiny fraction of the world's oceans are protected. This map illustrates just how little is protected. The combined area of the world's marine protected areas, shown diagramatically in yellow, covers less than half a percent of the oceans, while perhaps only one ten thousandth of the sea is legally protected from all forms of fishing (red). Sadly, the majority of existing marine protected areas are not yet adequately managed.**



The above examples offer only a glimpse into why reserves are so valuable. The aim of this book is to explain in detail what they have to offer. Fully-protected reserves have been pioneered in the tropics and warm temperate regions, and are often characterized as only being useful in these regions. This book has a global focus and we will show how reserves can work in any region from cold water to warm. Reserves are also usually portrayed as only benefitting animals that stay put. We explore ways in which they can work for both migratory and site-attached species. We start by asking why reserves should be protected from fishing and review the evidence to support these claims. Throughout the book we consistently highlight the conservation and economic benefits of reserves. We try to answer commonly-asked practical questions such as how large fully-protected zones should be, where they should be placed and how they can be enforced. We also aim to stimulate further questioning which can help advance everybody's appreciation and understanding of reserves.

Key points:

- Less than half a percent of the seas lie within marine protected areas, and most of them are under-resourced, poorly managed and offer little protection.
- Perhaps only one ten thousandth of the oceans are protected from all forms of fishing.
- Fully-protected reserves, areas closed to fishing, extractive or harmful uses, are powerful management tools. There is an urgent need to establish more to reverse species losses and habitat destruction.
- Fully-protected reserves represent a precautionary, ecosystem-based approach to management.

3. Why should reserves be protected from fishing?

In the past, fishing was thought to have very little influence on the marine environment. Indeed, many distinguished naturalists of the 19th century, Thomas Huxley for example, sincerely believed that the great fisheries of the seas were inexhaustible. It was felt that fish produced so many offspring, and the seas were so vast, that fishing would never do more than remove a small fraction of the animals present. This optimism was misplaced. Even in the 19th century, the development of industrial fishing methods, such as steam powered trawlers, allowed fishers to scoop larger and larger fractions of fish populations from the sea, and to reach ever more distant fishing grounds. Tagging studies on plaice *(Pleuronectes platessa)* in the first decade of the 20th century showed that, even then, fishers were catching up to half the animals present in the North Sea every year (Alward 1932)!

Despite a gathering flow of evidence that fisheries could collapse locally, and that people had to fish farther and farther afield to sustain catches, optimism persisted well into the 20th century that there would always be plenty of fish in the sea. The very language commonly used by fishers and fishery managers suggests no more than a benign removal of excess production. 'Harvesting' and fish 'stocks' are terms that have been inappropriately borrowed from farming. Fish are not planted, grown and harvested - they are hunted. The means we employ to catch them are destructive. Imagine that to catch deer we clear cut the forests in which they lived, or to hunt wildebeest we burned the grasslands upon which they grazed. But this is effectively what we do in the sea. The passage of trawls across the seabed destroys and transforms ecosystems, often converting them from rich, structurally complex, biologically-created habitats dominated by invertebrates, into low diversity, much simplified habitats dominated by physical disturbance. Trawls that consist of steel beams weighing tonnes, and equipped with heavy 'tickler' chains to flush fish from the bottom and into the net, crush and scour the seabed. Their repeated passage grinds down the physical structure of the bottom. Reefs and marl have been turned into rubble, sand and mud.

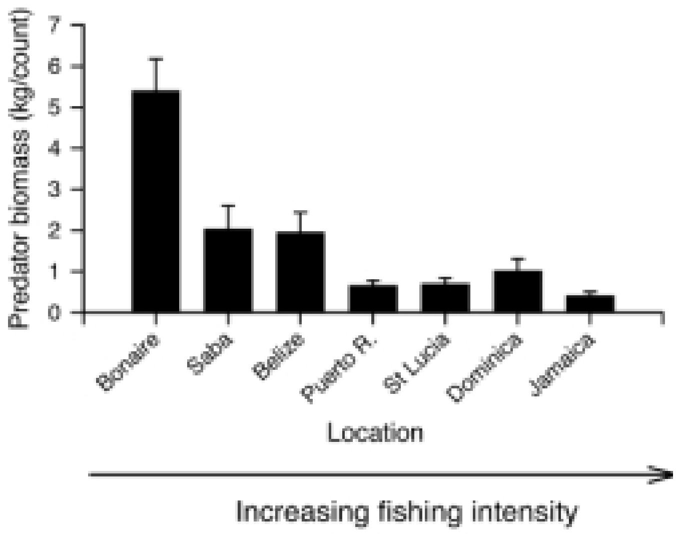


***Figure 2:* Biomass of predatory fishes versus fishing effort in the Caribbean. Predatory fishes are often the most highly prized by fishers but are vulnerable to over-exploitation. Artisanal fishing in the Caribbean has caused widespread loss of predatory fishes, transforming coral reef ecosystems in the process. Puerto R. = Puerto Rico.**

Until recently, the destruction of seabed communities has largely gone unnoticed. Modification of the terrestrial landscape is highly visible and has been recorded in art and writing for the last thousand years, but the sea still looks the same. This unchanging appearance belies the reality beneath the waves. Marine habitats have been as dramatically changed as terrestrial ones, but these changes were not chronicled as they occurred. A stray comment here, an anecdote there are all the hints we have. For example, the first steam trawlers in the North Sea dragged up huge quantities of decaying vegetation from the sea bed that had been submerged at the end of the last ice age (Alward 1932). With this came dense mats of invertebrates and the bones of extinct land mammals. By the beginning of the 20th century those communities had all but disappeared and bones were rarely found (Reid 1913). Over the same period, species of flatfish began expanding their ranges from shallow, high energy sand bottoms of the southern North Sea into areas where they had previously been uncommon (Alward 1932). This movement reflected changes to the sea bed caused by trawling.

The impacts of trawling have been highly controversial and authors who likened it to clear-cutting of forests have been vilified in the press. People have found it hard to accept that dragging tonnes of steel across the ocean floor causes damage because they have never witnessed trawlers in action on a pristine sea bed. On land it is clear

Kicker Rock in the Galapagos. Above water, the seas look the same as they have for thousands of years, but this conceals the transformation of marine habitats that human activities have caused.

to see how ploughing can destroy vegetation and modify the landscape, but by the time we first looked underwater, the oceans' plains, rolling hills and river valleys had already been transformed by these underwater ploughs. The only organisms to persist formed simplified communities resilient to trawling. Once this stage is reached, further trawling causes little additional change, making assessments of its impacts virtually meaningless. Today's studies generally compare areas badly damaged by trawling with places severely affected by it and so conceal the true degree of modification that has occurred. We no longer have suitable undisturbed baseline sites to compare affected areas to.

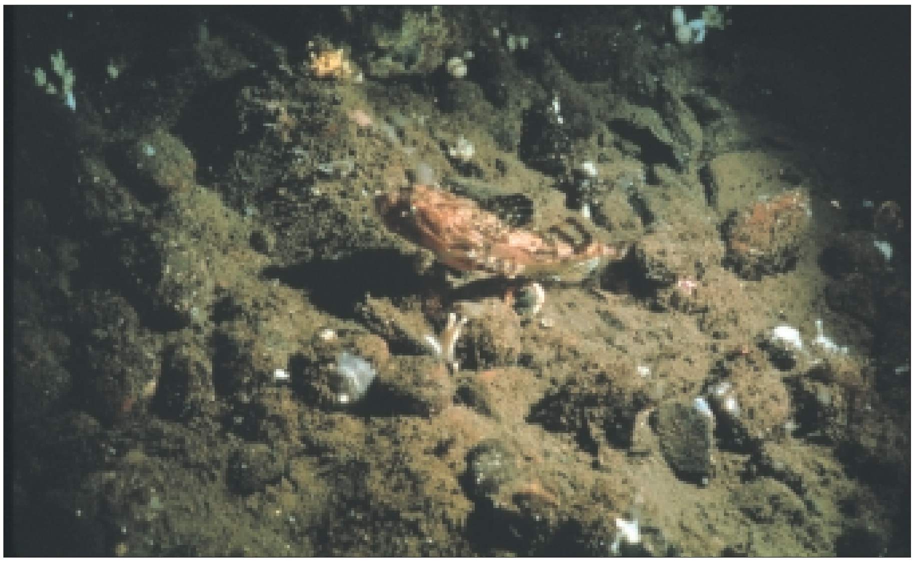
There is some evidence that the use of mobile fishing gears like trawls can lead to changes in habitats that support production of the animals we pursue. For example, shrimp trawling disturbs habitats so regularly that seabed communities are kept in highly disturbed states that favour the growth of shrimp populations. Similarly, beam trawling for flatfish produces low topography habitats and prey-communities well-suited for the growth and survival of those flatfish. However, there are limits to the production that can be sustained. Heavy fishing can outstrip the capacity of populations to replace themselves, forcing fishers to use ever more damaging gears. As densities of fish fall, so trawls need to be dragged faster across the bottom to sweep larger areas. At higher trawling speeds the nets tend to bounce off the bottom, reducing fishing efficiency and so heavier and heavier beams must be adopted to hold them down. The number of species able to persist under such impacts declines and habitats gradually become more impoverished.

Some vulnerable habitats are threatened by fishing. This picture shows a cobble-shell bottom in the Swan's Island Conservation Area, Gulf of Maine, where trawling is prohibited. Left undisturbed by human activity, rich biological communities develop on the sea bed. The influence of trawling is so widespread that communities such as these have become very rare. Marine reserves provide a reminder of how the seabed once looked. Photograph by Peter Auster.

Trawling is certainly a highly efficient method of catching large quantities of fish at relatively low cost. Although trawl gears damage marine environments, it is inconceivable that they should ever be abandoned. Heavily trawled areas can be highly productive. Such areas represent the underwater equivalent of intensive agriculture, places where habitats are transformed and put to our use. Yet just as we protect terrestrial environments from modification by agriculture, so we should also offer some areas of the sea protection from trawling. Fully-protected marine reserves could achieve much in re-establishing a balance between areas affected by fishing and areas where species and habitats can exist undisturbed.

Other kinds of fishing gear have also transformed marine habitats and annihilated species. As you read this, the giants of the sea, including sharks, swordfish *(Xiphias gladius)* and bluefin tuna *(Thunnus thynnus)* are being pursued relentlessly for their meat and fins. As their numbers have dwindled, bluefin tuna have become so highly-valued that it now pays to hunt them with spotter planes before boats are sent in for the kill. Offshore longline fisheries are inflicting heavy collateral damage on animals such as loggerhead turtles *(Caretta caretta)* and albatross, species that can scarcely sustain themselves even without this unintended mortality. These animals take baited hooks and are drowned.

Industrial fisheries are not the only ones changing the sea. Even artisanal and recreational fishers, equipped only with 'primitive' gears like hook and line, traps and spears, have inadvertently been responsible for large-scale losses of diversity. Throughout the world there are growing numbers of intensively fished coral reefs



A single pass of a trawl has devastated communities on this sand-shell bottom in the Gulf of Maine. Trawling destroys delicate habitat structures that provide critical protection and food for juvenile fish, leading to diminished biodiversity and possible loss of fishery productivity. Photograph by Peter Auster.

where the largest fish are hardly big enough to fill a sandwich. The prized, platter-sized fish have long since disappeared and people struggle to eke out a living from animals that were once considered waste. Kelp forests off the coast of California used to throng with enormous black seabass *(Sterolepis gigas)* and large, colourful male sheepshead wrasse *(Semicossyphus pulcher)*. Such species were a magnet for spearfishers and consequently kelp forests are now virtually empty of these and other fish. Paul Dayton of the Scripps Institution of Oceanography in San Diego has documented this disappearance. He calls the kelp forests of today 'ghost habitats' - the kelp is still present but the canopy is filled with only memories of the large animals that once flashed and shimmered among the fronds.

The oceans are still shrouded in mystery. We know far less about species that live in the sea than we do about those on land. For every marine species known to be in

Scallop dredges like this are underwater ploughs and cause extensive damage to bottom habitats. They can also retain large quantities of unwanted by-catch and kill many other organisms on the bottom. Throughout vast areas of the world's oceans trawls pass too frequently for marine life to recover from their effects, and only the most resilient survive. Marine reserves provide much needed refuges where communities can recover and develop away from the influence of trawling.

trouble there are probably hundreds more whose populations are also declining, many of them still unknown to science. Even the species we should be keeping track of, the ones we hunt, are poorly understood. Of more than 800 species exploited in US waters, the status of over 60% was unknown to the National Marine Fisheries Service in 1998. In many other countries, data on marine species is even more rudimentary. Nevertheless we continue to exploit, blindly hoping that things will not go badly wrong.

There is good reason for us to be more cautious. We depend on healthy marine ecosystems in more ways than most people ever realise. The seas, as well as producing much of the fish we eat and providing great places for a vacation, also give us many of our medicines, regulate global climate, and even help generate the air we breathe. Already, we are seeing many signs that marine ecosystems are threatened, and with them the ecological processes they support and services they provide. Increasing frequency of disease outbreaks in the sea, poisonous algal blooms that kill fish and close beaches, and bleached coral reefs are all signs that we are pushing the limits of what marine ecosystems can stand. Healthy and functioning marine ecosystems are vital to all of us. Fully-protected reserves can help to maintain intact ecosystems and the ecological processes that underpin the services we enjoy. Such reserves are not mere conservation tools to protect the odd threatened species or habitat. They are critical to ensuring that fisheries remain productive and marine ecosystems stay healthy.

Throughout the world, we are systematically emptying the oceans of fish, leaving ghost habitats and the rubble of communities torn apart. Unless we are careful, new generations will come to see these impoverished habitats as ‘natural’, just as we have mistaken trawled seabeds for natural. Our baselines, what we think unimpacted environments are like, are sliding and with them our expectations are diminishing. We need fully-protected reserves to protect habitats from destructive fishing gears, to help rebuild seriously depleted animal populations, and to provide a refuge for species that simply cannot tolerate heavy fishing. We can’t expect habitats that grew over centuries to recover overnight, but we can expect reserves to begin the slow process of recovery. Moreover, it is worth remembering that no-fishing areas of the past, places that couldn’t be fished with the technology available then, probably played a key role in supporting fisheries until modern technology and growing human populations eroded them away. Today we must restore these refugia with fully-protected marine reserves.

Key points:

- Fishing has transformed the seas, leading to widespread depletion of species and the alteration and destruction of habitats.
- Although losses of some species have been highly publicized, such as the great whales, most have gone virtually unnoticed. In many cases this is because habitats were transformed by fishing long ago. Any unfished, undamaged ‘baseline areas’ that could be used for comparison have long since disappeared.
- Few refuges from fishing remain in waters shallower than a kilometre deep. This is due to technological advances in fish finding, navigation and fishing gears, together with a greatly increased human population.
- Some species are so vulnerable to the effects of fishing that they have disappeared from most of their ranges. For some, extinction seems imminent. Fully-protected marine reserves may be the only means of ensuring their survival.

Further reading: Norse 1993; Dayton et al. 1995, 1998; Safina 1995, 1997; Sobel 1996; Botsford et al. 1997; Pauly et al. 1998; Watling & Norse 1998; Roberts & Hawkins 1999.

4. Fully-protected reserves in a nutshell

Marine reserves have enjoyed a great increase in attention over the last few years. A decade ago they sounded like a good idea, but now we have results proving that they really do work. People who pioneered reserves, the fishers who gave up part of their fishing grounds in the hope of better times ahead, are beginning to reap benefits from their foresight. Those who wanted to wait and see the evidence first are now feeling they have waited long enough and want to take the plunge themselves. After starting small and accumulating slowly, fully-protected areas are now recognized as a major asset to fishers, fishery managers and conservationists. What makes them so useful?

Marine reserves provide an opportunity for slow growing species like this black grouper* (Mycteroperca bonaci), *pictured in the Hol Chan reserve in Belize, to become really big. This is important because the bigger a fish gets, the more eggs it produces. Large fish in protected areas should play a significant role in helping restock fishing grounds.

(1) Fully-protected reserves enhance the production of offspring which can restock fishing grounds

If you stop fishing an area, none of the animals there will die by getting caught. This means that many individuals will live longer and grow larger. Bigger animals produce many times more eggs than smaller ones. For example one ten kilogram red snapper *(Lutjanus campechanus)* produces over twenty times more eggs at a single spawning than ten one kilogram snappers. Big fish may also spawn more frequently than small. On the Pacific coral reefs of Guam, half kilogram goatfish reproduce four to five times more often than goatfish half this size, and produce 100 times more eggs over a year. Therefore a few very large animals are more valuable as egg producers than many smaller ones. In addition to increases in average body size, reserves often increase population densities. A greater abundance of fish within a reserve will also result in increased egg production relative to fishing grounds. Some animals, especially those that are attached to the bottom or have limited powers of movement (eg. oysters, clams or abalones), can only reproduce successfully at high population densities. As they get further apart, fertilization rates decrease and fewer offspring are produced. By increasing population densities, reserves can greatly increase the number of young spawned. Many of the eggs and larvae produced by fish in fully-protected reserves will drift into fishing grounds and help restock the fishery.

*(2) Fully-protected reserves allow **spillover** of adults and juveniles into fishing grounds*

As the number and biomass (body weight) of individuals within reserves increases, for many species there will come a point when animals start to emigrate out of reserves and into fishing grounds. Thus a proportion of the fish which once received protection in reserves do eventually become available for fishers to catch. This, together with their ability to provide eggs and larvae to fishing grounds provides the basis for fully-protected reserves to be economically beneficial to fishers. Spillover can help compensate for the short-term loss that fishers may experience in the early years after reserves are established.

(3) Fully-protected reserves provide a refuge for vulnerable species

Some species are particularly vulnerable to fishing and may be unable to persist even in areas where fishing pressure is quite light. If this is the case no-take zones offer a critical refuge. For example, barndoor skate *(Dipturus laevis)* have been driven to the edge of extinction by trawl fishing on continental shelves of the eastern United States and Canada, even though they have never been directly targeted by fishers (Casey & Myers 1998). Their large body size means they are caught as by-catch, and their low reproductive rates mean they cannot persist in areas that are trawled. There are similar concerns for several species of rockfish (*Sebastes* spp.) in the Pacific (Yoklavich 1998). Since fishing gear is so unselective, rare species will continue to be caught as long as fishing continues. Protecting vulnerable species is a key benefit of fully-protected reserves for conservationists.

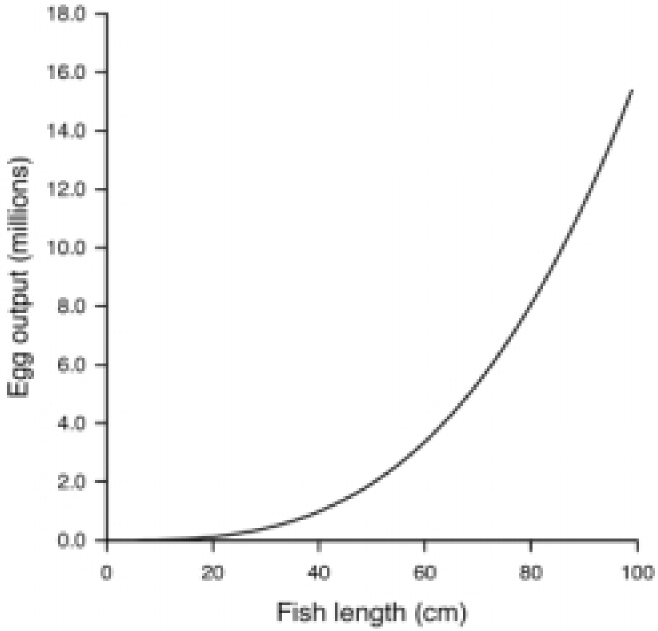


Figure 3: ***Egg output versus body size in tropical groupers (Serranidae). Egg production increases exponentially with fish length, so large individuals can produce many times more eggs than small ones. By protecting fish from being caught, reserves can greatly increase the abundance of large and highly fecund individuals.***

(4) Fully-protected reserves prevent habitat damage

All forms of fishing can damage the marine environment in some way and impacts vary from minor and localized to large-scale and devastating. Trawling and dynamite fishing are amongst the worst forms, but even hook and line fishing can disrupt bottom communities and produce litter which can be dangerous to marine life. Just as reserves provide a refuge to species from fishing, they also provide a respite from damage to their habitats. In the aftermath of fishing this will allow time for the process of recovery and will ultimately lead to restoration of biodiversity within the area.

Fishing is not the only activity that can cause habitat damage. Mining, dredging, oil and gas drilling, **infilling,** anchoring, boat groundings, **eutrophication,** even too much scuba diving, among many other things can damage or destroy habitats. Excluding or limiting such harmful activities from in and around reserves is important for protecting ecosystems and the ecological processes they support.

(5) Fully-protected reserves promote development of natural biological communities which are different from communities in fishing grounds

Fully-protected reserves have offered remarkable insights into how human activity has transformed marine ecosystems. For example, protection of rocky shores in Chile led to a change from communities dominated by mussels to ones dominated by barnacles. This shift was facilitated by the recovery of loco *(Concholepas concholepas),* a predatory snail, which had been overexploited before protection (Castilla & Duran 1985). Reserves create conditions that are different from surrounding fished areas. In doing so, they promote development of different community structures, and enhance regional biodiversity. In other words reserves facilitate increases in diversity at the 'seascape' level.

(6) Fully-protected reserves facilitate recovery from catastrophic human and natural disturbances

There is growing evidence that human impacts and stresses undermine the capacity of ecosystems to recover from major disturbances. Intact, fully-functioning ecosystems rebound more quickly from catastrophes like storms, or oil spills, than places where animals and plants are affected by other stresses. For example, Connell (1997) reviewed studies of recovery of coral reefs from major disturbances and found that healthy reefs are resilient and recover relatively quickly. However, reefs suffering from multiple stresses showed little or no recovery. The reasons are simple. Healthy ecosystems tend to support larger populations of plants and animals that reproduce at higher rates. This means that disturbances are less likely to completely eliminate populations, and so recovery will be faster. Fully-protected reserves help maintain populations at higher levels, so promoting recovery from disturbance. They also help reduce levels of stress from other human activities.

Key points:

Fully-protected reserves can:

- Protect exploited populations, enhancing production of offspring which help restock fishing grounds.
- Supplement fisheries through spillover of adults and juveniles into fishing grounds.
- Provide a refuge from fishing for vulnerable species.
- Prevent habitat damage and promote habitat recovery.
- Maintain biodiversity by promoting development of natural biological communities that are different from those in fishing grounds.
- Facilitate ecosystem recovery after major human or natural disturbances.

Further reading: Ballantine 1991, 1995; Bohnsack 1993, 1996, 1998; Sobel 1996; Connell 1997; Allison et al. 1998; Roberts 1997a, 1998a, 1998b, Castilla 1999, Murray et al 1999.

5. What is the evidence for recovery of animal populations in marine reserves?

The number of documented successful examples of fully-protected reserves is growing rapidly. The case studies in this book consider reserves from throughout the world and there are many other excellent examples that we do not have the space to cover in such detail. There is now abundant evidence to show that protecting areas from fishing leads to rapid increases in abundance, size, biomass and diversity of animals, regardless of where reserves are sited. Halpern (in press) has reviewed 76 studies of reserves that were protected from at least one form of fishing. He derived aggregate measures of reserve performance, by combining responses of all the organisms studied, for each of four variables: abundance, total biomass, average body size and species diversity. His study included reserves that ranged from full to partial protection from fishing (e.g exclusion of some kinds of fishing, such as spear fishing). It also included reserves where protection had been implemented well to places where there were violations or lapses. Since reserves that offer protection from fishing are a relatively recent phenomenon, most studies demonstrate short-term effects of reserves. This means comparisons like this almost certainly underestimate their eventual performance. For all these reasons, Halpern's findings should be considered minimum levels of performance for fully-protected, well-respected reserves, that are achievable over the short-term. Nevertheless, they are impressive. Across all reserves studied, abundance (measured as density) approximately doubled, biomass increased to two and half times that in fished areas, average body size increased by approximately one third (equivalent in many fish to an increase in egg output of 240% or more), and the number of species present per sample increased by a third. Table 1 summarizes examples of reserve effects from a range of different places and habitats. Many other examples can be found in Roberts & Polunin (1991), Dugan & Davis (1993), Rowley (1994), Bohnsack 1996, and Fujita (1998).

Wall of fish in the central part of the Hol Chan Marine Reserve, Belize. Within only four years of protection from fishing, this reserve supported higher densities of large fish than any other coral reef the authors have visited anywhere in the world.

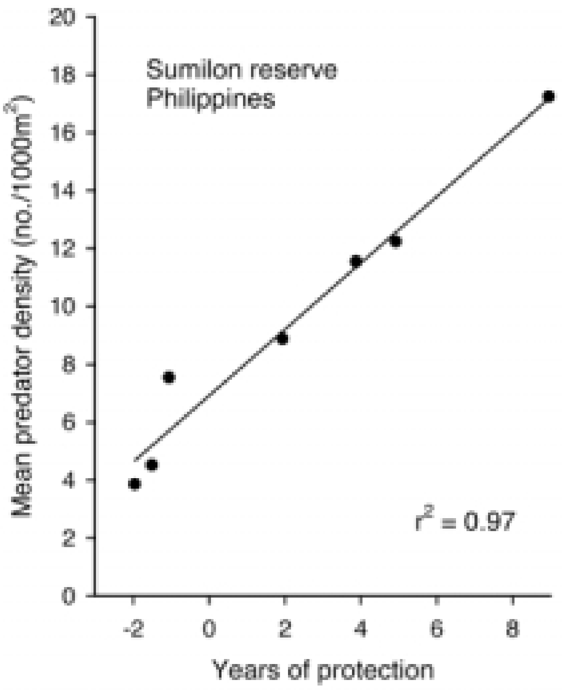


Figure 4: ***There has been a rapid and sustained increase in abundance of large, predatory fish in the Sumilon Island reserve in the Philippines over its 9 years of protection. Such fish are among the most valuable in landings but are highly vulnerable to overexploitation. Reserves provide a much needed refuge in which fish can reproduce and so replenish populations and fisheries. Reproduced from Russ and Alcala (1996a) with permission.***

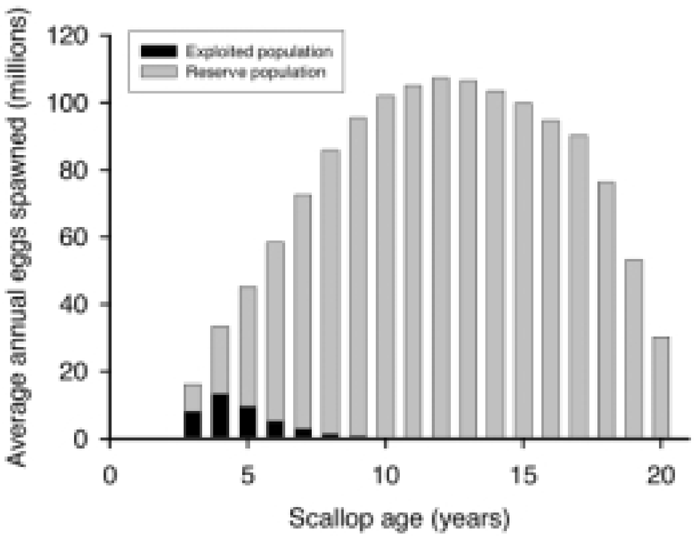


Figure 5: ***Fully-protected reserves allow animals to live longer and grow larger. This model shows the difference that would develop in size structures and reproductive output of scallop*** **(Placopecten magellanicus)** ***populations if fully-protected reserves were created off the east coast of the USA and Canada. Protection from fishing would greatly increase the average size of individuals in reserves. Since they produce many more eggs than small ones this would lead to a huge increase in reproductive output from the population. Figure redrawn from McGarvey and Willison 1995.***

Key points:

- There is compelling, irrefutable evidence that protecting areas from fishing leads to rapid increases in abundance, average body size, and biomass of exploited species. It also leads to increased diversity of species and recovery of habitats from fishing disturbance.
- Reserves are often portrayed as working only on coral reefs. In fact, they have been successful in a wide range of habitats in environments ranging from tropical to cool temperate zones. Reserves are a valuable tool globally.

***Table 1:* Examples of the effects of reserves that offer protection from fishing, drawn from experiences in many parts of the world and from many different habitats.**

Reserve name and location	Years of protection	Habitat type	Effects reported
Leigh Marine Reserve, New Zealand	21	Warm-temperate rocky reef	The most common predatory fish *Pagrus auratus* was 6 times more common in the reserve than outside, while the spiny lobster *Jasus edwardsii* was 1.6 times more abundant, and had a bigger carapace (a part of their horny outer skeleton: average size = 110mm in reserve, 94mm outside). In 18 years, sea urchin densities declined from 4.9m^2 to 1.4m^2 in the reserve while urchin cover rose from 14% to 40% in unprotected areas (Babcock 1999).
Tawharanui Marine Park, New Zealand	14	Temperate rocky reef	The most common predatory fish *Pagrus auratus* was 9 times more common in the reserve than outside, while the spiny lobster *Jasus edwardsii* was 3.7 times more abundant, with a carapace about 16mm bigger (Babcock 1999).
Mayotte Island, Indian Ocean	3	Coral reef	Total numbers of species present did not differ between protected and unprotected areas, however most large carnivores were more diverse and abundant in the reserve. The mean biomass of commercial species was 202g/m^2 in the reserve compared to 79g/m^2 outside (Letourneur 1996).
Looe Key, Florida, USA	2	Coral reef	15 species that were targets of spear fishers increased in abundance after spearfishing was banned: snappers by 93%, grunts by 439% (Clark et al. 1989).
Cousin Island, Seychelles	15+	Coral reef	Groupers, emperors and snappers were more abundant and diverse within the reserve than in fished sites (Jennings 1998).
Sainte Anne, Seychelles	11	Coral reef	Despite the fact that a few families retain fishing rights and poaching is fairly common in this reserve, the diversity of **target species** and total fish biomass was higher than in heavily fished areas. The biomass of prey did not increase when predators were removed by fishing (Jennings et al.1995, Jennings et al. 1996).
Merritt Island Wildlife Refuge Florida, USA	28	Sub-tropical estuary	Experimental catch per unit effort (the amount caught for every unit of fishing effort) was 2.6 times greater in the reserve for all game fish combined, 2.4 times for spotted sea trout *(Cynoscion nebulosus),* 6.3 times for red drum *(Sciaenops ocellata),* 12.8 for black drum *(Pogonius cromis),* 5.3 for snook *(Centropomus undecimalis)* and 2.6 for striped mullet *(Mugil cephalus).* Fish in the refuge were larger and more abundant, and anglers were preferentially targeting the reserve boundary (Johnson et al. 1999).
Kisite Marine National Park, Kenya	5	Coral reef	Snappers, emperors and groupers were more abundant in the park and appear to be spilling over into fishing grounds. Protection did not affect species number or diversity (Watson et al. 1996).

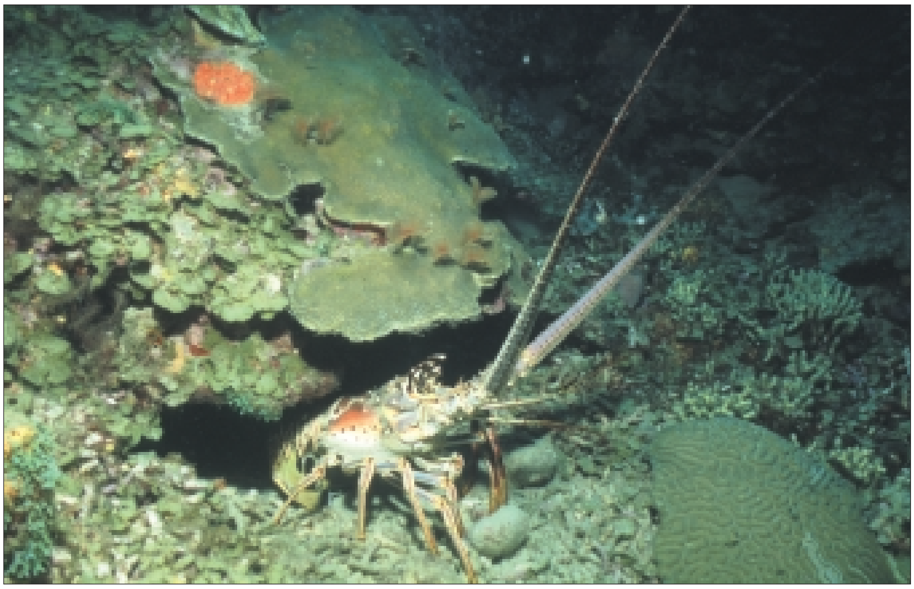
Reserve name and location	Years of protection	Habitat type	Effects reported
Punta El Lacho, Chile	2	Temperate rocky intertidal	The commercially important marine snail, the Loco *(Concholepas concholepas),* increased in density from 5 to 14 times and doubled in body size following protection (Castilla & Duran 1985).
Barbados Marine Reserve	11	Coral reef	Large, trapable fish were approximately twice as abundant in the protected area, and 18 of 24 species were bigger (Rakitin & Kramer 1996, Chapman & Kramer 1999).
Exuma Cays Land and Sea Park, Bahamas	36	Tropical seagrass meadow	The average density of adult queen conch *(Strombus gigas)* was 15 times higher in the reserve, and late stage larval densities were 4-17 times higher (Stoner & Ray 1996).
Exuma Cays Land and Sea Park, Bahamas	10	Coral reef	The reproductive output of Nassau grouper *(Epinephelus striatus)* was 6 times greater in the reserve (Sluka et al. 1997).
Hawaii Marine Life Conservation Districts	not reported	Coral reef	Fishes were 63% more abundant in areas protected from fishing (Grigg 1994).
De Hoop Marine Reserve, South Africa	2	Warm-temperate rocky reef	Experimental catch per unit effort increased by up to five-fold for 6 out of 10 of the most commercially important species (Bennett & Attwood 1991).
Saba Marine Park, Saba, Netherlands Antilles	4	Coral reef	In the no-take zone the biomass of target species was over twice that in fishing grounds (Polunin & Roberts 1993).
Hotel Chan Marine Reserve, Belize	4	Coral reef	Biomass of target species in the reserve was on average almost double that in fishing grounds, while in certain parts of the reserve it was ten times greater (Polunin & Roberts 1993, Roberts & Polunin 1994).
Anse Chastanet Reserve, St. Lucia	2	Coral reef	Total biomass of commercially important species was more than double that in fishing grounds and the reserve contained three easily caught species found nowhere else (Roberts & Hawkins 1997).
Ras Mohammed Marine Park, Egypt	15	Coral reef	Mean biomass of fish was 1.2 times greater on protected reefs, while differences for seven target species were much greater. Individuals of the lunartail grouper *(Variola louti)* were three times larger in the reserve (Roberts & Polunin 1993a, 1993b).
Kisite Marine National Park and Mpunguti Marine National Reserve, Kenya	Kisite 20 Mpunguti 0 (open to fishing using traditional methods	Coral reef	Abundances of key commercial species (groupers, snappers and emperors) were up to 10 times higher in the fully-protected Kisite Marine National Park compared to the fished Mpunguti reserve. Furthermore, keystone species such as triggerfish (a predator of urchins) were also more abundant in the Kisite Park, while their urchin prey were much more abundant in the fished Mpunguti reserve (Watson & Ormond 1994).

Reserve name and location	Years of protection	Habitat type	Effects reported
Three Kenyan Marine Parks: Malindi, Watamu, Kisite	Malindi 24 Watamu 20 Kisite 19	Coral reef	Reserves helped to support regional diversity by protecting species that were unable to persist in fished areas. Of the 110 species recorded on protected reefs, 52 were not found in fished areas (McClanahan 1994).
South Lagoon Marine Park New Caledonia	5	Coral reef	Within protected areas the species richness of fish populations increased by 67%, density by 160%, and biomass by 246%, but the average size of most species did not increase (Wantiez et al. 1997).
Banyuls-Cerbere Marine Reserve, France	6	Warm-temperate rocky reef	18 target species were bigger in reserves (Bell 1983).
Shady Cove, San Juan Islands, Washington, USA	7	Temperate rocky reef	Lingcod *(Ophiodon elongatus)* were nearly three times more abundant in the reserve (Palsson & Pacunski 1995).
Edmonds Underwater Park, Washington, USA	27	Temperate rocky reef	The number of rockfish eggs and larvae originating from within the park is 55 times greater than outside. For lingcod *(Ophiodon elongatus)* the figure is 20 times as many (Palsson & Pacunski 1995).
Anacapa Island, Channel Islands, California, USA	20	Warm-temperate rocky reef	Densities of the commercially exploited red sea urchin *(Strongylocentrotus franciscanus)* were 9 times higher in the reserve than in nearby fished areas (Gary Davis quoted in Fujita 1998).
Tsitsikamma National Park, South Africa	22	Rocky reef	Of three species studied, one was 4 times more abundant in the reserve and another 13 times more. Bream, *Petrus rupestris,* were on average twice as large when protected. The biggest individuals for all species were found in the reserve and maximum sizes in fished areas were depressed. (Buxton & Smale 1989).
Sumilon Island Reserve, The Philippines	10	Coral reef	Eighteen months after fishing was resumed in the reserve, catch per unit effort fell by a half, and the total yield of fish was 54% less, despite a greater area available for fishing (Alcala & Russ 1990).
Apo Island Reserve, The Philippines	6	Coral reef	The biomass of large predators increased 8-fold in the reserve. In fishing grounds mean density and species richness of large predators also increased (Russ & Alcala 1996 a,b).
Kyoto Precture Closure, Japan	4	Temperate sand and mud bottom	The proportion of large male snow crabs *(Chionoecetes opilio)* rose by 32% in the closed area (Yamasaki & Kuwahara 1990).
Maria Island Reserve, Tasmania	6	Temperate rocky reef	The densities of rock lobster *(Jasus rubra)* and bastard trumpeter fish *(Latridopsis forsteri)* increased by 1 and 2 orders of magnitude respectively within the reserve. The numbers of species also increased for fish, invertebrates and algae, as did the densities of fish larger than 33cm (Edgar & Barrett 1999).

6. What is the evidence for spillover from marine reserves?

One way in which reserves are expected to benefit fisheries is through spillover. In theory, populations of exploited species will increase in reserves until conditions become sufficiently crowded, and resources scarce enough, that animals will move to places where population densities are lower. Such places lie outside reserves. Protection will therefore lead to a net emigration of animals from reserves to fishing grounds. The rate of this movement will be proportional to the density difference between the reserve and fishing grounds. The amount of spillover will depend on six factors:

(1) Efficacy of protection from fishing. Where protection is very successful, populations will build up rapidly inside reserves and reach higher levels than where protection is incomplete.



Spiny lobsters* (Panulirus argus) *are protected in their juvenile habitat in Florida Bay. They migrate to reefs in the Florida Keys where they support a highly lucrative recreational and commercial fishery. Without this reserve, and a reserve that protects adult lobsters in the Dry Tortugas, the fishery would likely collapse. The American scientist Gary Davis studied these lobsters in the 1980s and estimated that virtually every adult lobster was removed from fished reefs every year.

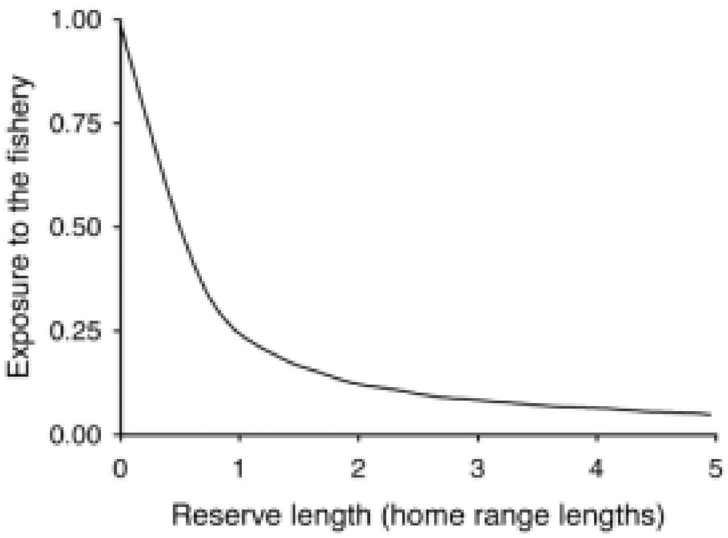
(2) Time since reserve creation. The longer a reserve has been established, the closer animal populations will approach to the carrying capacity of the environment (that is, the maximum abundance the environment will support), although natural disturbances may limit numbers to some level below this.

(3) Intensity of fishing outside the reserve. The higher the fishing intensity outside reserves, the lower will be the population densities of organisms present. This should encourage rapid spillover, since density differences will grow wider than in areas where fishing pressure is less. However, it is possible that fishing disturbance outside reserves could act as a constraint on movements if animals avoid disturbed areas, or the habitats they depend on have been damaged.

(4) Mobility of the organisms involved. Animals must be mobile to leave reserves and so species like giant clams *(Tridacna spp.)* or mussels that are fixed to the bottom will not spillover (although their offspring will be exported to fishing grounds - see Section 7). As mobilities increase, so will the opportunity for spillover. Yet paradoxically, the biggest net support to fisheries from spillover may be from species with intermediate levels of mobility. These will gain greater protection from reserves than the most mobile species which frequently move in and out of fishing grounds where they expose themselves to being caught. The population densities of less mobile species will reach much higher levels in reserves, whereas those of very mobile species will probably be more similar to densities found in fishing grounds (Figure 6).

(5) Boundary length of reserves. The greater the length of boundary available, the more opportunity available for movement out of a reserve. However, the amount by

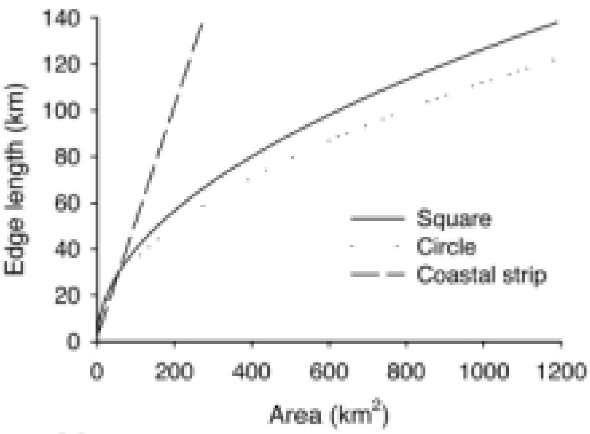
Figure 6: ***The likely effects of reserve protection on populations of species that differ in their range of movements. Species that move long distances will gain less protection from reserves, and their populations may not build up to such high levels as those that have more limited ranges. The larger reserves are, the greater the spectrum of mobilities they will encompass and the more species they will benefit. The figure shows how the larger a reserve is in relation to the range of movement a species has, the greater the protection provided to a population. Furthermore, population densities inside the reserve may be lower at the edges compared to the centre, due to greater mortality of fish that live close the edges. Reproduced from Rakitin and Kramer (1996) with permission.***



which spillover enhances fisheries is likely to be maximized not at the largest boundary lengths, but at some intermediate level. This is because the greater the edge to area ratio of a reserve, the faster will be net movement rates across reserve boundaries. Reserves with a large edge to area ratio will offer less protection to animals inside than those with less edge (Figure 7). This acts in the same way as increasing animal mobility, leading to a lower population build-up inside reserves and less difference in population density between protected and fished areas. Small reserves have greater edge to area ratios than large, as do long, thin reserves compared to circular reserves.

<u>(6) Boundary porosity.</u> Spillover will be facilitated where the boundaries of reserves cross areas of continuous habitat, but inhibited if the boundaries are coincident with habitat breaks. Organisms are less likely to leave a reserve if they have to cross a different kind of habitat than if they can move through a continuous area of the same habitat.

The above sets out theoretical expectations we have about spillover, but how much evidence is there that fisheries do benefit from animals leaving reserves? We have ample evidence of the first condition for spillover. Reserves do allow population densities of animals to increase well above levels in surrounding fished areas (see Section 5). There have also been many tagging studies, of fish and crustaceans in particular, showing that they travel sufficiently long distances to move out of reserves. Some of these have been designed specifically to detect spillover from reserves. For example, in South Africa a recreational game fish, the Galjoen *(Dichistius capensis)*, were tagged inside the De Hoop reserve and tag recoveries monitored (see Case Study). Of



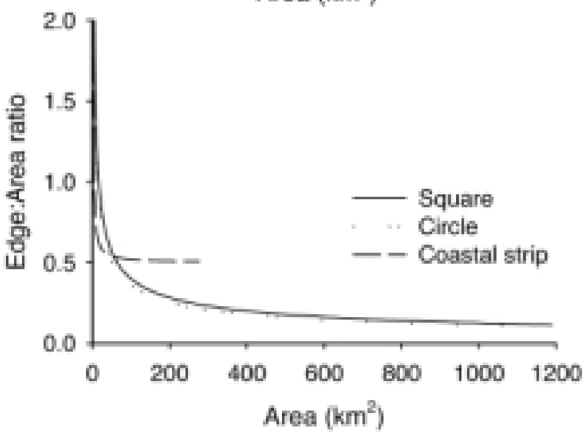


Figure 7: ***Edge to area ratios of different sized and shaped reserves: circles, squares, and rectangular reserves with a fixed width (1km) and variable length, to simulate reserves that follow coastlines. Edge to area ratios decrease with increasing reserve size, suggesting that rates of spillover per unit area will be lower for large reserves. However, the total amount of spillover will be greater from a large reserve compared to a small because they have a greater edge length.***

11,022 fish tagged, 1008 were recovered, and of these 828 were recovered within 5km of where they were released. The remaining 180, (18%) were recovered at least 25km from where they were released, and the maximum distance that any fish traveled was 1040km (Attwood & Bennett 1994). This tendency of certain individuals to move long distances was not related to age, sex or season.

The distances over which spillover is significant will depend on the mobility of species involved. Tagging studies on coral reefs usually show that most species have very limited movements. This suggests that spillover will be limited mainly to areas close to reserves, perhaps within a few hundred metres of the boundary. Even in habitats where **target species** move more extensively, the capture of spillover may still occur close to reserve boundaries since fishers tend to intensify their efforts there.

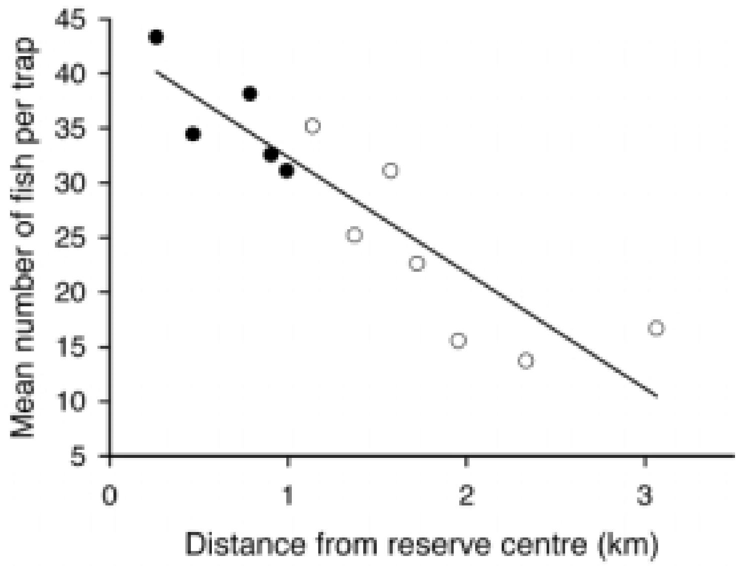


Figure 8: ***Differences in catch per unit effort of fish traps in relation to distance from the centre of a Barbados marine reserve. Experimental trap catches increased approaching the reserve centre from both the south and north, and catches were higher close to the edges of the reserve than further away. This suggests either that fishers avoid the reserve, and fishing pressure is lighter close to the boundary, or that there is spillover from the reserve to fishing grounds. Rakitin and Kramer (1996) who conducted the study suggest that spillover is a more likely explanation. Reproduced from Rakitin and Kramer (1996) with permission.***

If animals are moving out of reserves then densities should be higher in areas close to reserve boundaries than places further away. Rakitin and Kramer (1996) found evidence for this in Barbados (Figure 8). In experimental trap fishing, they found highest catches and catch per unit effort inside the reserve. However, outside the reserve catches increased approaching the boundary from both the north and south. Russ and Alcala (1996b) found a gradual increase in densities of fish outside of the Apo Island reserve in the Philippines, but very close to its boundary (Figure 9). This effect only became apparent after the reserve had been protected for nine years, suggesting it took this long for critical densities to accumulate inside the reserve and for spillover to begin. However, if people fish close to reserve boundaries, then spillover could be mopped up as fast as animals leave reserves. An observer counting fish outside a reserve might see no changes over time, but fishers could be landing more fish. It is only when the rate of spillover exceeds the rate of removal by fishers that increases in density will be apparent outside reserves. The Apo reserve has probably been supplying the local fishery for most of its existence.

People skeptical of reserves often point to a lack of direct fishery evidence for spillover. It is all very well proving that some animals can move out of reserves, they say, but where are the data showing improved catches? Unfortunately, very few people have yet examined fisheries around reserves. McClanahan and Kaunda-Arara (1996) found a 110% enhancement in catch per unit effort in fishing grounds close to the Mombasa Marine National Park in Kenya (see Case Study). This may have been due to a combination of spillover from the reserve and **recruitment** enhancement (recruitment is the replenishment of populations by young fish). In Sumilon Island, Alcala and Russ (1990) found that catch per unit effort and total catches fell by half after reserve protection broke down, despite a larger area of fishing grounds becoming available (see Case Study). This suggests that the reserve supported the fishery, again possibly through a combination of spillover and recruitment enhancement.

Single-species closures provide further evidence of spillover. Spiny lobster *(Panulirus argus)* are protected from fishing in their nursery grounds in the Biscayne Bay Spiny Lobster Sanctuary, but then move out to fishing grounds in the Keys as they grow (Davis & Dodrill 1980). Closures for snow crab in Japan also led to higher catches nearby (Yamasaki & Kuwahara 1990). But scientists are not the

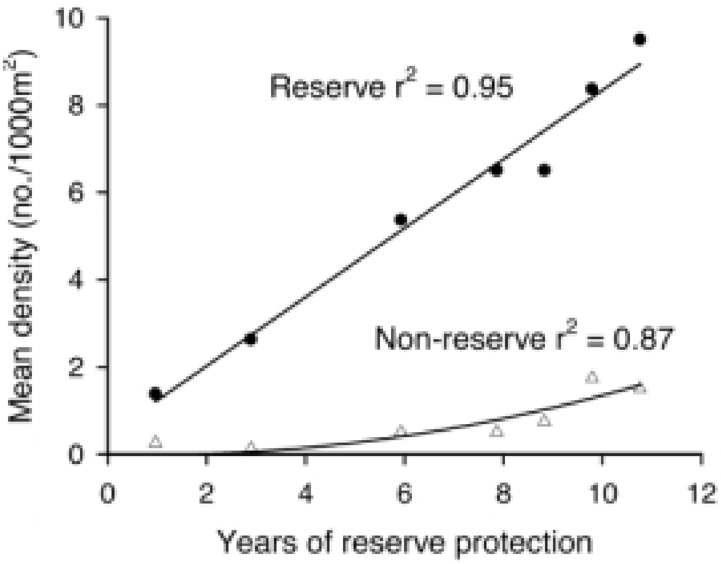


***Figure 9:* Evidence for spillover from the Apo Island reserve in the Philippines. Over 11 years of protection fish populations have built up rapidly in the reserve. In the area immediately adjacent to the reserve, populations began to increase after 9 years of the reserve being protected. Russ and Alcala (1996b) interpreted this to mean that populations inside the reserve took this long to reach a sufficient density to spillover into surrounding fishing grounds. However, densities will only build up in fishing grounds when the rate of spillover exceeds the rate of removal. Spillover from the reserve has probably been supplying fisheries of Apo Island for much longer than this. Reproduced from Russ and Alcala (1996b) with permission.**

only people who sample fisheries. Fishers are constantly sampling the marine environment looking for places where they can get the highest yields. The most compelling evidence that spillover is significant can be found in changing patterns of fishing effort following reserve establishment. In places where there are well-respected reserves, **'fishing the line',** as fishing close to reserve boundaries is called, becomes increasingly prevalent as time goes on. There are a growing number of examples of fishing the line from many different habitats in many different parts of the world. In New Zealand, a visitor to the Leigh Marine Reserve once complimented one of its founders, Bill Ballantine, on how well the boundary was marked by mooring buoys. Ballantine pointed out that they were actually the floats of lobster traps! Fishers for conch and lobster preferentially fish close to the edge of the Hol Chan marine reserve in Belize. In Spain, there are reports of 50-85% higher catches close to the Tabarca marine reserve after six years of protection (Ramos-Espla & McNeill 1994). Some would argue that fishers target areas close to reserves because they expect higher catches there, but this does not prove they actually get them. However, fishers are shrewd people and would not waste effort fishing in places that did not offer rewards, particularly if there is a large amount of competition for fishing space close to reserves. Fishing patterns show that spillover does happen and it does benefit local fishers.

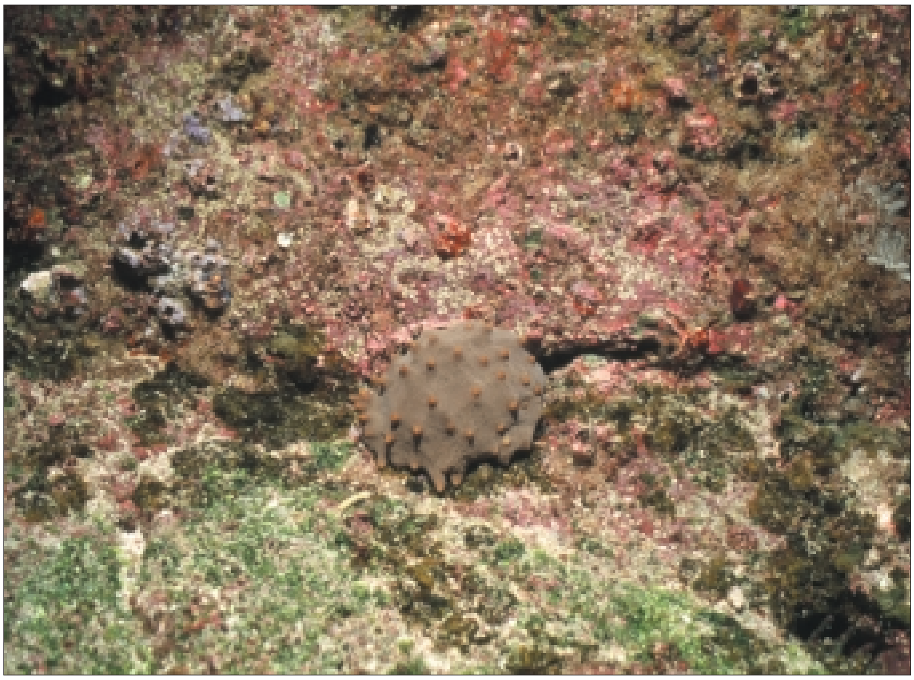
Key points:

- Spillover, the movement of marine animals out of reserves, is one of the two main mechanisms through which reserves can enhance fisheries.
- The rate of spillover varies among species and reserves, and depends on the mobility of animals, degree of compliance with the reserve, time since reserve creation, intensity of fishing around the reserve, the edge to area ratio of the reserve, and whether or not habitat is continuous across reserve boundaries.
- There is circumstantial evidence for spillover from studies of the movements of exploited species, and direct evidence of increased catches close to reserve boundaries from a growing number of studies.
- The most compelling evidence for spillover is 'fishing the line', the change in fishing patterns following reserve creation where fishers preferentially fish close to reserve boundaries.

Further reading: Rakitin & Kramer 1996; Russ & Alcala 1996b; Chapman & Kramer 1999.

7. Do reserves increase reproductive output and recruitment of animal populations?

Many studies show that fully-protected marine reserves promote a swift build-up in biomass of commercially exploited fish species within their boundaries. Typically biomass will at least double after three to five years protection, although some species, particularly those which have been intensively exploited, can grow in biomass by orders of magnitude. For any given area, increased biomass of a species should result in a greater reproductive output. For example, it has been estimated that, based on differences in biomass, the reproductive potential of Nassau groupers *(Epinephelus striatus)* in a reserve in Exuma Cay in the Bahamas is six times greater than that in fishing grounds. In Puget Sound off the north-west US coast such differences are even more spectacular. Here the reproductive potential of lingcod *(Ophiodon elongatus)* in a reserve has been calculated at twenty times greater than it is in fishing grounds while for the copper rockfish *(Sebastes caurinus)* it is a staggering hundred times greater.



The sea cucumber,* Isostichopus fuscus, *has been fished in the Galapagos since 1992 to supply Asian markets where it is considered a delicacy and is in huge demand. After massive over-exploitation the fishery was closed in 1996. It was reopened in 1999, despite the fact that stocks remained at very low levels, primarily because of continuous illegal fishing. 1999 catches netted US$5 million for local fishers. However, sea cucumbers only successfully reproduce when population densities are sufficiently high. Fully-protected zones that are currently being established in the Galapagos should help ensure that essential reproductive densities are sustained, so securing the future of this fishery. Without them, prospects for such fisheries are bleak.

Despite this positive relationship between biomass and reproductive potential, it has been difficult to obtain concrete proof that fish in protected areas contribute towards the replenishment of stocks in fishing grounds. There are good examples where fisheries have improved following establishment of large, single-species protected areas, such as those for Atlantic menhaden *(Brevoortia tyrannus)*, spiny lobster, stone crab *(Menippe mercenaria)* and pink shrimp *(Penaeus duorarum)* in south-eastern USA. Skeptics argue that other factors, such as good recruitment years or sound fishery management have produced these benefits rather than the closed areas.

Many questions still remain unanswered about the fishery effects of reserves. Part of the problem is there are too few fully-protected areas available for study and little research has been directed at the question. Contributing to the problem, recruitment is an extremely variable process. Because recruitment can quite naturally vary by orders of magnitude, it is extremely difficult to prove that any increases measured in fishing grounds are a result of nearby reserves. To do so will require a very long time-series of data, in the absence of which modelling studies must suffice for insights into reserve contributions to recruitment.

In 1991 Jim Bohnsack modeled egg production by red snapper in the Gulf of Mexico with and without a 20% **network** of fully-protected marine reserves

(Bohnsack 1992). He estimated that if 20% of the fishing grounds were closed, egg production would rise by 1200% due to the increased contribution from more older, larger fish which can produce many times more eggs per individual than smaller young fish. Similarly, a model for scallops *(Placopecten magellanicus)* on the Grand Banks showed that egg production per female could increase by 15 times in protected reserves (McGarvey and Willison 1995, Figure 5). As these increases would be matched with an increased density of individuals, the production of recruits to fishing grounds should be significant. In this case the model prediction seems to have been borne out in reality. When two large areas protected from scallop fishing were established on Georges Bank, stocks of scallop rebounded within them in only four years and recruitment to adjacent fishing areas also increased (Murawski et al. in press). In fact the benefits of this export were so pronounced that fishers preferentially targeted the reserve boundaries.

Most of the eggs and larvae produced by commercially important species remain in the plankton from one week to several months. Some drift passively whilst others actively influence their settlement destinations. Consequently, larval production from marine reserves may be retained locally, dispersed widely, or fall somewhere in the middle of these extremes. The smaller a marine reserve, the less likely it is to retain larvae produced there. However the contribution to recruitment of increased spawning stock biomass accumulated within reserves will not depend so much on the size of a reserve itself, but on the relative area of all reserves in relation to fishing grounds. For example if 1% of a management area is closed to fishing, the reserve, or reserves could export larvae and provide adult spillover to fishing grounds. However, the magnitude of that contribution will increase as the proportion of the management area protected grows. Modeling studies suggest closures to fishing of between 20 to 50% provide the greatest benefits to fisheries, although closures of 10% can be expected to provide significant advantages.

As a rule of thumb, the degree to which reserves are likely to enhance recruitment to fishing grounds will be equivalent to the fraction of the total biomass of a population which they contain. However, it can sometimes be much greater. For example, if a fishery removes most animals before they reach sexual maturity there will be very little reproduction in fishing grounds. It would be more accurate to view the reserve contribution to recruitment on the basis of the proportion of the biomass of reproductively active animals in reserves compared to fishing grounds. In this situation the biomass of sexually mature individuals will be much higher in protected areas and so recruitment to fishing grounds will probably derive mainly from animals reproducing in reserves.

A similar situation also occurs when the reproductive success of a species is strongly affected by population density. This is often the case for animals like invertebrates that are fixed to the bottom or have limited powers of movement. For them, successful spawning depends on high population densities. Individuals need to be sufficiently close that eggs and sperm can fuse before the sperm lose their short-lived motility. In fishing areas, individuals are likely to be much further apart than in reserves. Hence a small proportion of the population biomass, which is densely packed within a reserve, can account for a large proportion of the species' reproduction and hence ability to provide recruitment to fisheries.

The final case in which reserves may produce a disproportionately high contribution to recruitment is where fishing reduces the availability of males. This happens to species which change sex during their lives, such as many groupers, parrotfish and large wrasse. In most sex-changing fish, animals are female first and transform into males when large. However, if heavy fishing pressure prevents females from reaching a size where they are big enough to do this, then males can become very rare or even disappear from a locality. Ultimately this could decrease the reproductive potential of a population, even allowing for the fact that as size structures change, females may adapt, by changing sex when they are smaller. In these circumstances protected areas could once again contribute disproportionately towards recruitment because, within their boundaries, male availability will be much greater.

When all things are considered, it seems highly likely that marine reserves will enhance recruitment to fishing grounds. They certainly increase the reproductive output of fish populations, whilst fishing can be highly effective at reducing it. Given this and the recognizable difficulties in studying recruitment that we have discussed, the burden of proof should lie with critics of marine reserves to prove that they don't contribute to recruitment, if this is to be used as an argument against their implementation. The most parsimonious view, given the likely sizes of reserves and the large dispersal distances of marine organisms, is that export to fisheries will be significant.

Key points:

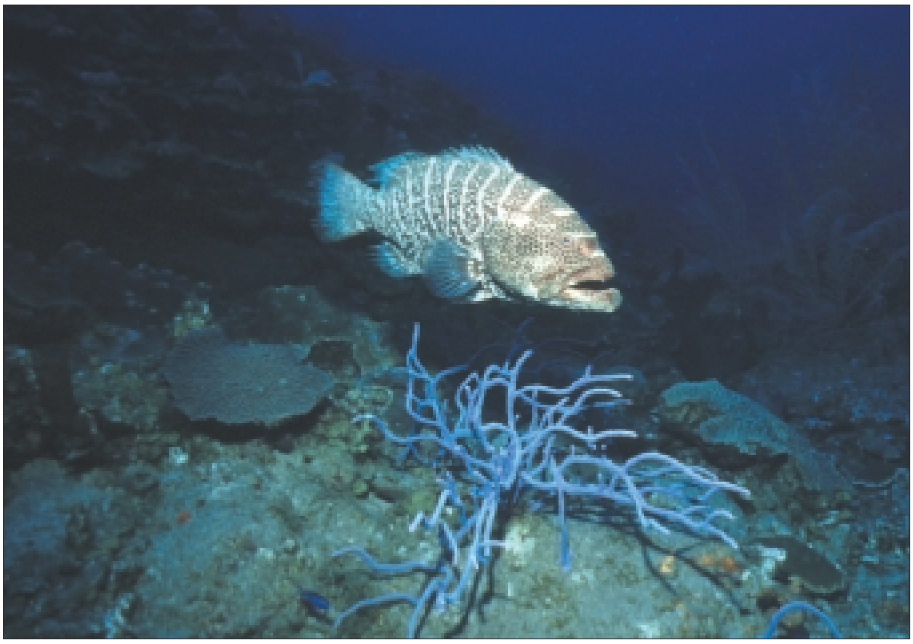
- Well respected, fully-protected marine reserves typically lead to at least a doubling in the biomass of exploited species after three to five years protection. Sometimes biomass can increase by orders of magnitude over levels in fishing grounds.
- Much of that biomass is concentrated into larger individuals than in fished areas, and they usually produce many times more offspring.
- For intensively exploited species, reserves may support the bulk of successful reproduction by a population.
- Most exploited species have an open water dispersal phase and their offspring can be expected to disperse widely into fishing grounds.
- Over time, reserves may come to produce orders of magnitude more offspring per unit area than fishing grounds, and even relatively small reserves could produce regionally-significant replenishment of exploited populations.

Further reading: Roberts & Polunin 1991; Dugan & Davis 1993; Rowley 1994; Bohnsack 1996; Fujita 1998.

8. How useful are marine reserves as tools for conservation?

There is no doubt that fishing is causing major problems in the sea. Some species that once supported valuable fisheries, such as Atlantic halibut *(Hippoglossus hippoglossus)*, southern bluefin tuna *(Thunnus maccoyii)* and the boccacio rockfish *(Sebastes paucispinus)* have declined so much they are now included on the World Conservation Union's Red List of Threatened Animals. However a species does not need to be rare, or specifically targeted, to be at risk from fishing. Over-exploitation has indirectly caused the decline of many species that have no commercial importance. Fully-protected marine reserves provide an excellent opportunity to protect species from the deleterious effects of over-fishing. In this section we concentrate on how no-take areas can help regenerate biodiversity that has been lost to fishing. In certain situations the establishment of a reserve might come too late to help some species recover. While such failure is disappointing, it only helps emphasize the urgent need for more reserves to stem biodiversity loss. If reserves fail to restore certain species to an area, it is most likely because of previous misuse.

Despite concerns about biodiversity loss in the sea, many scientists still believe marine species are highly resilient to global extinction. They argue that most marine organisms produce enormous numbers of offspring and are very widespread. So, for



Tiger grouper* (Mycteroperca tigris) *have been heavily depleted by fishing in the eastern Caribbean. If a species is fished out of an area there is no magic formula to make it reappear. A marine reserve will allow such species the opportunity to become re-established, but this will first require recruitment from outside the protected area. In the Saba Marine Park numbers of tiger grouper remain very low, despite more than a decade of protection. For a population to become reproductively viable, the reserve will need to build up a critical density of individuals, which may be possible over time for long-lived species like tiger grouper, even with very low recruitment. Several other species of grouper, whose populations were less heavily depleted at the time of protection, now thrive in the marine park.

any given species, whatever the threats, people believe that somewhere, enough will survive to restock the population. However, a recent study has shown that nearly one in ten coral reef fish species have a highly restricted geographic range (less than 50,000km^2), and a quarter of all reef fish species have a limited range (less than 800,000km^2) (Roberts et al. in press a). Add to this the fact that very little of these ranges (a quarter of one percent) actually consist of coral reefs, and it means that coral reef fish are much less widespread than we previously thought. This also appears to be true for several other groups of marine organisms studied to date (Roberts & Hawkins 1999). Consequently as species are eliminated from an increasing number of locations, global extinctions become a real possibility, especially for those with restricted ranges.

Long-term, intensive fishing will reduce population densities generally and eliminate some species entirely. Whenever a fully-protected reserve is established it can help to reverse these trends. However, its potential to restore biodiversity will depend on how badly fishing has affected the biological communities present and whether there are sources of new recruits to the reserve. Although many marine organisms produce eggs and larvae that can potentially drift long distances on ocean currents, if the effects of over-fishing are widespread, few offspring may reach a protected site. For example, the tiger grouper *(Mycteroperca tigris)* is still very rare in the Saba Marine Park, despite over a decade of protection from fishing. It seems likely that intensive fishing throughout the eastern Caribbean has removed most possible sources from which populations of this species in Saba could be replenished. Nevertheless, it may still prosper there despite its slow recovery. The tiger grouper is a long-lived species so even a very slow trickle of recruitment may be enough to eventually restore a population to a site that is protected from fishing. That site may then begin to supply offspring to other areas, and so the species may recover.

The rate of recruitment to new reserves will depend on the size of source populations, how close they are, and the ability of recruits to disperse from them. If animals that disperse only short distances are to repopulate then reserves must be close to source populations. For the many species that need to have high population densities to successfully reproduce, this is particularly important. Unless critical densities already exist within reserves or very close by, these species will recover very slowly, or possibly not at all. For example, despite a long-term closure to fishing, conch *(Strombus gigas)* populations in the Florida Keys have not rebounded.

Life history will also affect re-establishment of species eliminated by fishing. In reserves in St. Lucia, parrotfish, soldierfish and the smaller grunts, which are short-lived, fast-growing and recruit prolifically, have shown the quickest response to protection from fishing. Unsurprisingly, these species also dominate fishing grounds because they are the most resilient to fishing. Species which are long-lived, slow-growing and recruit sporadically will take longer to reappear inside reserves, especially, as we have already discussed, if they have been fished out from surrounding areas.

In order to conserve species, fully-protected reserves need to maintain populations of marine organisms that are viable over the long-term. Even when species have become re-established in a reserve their persistence is still dependent on recruitment. Species that disperse only short distances may be self sustaining within a reserve, and the larger a reserve is, the more recruits it can retain. However, species that disperse more widely may not contribute towards their own proliferation within a single reserve. If such species are unable to persist in fishing grounds, their survival will depend on the creation of networks of reserves that help replenish each other through dispersal. The viability of such species should then be judged over the whole network rather than in any single reserve. Species that can persist in fishing grounds will also help restock reserves and support conservation. Hence the maximum benefit to conservation will occur when fully-protected areas are surrounded by well managed fishing grounds.

One final benefit of protected areas in relation to recruitment is the refuge they provide for species with sporadic recruitment. If a species only recruits occasionally (often at intervals of many years) it is essential that populations always contain enough sexually mature adults to provide offspring when favourable conditions arise. In areas subject to heavy fishing pressure the population structure of many species is often so altered that few sexually mature adults are present when this happens. Without the safety net of reserves, some populations might not persist from one period of recruitment to another.

Fully-protected marine reserves help restore habitats that have been damaged by fishing. Organisms such as bottom dwelling hydroids, micro-crustaceans and gorgonians can all be damaged or eliminated by practices such as trawling. When fishing is stopped, the source of damage is removed, further deterioration is prevented and species have the chance to recover. As we have learned more about the sea, it now seems apparent that hundreds of species may be in trouble for every one that we know about. Fully-protected areas provide a valuable insurance policy for species' survival.

While marine reserves provide undoubted benefits for conservation, some species may decline in them following protection. While this appears to contradict the aims of conservation it can happen because species which are tolerant to heavy fishing are not the same as those that thrive in its absence. When viewed at the regional level, reserves create a mosaic of different ecological conditions, promoting biodiversity and helping redress the changes brought about by over-exploitation. To properly appreciate the conservation benefits of reserves, it is necessary to look at both the species that prosper within them and those that prosper beyond their boundaries.

Key points:

- It was once believed that fishing could never cause the extinction of marine species but it is now clear that there are many threatened species in the sea.
- Many species have been seriously depleted by overfishing, and some have been eliminated from large areas of their former ranges. Where source populations still exist, reserves can help promote their recovery.
- Where fishing is intense and widespread, reserves may be the only means of protecting species that are highly vulnerable to depletion by fishing.
- Reserves protect habitats from damage by fishing gears, and foster the recovery of damaged habitats. Reserves may be essential for protecting vulnerable habitats, especially those that are limited in distribution.
- Reserves promote biodiversity by creating conditions that favour the development of communities that are different from those in fishing grounds.

Further reading: Sobel 1996; NMFS 1998; Roberts in press a.

9. Are fully-protected reserves beneficial to migratory species?

It is usually argued that marine reserves are pointless for migratory species, because these fish will spend much of their time outside them in areas where they can be caught. Fishers, scientists and government ministers all seem to accept this view and, partly for this reason, there are few fully-protected reserves in temperate regions where industrial scale fisheries tend to be dominated by wide-ranging species. In fact there are good reasons why no-take areas can benefit migratory species. People have tended to overlook them because they have based their views on simplistic models which ignore vital aspects of fish behaviour and ecology. Many migratory species predictably occur in large aggregations at specific locations for part of their life cycles. At such times they are especially vulnerable to capture, and very easily over-fished. Establishing reserves in such critical areas is the key to making them work for migratory species.

As adults, migratory species can range widely, then congregate to breed in predictable spawning grounds. On migration routes they may also pass through physical 'bottlenecks' and become highly aggregated. As juveniles they may remain in nursery areas for periods from months to several years before moving on. Therefore it makes great sense to place reserves in spawning grounds, nursery areas and other bottleneck sites. If you prevent fishing in nursery grounds you will increase juvenile survival which can then increase fish landings. Protecting animals at spawning aggregation sites gives them the opportunity to reproduce undisturbed.

Bluefin tuna* (Thunnus thynnus) *in the Tokyo fish market in Japan. Bluefin tuna are seriously threatened by overfishing. They have now become so valuable (US$10,000 upwards per fish) that spotter planes are used to find fish and then direct boats toward them. Highly migratory species like this could benefit from marine reserves in places where they become highly vulnerable to capture, such as off the coast of New England in the USA.

In fact fishery managers in temperate regions have often used single-species closed areas to protect juveniles of migratory species. For example, nursery grounds of plaice have received some protection in the "plaice box" in the southern North Sea. This area is permanently closed to large beam trawlers targetting plaice and sole *(Solea solea)*. As a result of the "box" it is estimated that yields of plaice have risen by 8% in the ten years since it was established. However small trawlers are still allowed to operate in the area, so juvenile plaice continue to get picked up as by-catch. It has been estimated that benefits of this closure would be three times greater if all boats were excluded. Measures to protect areas for juvenile mackerel *(Scomber scombrus)* in the south-west of England have resulted in decreased juvenile mortality of between 20 and 83% depending on the age of the fish. In this "mackerel box" all industrial purse seining is banned, but once again closure is incomplete as people are allowed to fish using hook and line.

Fishing spawning aggregations is perhaps the simplest way to cause stock collapse. In many cases, individuals are so closely aggregated they can be mined rather than fished. Throughout large areas of the Caribbean, the Nassau grouper has been all but eliminated because of spawning aggregations being fished. Population collapses have usually occurred within a few years of aggregation sites being discovered. In fact, for this species the effects of fishing on spawning aggregations have been so great it has been listed as vulnerable to extinction in the World Conservation Union's Red List of Threatened Species. Spawning grounds of temperate species

Feeding aggregation of Totoaba* (Totoaba macdonaldi) *in the Gulf of California. This photograph was taken by Jake Miller in the early 1940s. The Totoaba is a giant species of croaker which is entirely restricted to the northern waters of the Gulf. It once undertook spectacular annual spawning migrations from deeper water, following the coast closely as it swam to the Colorado River estuary in the north where thousands of fish would reproduce in writhing masses. At the time the photograph was taken, individuals used to grow up to 140kg and over 2m long. Today, the species is on the brink of extinction, and the few that are left barely make 10kg. Its populations have been decimated by overfishing, and loss of estuarine spawning and nursery habitats due to abstraction of water from the Colorado river. Young fish also suffer heavy mortality as by-catch in shrimp trawls. In less than a century, the species has gone from superabundant to endangered. Strategically placed marine reserves could help the species recover by protecting spawning and juvenile fish. Photograph reproduced with permission from National Geographic Magazine.

have also been decimated and not all examples are recent. Before the turn of the 20th century fishers had eliminated turbot *(Scopthalmus maximus)* from many spawning areas along the south coast of England. At about the same time, fisheries for the eastern Atlantic bluefin tuna collapsed in the Mediterranean. These fish were caught on migrations to spawning sites, when they passed through straits and close to coasts. This physical constraint within narrow stretches of water made them extremely easy to catch. In New Zealand and the Atlantic, exploitation of deepwater orange roughy *(Hoplostethus atlanticus)*, only becomes economically viable to fishers when the fish congregate to spawn over seamounts and at the continental shelf edge. These examples all show that if reserves are situated in areas where migratory species congregate and become most vulnerable, they could provide extremely worthwhile protection.

One of the recognized benefits of fully-protected reserves is that they safeguard marine habitats from damage caused by fishing gear. This can enhance an area's carrying capacity (its ability to support fish production) and promote growth and reproduction of fish. Such benefits become available to migratory species whenever they pass through a protected area. Some migratory fish may even start to loiter in reserves, and so reduce their risk of getting caught. Reserves also protect fish from disturbance caused by fishing. For example, studies in Canada showed that if a trawl passes through a spawning aggregation of cod *(Gadus morhua)* it can take up to an hour for the fish to regroup. Before the fishery was closed, nearshore spawning aggregations of northern cod were trawled between 600 and 1880 times per year. With trawling intensities this high, any fish that escape capture may be hindered in their attempts to reproduce. Research has shown that artificially stressed fish produce greater numbers of abnormal offspring than unstressed fish.

Finally it appears that populations of some migratory species include reproductively active individuals that do not seem to migrate. Such fish would be afforded full protection by reserves. For example, there are anecdotal reports of giant cod in the North Sea that seem to have become permanent residents around oil platforms and pipelines. For safety reasons, boats are not allowed to fish within a 500m radius of these structures and so they act as *de facto* no-fishing zones. Some have suggested that this unintended refuge from fishing may have helped prevent North Sea cod stocks collapsing after spawning stocks were driven to an all time low in the late 1990s. Although this is highly speculative, such findings highlight our lack of knowledge about fish behaviour, even amongst species we have pursued for hundreds of years.

The complex behaviour of many migratory species is something which should not be over-looked when taking management decisions. For example, large cod have been seen leading smaller ones across the Canadian continental shelf on their migration routes to spawning grounds (Rose 1993). Scientists are worried that elimination of older fish by intensive fishing will lead to young fish not being able to locate traditional spawning areas. Similarly, in the tropics we don't know how fishing out of grouper spawning aggregations will have affected the remaining young. Will these fish ever return to their spawning grounds and if not can they successfully reproduce? Reserves can help prevent such problems by protecting species at critical times in their life-cycle.

To benefit migratory species it is important that reserves are set up in the right areas. We need to understand what aspects of a species' behaviour make it vulnerable to fishing, and where fishing activities exploit this behaviour. Much of this information can be gained by interviewing fishers and discovering what they catch, where they caught it and when. Areas can then be identified which would benefit either a single, or several species if protected. For example, fishers from the south-west of England have proposed that Trevose Head, off the north coast of Cornwall, should be a fully-protected reserve. This area is an important spawning ground for sole, plaice, bass and several other commercially important fish species.

If reserves are put in the wrong places, they could actually harm migratory species, for example, if fishing effort is directed from somewhere the animals are not vulnerable to somewhere where they are. Therefore it is very important to use reserves in combination with restraint on effort in fishing grounds. Scientists in Canada concluded that without other management measures it would have been necessary to close approximately 80% of the cod fishing grounds to prevent the fishery collapse. However if reserves had been used as part of a mixed management strategy the disaster could have been prevented with only a 20% closure.

Fully-protected reserves can clearly benefit migratory species. The reason scientists were late in recognizing this is because they failed to take full consideration of the complex life histories and behaviour of many of these species. A few migratory species may not benefit from reserves, but this is no reason not to implement reserves, although some people take this narrow minded view. There are proven benefits of reserves to a broad cross section of species and habitats and these will not disappear simply because a few species exist that might be better managed using other means.

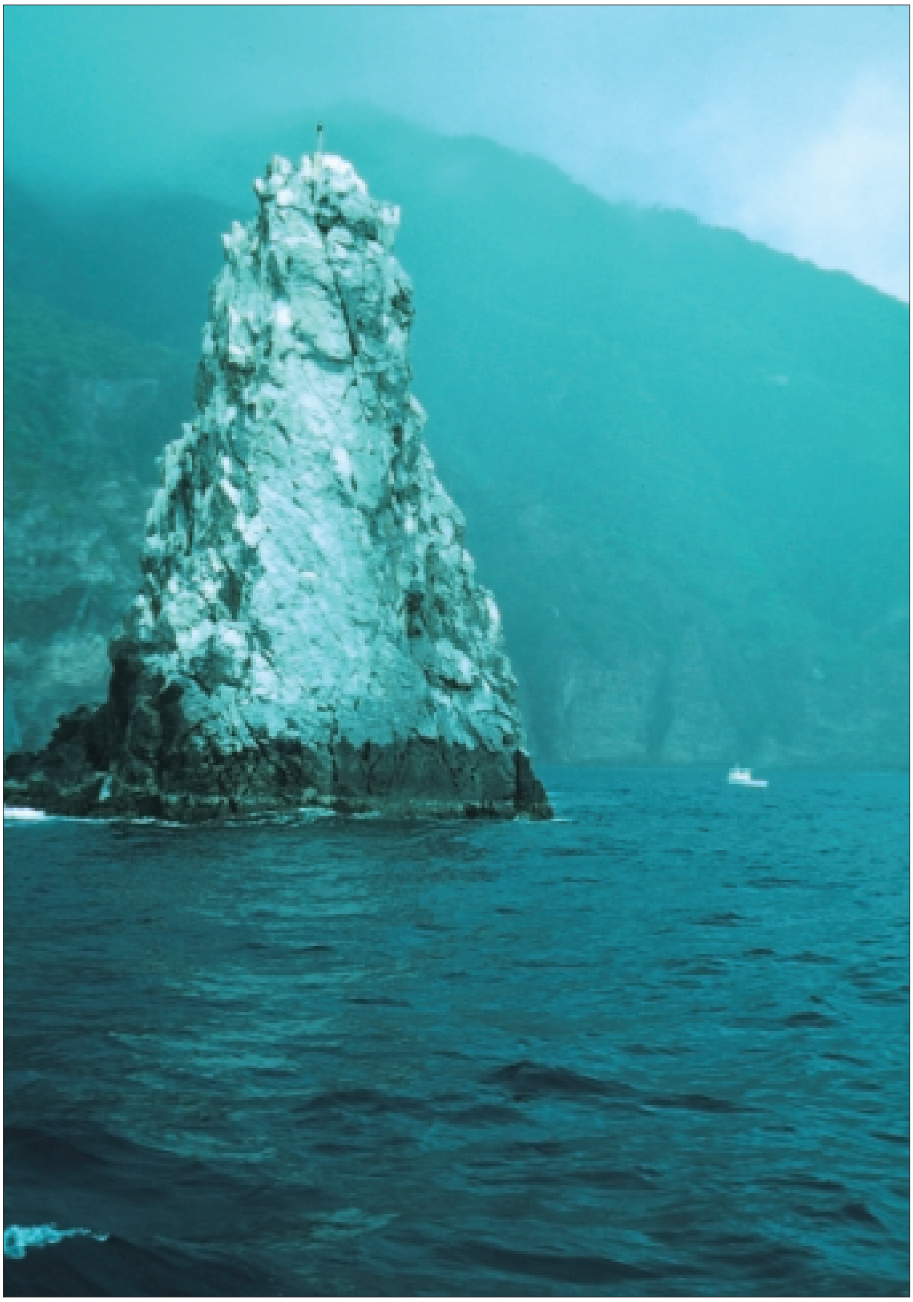
Key points:

- Many people believe that fixed location marine reserves will not benefit migratory species because they will move in and out of them and periodically be exposed to fishing. In fact, there are numerous ways in which migratory species can benefit.
- Many migratory species pass through population bottlenecks where they become highly vulnerable to capture, such as spawning aggregations, and fisheries often target such locations.
- Strategically-placed reserves can provide protection at critical places and times.
- Reserves can prevent premature capture of juveniles in nursery grounds.
- Reserves can protect places where by-catch of migratory species is excessive.
- Reserves can promote habitats that provide better conditions for growth, survival and reproduction by migratory species.
- Reserves can provide important protection but most migratory species will require other forms of management to supplement them.

Further reading: Full details of studies mentioned above can be found in Roberts in press b.

10. How long will it take before reserves produce benefits?

This is the question on everybody's lips when reserves are first suggested. The expected timescale of benefits is critical to whether or not people are willing to accept them. If benefits are expected to accrue rapidly, support will be much greater than if they require some lengthy and undefined period. Fortunately, working reserves from many different regions of the world give us a good idea of what to expect and indicate that benefits come quickly.



Diamond Rock in the Saba Marine Park, eastern Caribbean. This guano covered rock lies within one of the park's fully-protected zones and fish there have been protected since 1987. During this period there have been swift increases in the biomass of many commercially important species both inside the fully-protected zones and in fishing grounds. Diamond Rock is now home to spectacular schools of large predatory fishes and is one of the most popular diving sites around the island.

Reserve benefits depend on the biological processes of reproduction, recruitment, growth and migration. Protection from fishing will lead to a rapid increase of biomass in reserves as fish start to get bigger. New recruitment is not necessary for biomass to increase, since growth of individuals present at the time of protection will be sufficient to assure this. However, recruitment rates could limit the rate of population and biomass increase. Where there is unlimited recruitment to a reserve, maximal rates of population build up will be sustained. However, in many cases, recruitment is limited and places constraints on reserve performance (Figure 10). Where populations have been severely depleted over large areas prior to reserve establishment then rates of recruitment will probably be low, especially for long lived, high value species. For example, in Jamaica, after a couple of years of protection, few of the larger snappers and groupers had yet recruited to a new reserve in Discovery Bay (Watson & Munro in press). Here it seems that fishing has depleted these species to such low levels there is virtually no local reproduction to supply new recruits. Under such circumstances reserves may be entirely dependent on recruits arriving from distant sources and rates of population recovery could be very low.

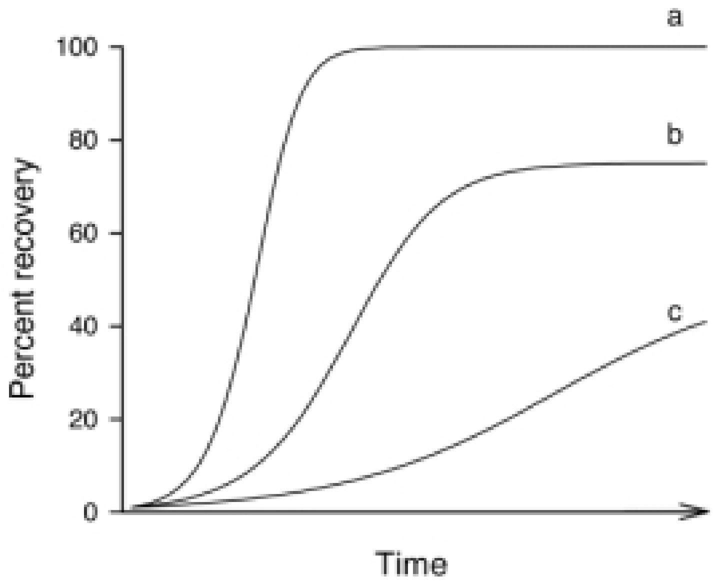


Figure 10: ***Population recovery in a reserve following protection will depend on there being sufficient replenishment by young fish (termed recruitment). This figure shows three possible trajectories for recovery: (a) high recruitment, (b) moderate recruitment, and (c) low recruitment to reserve. The rate and extent of recovery will be greater, the more recruits are available. Recruitment to reserves will be reduced by increasing intensity of exploitation or habitat degradation outside. Recruitment rates to reserves can be increased by establishing more of the management area as networked reserves. Redrawn from Roberts (in press c).***

For reserves to benefit fisheries the biomass of reproductively active animals must first increase within them. Only then will recruitment to surrounding areas improve. Growth in biomass and population densities in reserves are also a pre-requisite for spillover into fishing grounds. Consequently, fishery benefits will lag behind biomass increases. However, the good news is that recovery in biomass and population densities tends to be very rapid with a doubling or tripling in total biomass within three to five years of protection (see Section 5). During the world wars, the North Sea became a *de facto* reserve as it became too dangerous to fish there. Fish stocks tripled in the five years of the second world war. On coral reefs, we have seen significant increases in biomass only one year after reserves were set up. People typically begin 'fishing the line' around reserve boundaries within only two or three years of protection, indicating swift spillover benefits. However, it is harder to predict exactly which species will respond most rapidly to protection. Large offshore closed areas on Georges' Bank in the USA were intended to protect the habitat of juvenile groundfishes. Few people expected scallop *(Placopecten magellanicus)* populations to take off in the way they did (Murawski et al. in press). Ironically, the growth of scallop populations led to a reopening of reserves to scallop fishing, with consequent impacts on groundfish habitat, before groundfish had benefitted much from the closures.

The first species to respond to protection will be those that were fished (or impacted by fishing in some way) but were also reasonably common when the reserve was set up. In areas where fishing effort was high, they will be dominated by species resilient to fishing. However, the first species to respond may not be those that eventually dominate in reserves. For example, in St. Lucia a long history of intensive fishing meant that prior to reserve establishment the reefs were dominated by small, fast-growing, prolifically recruiting fishes. Squirrelfish, small parrotfish, grunts, surgeonfish and wrasses were common, but large snappers and groupers virtually absent. Of course, the small species responded most quickly to protection, while recovery of large species is only just beginning. Over time, we expect that large, predatory species will come to dominate the biomass, while the smaller prey fish will decline in numbers.

When reserves are first established, lost fishing grounds may cause initial problems for fishers. As time goes on, benefits from reserves start to pick up and fisheries should begin to improve. How fast fishers see their costs turn to benefits depends on how overfished a fishery was to begin with. The more heavily depleted populations are, the faster fishers will feel improvements (Figure 11). In places where fishers are suffering worst from overfishing, reserves can turn the situation around most quickly!

Early benefits promote support for marine reserves but people are obviously keen to know how long benefits will continue to increase? This depends on several factors, including how depleted populations were to begin with, recruitment rates, longevities of the species, and the severity of habitat damage. Build-up of benefits depends on good recruitment, and for some species successful recruitment occurs sporadically and unpredictably. It may be years after a reserve is established before

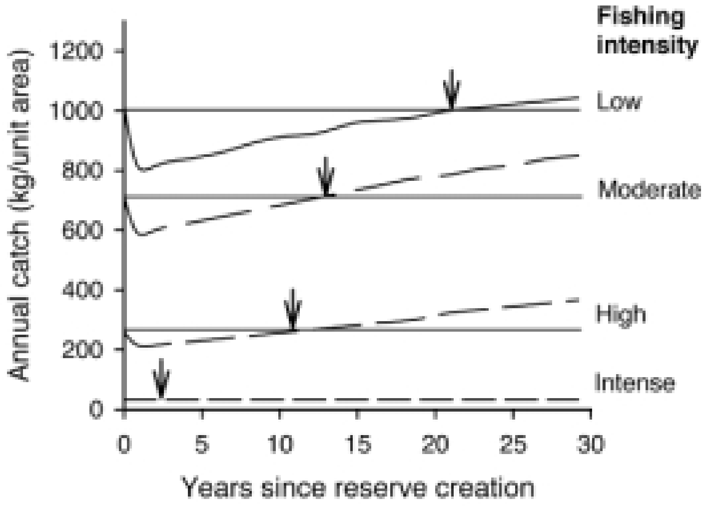


Figure 11: ***The results of a modeling study suggest that the time it takes for a reserve to provide net benefits to a fishery depends on how overexploited that fishery is at the time the reserve was created. The more overexploited the fishery is, the faster fishers can be expected to feel net benefits. Fishing intensity in this figure increases from the upper to the lower curves. Redrawn from Sladek Nowlis and Roberts (1997).***

a recruitment event kicks off population recovery. Successful recruitment pulses may in themselves become more likely as time goes on after reserves have been created. This might happen when the slow trickle of recruits produced by long-lived species eventually come to reproduce themselves. This increase in spawning stock will then produce still greater supplies of recruits. Amongst the largest predators, biomass will tend to increase for as long as the species lives. For example, if a species of shark typically survives for 20 years, then its biomass should only peak after at least this time, as some individuals in the population will have had the opportunity to reach this age. However, because most species are eaten by others, predation may cause their biomass to peak earlier than their potential longevity since populations could later be suppressed by build-up of predators. In the majority of cases, exploited species will continue to build up for at least two decades after protection.

Habitats will recover more slowly than exploited species, especially where their structures have been destroyed by fishing. Deep sea habitats, for example, are dominated by extremely slow growing invertebrates that a trawler can sweep aside in a few passes. Bottom communities develop over very long periods through slow colonization by invertebrates and plants whose skeletons and fronds become habitat for others. Like human cities, complex and diverse communities are built on the foundations of their predecessors. It could take centuries for these marine communities to re-establish. However, while full recovery may be achingly slow, some species will recover quickly, creating different and biologically richer communities than those present before protection. Some forms of habitat recovery may be pre-requisite for the re-establishment of other species. In general, processes of habitat recovery will take decades and benefits are likely to accrue for at least 30 to 50 years after reserves are established.

The long timescales of habitat recovery should not detract attention from the fact that real net improvements will be felt much faster than this. Richer communities and more prolific populations develop within a few years of reserve establishment and benefits to fisheries will follow close on the heels of such changes. People can expect reasonably fast returns for their investment in marine reserves.

Key points:

- Working reserves around the world show that benefits of protection can occur very rapidly. Population increases among exploited species can be seen within a year or two.
- Well-protected reserves can be expected to begin supplying fisheries within five years of creation, and benefits are likely to continue to build up for 10 or 20 years.
- Models suggest that the more overexploited a fishery is at the time of establishment, the faster there will be net benefit from reserves. However, recovery will be slow if populations have been so seriously depleted that there is little reproduction to stock reserves in the first place.
- Damaged habitats will recover more slowly than populations, but recovery begins as soon as reserves are created and may continue for many decades.

Further reading: Sladek Nowlis & Roberts 1997, 1999; Roberts in press a.

11. How can fishers be helped through the economic transition following reserve creation?

Problems in fisheries are often driven by too many people chasing too few fish. In some places this is because they lack any alternative employment opportunities and must fish to survive. In others **overcapacity** may be a consequence of subsidies encouraging more people into fishing than the resources could support. Whatever forces have led to overcapacity, fishers and fisheries will be better off with fewer people pursuing fish. However, creating reserves will displace fishers into a smaller area of fishing grounds. If their numbers remain the same, with a smaller area to fish there will be more competition and fishers may have to work longer to maintain their income, or may suffer reduced catches.

The network of fully-protected reserves implemented in St. Lucia in 1995 initially displaced trap fishers from approximately 50% of their coral reef fishing grounds (see St. Lucia case study), later reduced to 35%. In response, they increased the length of fishing trips by 50% while overall catch per unit held steady in the year after reserves were established (Goodridge et al. 1996). Thus there was no change in overall landings. While these reserves did not lead to a short-term fall in catches, others might. Furthermore, increased fishing effort entails higher costs.

Artisanal trap fisher in the Soufriere Marine Management Area, St. Lucia. Trap fishers were the hardest hit by the creation of no-take reserves and their protests nearly led to the re-opening of all the reserves to fishing. In the end, the government stepped in with one year's cash compensation for a small group of long-established trap fishers and this saved the reserves.

Given that it takes several years for reserve benefits to filter through to fishing grounds, fishers will likely feel some short-term hardship after reserves are established. For people living hand-to-mouth, even small losses are hard to bear. Although there may be the prospect of better times ahead, a family still needs feeding. If reserves tip the balance from just getting by to just failing to do so then fishers will not support them, no matter how much they would like to receive the future benefits of protection. In such cases it may be necessary to get reserves off the ground by supporting fishers over the transition to reserves. This will help tide people over the difficult early years until reserves start producing.

One form of economic help is compensation. Some people feel that fishers should never be compensated because their overfishing caused the problem in the first place. This view is rather extreme. In agriculture subsidies are often given to support the income of people farming in marginal areas, such as high ground. In fisheries, subsidies have been directed towards capital investment allowing fishers to develop new fisheries. Subsidies also tend to be used to help out fishers after their stocks and industry have collapsed! However, subsidies could be used to a greater good if they facilitated the creation of reserves. In the northeast USA, fishers are being compensated for lost fishing opportunities due to the large scallop closures established there in 1994. In California, fishers are also to be compensated for the establishment of no-take zones in the Channel Islands National Marine Sanctuary. In both cases, the compensation provided is to pay fishers to help scientists to study the effects of the reserves. Such arrangements have several benefits. By getting involved with monitoring, fishers are able to use their skills in support of resource protection, rather than having their boats lie idle. It offers researchers and managers much needed insights into traditional knowledge that can help improve conservation measures. By bringing fishers and managers closer together, it also helps foster greater understanding between these groups.

There are very few examples of cash compensation being given to fishers for reserve establishment in the developing world, despite the fact that many people there are so critically dependent on fishing for their survival. In St. Lucia, the reserves were almost reopened to fishing following pressure from displaced trap fishers. However, the Government stepped in with compensation of around US$150 per month for a year and this was extremely effective in helping gain compliance with reserves. The Department of Fisheries also assisted fishers to begin exploiting deep water and offshore areas which were lightly fished compared to shallow water reefs. They provided help with fishing gear and installed fish aggregation devices. In the Philippines, several pilot projects have involved creation of artificial reefs at the same time that reserves were established. These reefs act as settlement sites for valuable aquarium fish, as well as aggregation devices for food fish. While, such measures might provide relatively short-term benefits, they could sustain fishers over the lean, early years of reserve establishment.

If cash compensation is to be offered, a good approach would be to offer it over a period of around 5 years, with staged annual decreases in the amount given. As reserves begin to work, fishers should begin to feel benefits and will need less compensation (see Section 10). A good means of calculating the amount of compensation offered in the first year would be to compensate income in proportion to the amount of fishing grounds made into reserves. So, if 10% of fishing grounds are converted to reserves, then fishers would be compensated to a maximum of 10% of their pre-reserve income. Cash compensation will be most effective if it is tied to fishers becoming involved in management, such as playing a role in monitoring.

There are several drawbacks to cash compensation. The first is accurately identifying who should be a legitimate recipient. In open access fisheries this can be very difficult, especially those in which many people only fish part-time. Identifying one group of fishers that is eligible and another that is not could create tensions and divide the community. A second problem is that paying people not to fish over the long-term is hard to justify. This is one reason why, fixed-term compensation with stepped reductions over time is preferable. However, a third problem is that talk of compensation can get in the way of negotiations to protect areas. Once the possibility has been raised, it may be hard to get fishers to think of anything else! Future negotiations, both locally and perhaps more broadly, may become polarized into an “either compensate or don’t create reserves” debate. Over the long-term, cash compensation is not a sustainable strategy.

In many places, fish populations have been so heavily over-exploited that fishers are almost destitute. Many are desperate to leave the fishing industry but are trapped by heavy investment in boats and fishing gear. Reserves can be expected to help such communities, but would perform much better with a parallel reduction of fishing effort. Economic assistance in the form of vessel buy-back or decommissioning could help address problems of overcapacity and improve the success of reserves.

Reserves can also offer other kinds of compensation to fishers, such as opportunities to move into alternative occupations like tourism, or marine park wardening (see Section 19). This can ease pressure on the fishery and help provide better incomes. Consequently, reserves need not always increase activity in fishing grounds, or cause financial hardship. For example, in the Philippines, some fishers on the reefs around Apo Island Reserve have turned their boats to ferrying tourists to the island while others have begun working in a local resort. The income from tourism has far exceeded any loss from reduced fish catches (Vogt 1997). However, fishers may need to be given help to take advantage of these opportunities. In East Africa, Malleret-King (2000) found that although some fishers around the Kisite Marine National Park in Kenya had benefitted from tourism, as a whole fishers had not benefitted as much as other sectors of society. Economic support can be offered to fishers, such as through grants to self-help savings groups, loans, or improved access to existing sources of credit, complemented by training. In southern Belize, some commercial fishers in the area of a coastal marine park are being retrained as fly-fishing guides, easing the pressure on the fishery and enabling them to improve their incomes. Others have been undertaking scuba diving courses, improving their appreciation of local coral reef resources and allowing them to get work as dive guides for tourists.

Key points:

- If fishers are living hand-to-mouth, they may feel they have no alternative but to oppose measures that will reduce income in the short-term.
- Fishers with large economic stakes in a fishery may find it hard to leave without assistance, even if they want to.
- Short-term economic assistance can help gain fishers' support for reserve proposals.
- Economic assistance can be offered in many forms, from cash to loans, vessel buy-backs or re-training.
- Economic assistance can be an extremely effective way of gaining compliance with reserves by those who remain within the fishery.

12. Will redirected fishing effort undermine the benefits of reserve establishment?

Critics of reserves often argue that their creation could actually be harmful to species and to habitats. Reserves displace fishing from one place to another. They argue that, if there are no parallel measures applied to reduce fishing effort, then decreasing available fishing grounds will intensify fishing effort everywhere else. We have good evidence that fishing effort is likely to become concentrated along reserve boundaries as fishers seek the higher catches associated with spillover (see Section 6).

Intensified fishing effort should, other things being equal, lead to higher fishing mortality in regions outside reserves. This, say critics, will undermine the benefits of reserves. It has led some fishery scientists in Britain to argue that reserves should never be implemented without cuts in fishing effort proportional to the area of reserves being established. So, for example, if reserves are set up covering 10% of fishing grounds, then effort should be cut by 10% at the same time. This would substantially increase the burden of reserve establishment on fishers and naturally is very unpopular. Unless they are compensated in some way (see Section 11), this kind of double hit makes it unlikely that fishers will support establishment of any reserves. Throughout the developing world, numerous marine reserves have been implemented with no corresponding cuts in fishing capacity. Yet, in the many cases we've reviewed where effects on fish populations outside reserves have been studied, there has not been any apparent harmful effect of redirected fishing effort. In fact, in two places where fishing intensities are high, Apo Island in the Philippines and St. Lucia, there have been increases in populations outside reserves. Under some circumstances, redirection of fishing effort could be a more serious problem. If fishing effort is moved from a place in which a species is not very vulnerable to capture, to somewhere that it is, then rather than protecting the species, reserves could result in higher fishing mortality. For example, if fishing was redirected from places where a species was dispersed to an area where it was highly

Spawning aggregation of cubera snapper* (Lutjanus cyanopterus) *in Belize. Fishers often target places like spawning aggregations where large catches can be obtained with the least effort. However, this strategy is highly risky and has led to fishery collapse in many parts of the world. Reserves that protect aggregation sites can redirect fishing effort to places where populations are less vulnerable, so promoting fishery sustainability. Photograph by Rachel Graham.

aggregated, such as a spawning ground, then reserves could do more harm than good. It is important, when designating reserves, to identify areas where species are particularly vulnerable (see Sections 9 and 15). For adult fishes, such areas should be relatively easy to identify from patterns of catch per unit effort in a fishery. Places and times with particularly high levels of catch per unit effort represent vulnerable sites. Juveniles may also be vulnerable in nursery areas, and these might be identified by high levels of juvenile by-catch in other fisheries. If vulnerable areas are limited in extent, for example grouper aggregation sites, it may be possible to protect them entirely. If they are extensive this may not be possible and reserves should be established covering just part of such areas.

People also argue that intensified effort with mobile fishing gears, like trawls and dredges, will cause serious habitat damage outside reserves. This will only be true where effort is being redirected from a place where the bottom has become resilient to trawling (i.e. has been intensively trawled prior to reserve establishment) to a place where bottom communities are more vulnerable (such as deep sea coral beds). Again, it is important to identify which areas of the seabed are potentially at risk from mobile gears and ensure they are also protected in reserves. Most places will suffer little additional modification from extra trawling. It is the first few passes of a trawl that transform habitats and little extra damage is caused by increasing passage rates from say 3 or 4 per year to 5 or 6.

Although people often dwell on the possible negative consequences of redirected fishing effort, there are positive outcomes to be gained. Turning the arguments around, reserves can redirect effort from places where species and habitats are especially vulnerable to fishing to places where they are less badly affected. This, for example, is why spawning aggregations represent high priority areas for reserves. It is much better to redirect fishing effort away from areas of known risk, than to delay because of worries over possible unknown consequences. If other areas are later identified as vulnerable, they can then be protected in turn.

Key points:

- Problems caused by redirection of fishing effort following reserve creation are highly unlikely to outweigh the benefits of reserves.
- Problems can be caused if fishing effort is redirected from a place where a population is less vulnerable to capture to one where it is more vulnerable, or from places where habitats are resilient to places where they are vulnerable to damage from fishing gear.
- It is important to protect sites where populations and habitats are highly vulnerable to fishing, and reserves are a valuable means of facilitating such a beneficial redirection of fishing effort.

Further reading: Johannes 1998; Roberts in press b.

13. How large should a marine reserve be?

Small marine reserves have proved remarkably effective in allowing stocks of commercially important species to build up. As populations increase within reserves fishers start to focus their attention around reserve boundaries. For example, conch *(Strombus gigas)* fishers in Belize preferentially target the border of the Hol Chan Marine Reserve's no-take zone, while some of the best hook and line fishing in St. Lucia occurs right beside the Anse Chastanet reserve. Both these reserves are tiny, the no-take zone of Hol Chan being 2.6km^2 (see Case Study) and Anse Chastanet a mere 2.6 hectares (see Case Study).

Those fishers who gave up part of their fishing grounds to support reserves were taking a gamble. They agreed to undergo possible short-term hardship for the prospect of better times ahead without any proof that marine reserves would actually bring them benefits. Consequently, proponents of marine reserves have had to make the first ones small. If hardships caused by lost fishing grounds proved too great, fishers would lose faith in reserves before they had time to feel any benefits. This also meant that in order for marine reserves to gain wider acceptance it was essential for small reserves to be successful. Fortunately, this has been the case.

Since most reserves are small, it is difficult to determine the effect of size on reserve performance. However, as more reserves of different sizes have become established, answers are at last beginning to emerge. In Halpern's (in press) recent review of reserve performance, he found that abundance, biomass, size and diversity of organisms increased in almost every case. Interestingly, the magnitude of these effects was independent of reserve size. In other words if the biomass of fish were to double as a result of protection it would double in a small reserve and double in a large reserve. From this it might seem that size does not matter. However, in order for small reserves to provide as great an overall benefit (i.e. combined benefits aggregated across reserves) as large there would need to be more of them.

The bigger an area protected, the more species it will contain and the more likely their populations are to survive periodic disturbances. In small reserves, disturbances might wipe out entire protected populations. Additionally, species whose populations naturally fluctuate widely, need larger protected areas than those that fluctuate less. This is because their persistence depends upon regular recolonization of habitat patches from which they have disappeared. Larger protected areas make it more likely that such sources will exist. For these reasons, conservationists generally want reserves to be large not small. However, for any given total area to be protected, several small reserves may prove more beneficial than a single large one. Large reserves tend to cause more disruption to existing human activities, like fishing. Consequently, from a fishery perspective it would be better to have a network of smaller reserves rather than a single large area. Such a network would probably create less opposition. It would also spread the benefits from spillover and export of offspring over a management area rather than concentrating them in one place. The rates of spillover and export would also be greater from small reserves than large due to their greater edge to area ratios. However, it is important not to go too small with reserves, since if they are too leaky fish stocks will not build up.

Small reserves will fail fishers as well as conservationists if they do not maintain viable populations of marine organisms. However, while a large reserve could provide better protection for species against a catastrophic disturbance than a small reserve would, that same area of protection might perform even better in this respect if it were divided into a number of smaller units which were spread out. This concept has recently been illustrated in the USA. In Washington State three reserves were established to protect razor clams *(Siliqua patula).* When a local river changed its course, all the clams in one reserve were eliminated while those in the other two were unaffected. If there had been only one large reserve instead of three smaller ones, the entire population could have been wiped out.

A critical feature of marine reserves is that they protect habitat. A network of smaller reserves would probably encompass a greater range of habitats and species than a single large reserve would. Again, there is a trade-off because it is essential that reserves are big enough to protect viable populations of organisms. The smaller the reserve, the less likely this will be.

The fact that Halpern's (in press) study found abundance and diversity increases in small reserves may have been because they were supplied with recruits from unprotected areas. Many of the reserves he reviewed were isolated, and may not have been able to protect self-sustaining populations. Consequently, the viability of species within any particular reserve could depend on the existence of other reserves offering protection to other similar habitats nearby. If a particular habitat is regionally common, then a protected area containing a viable example of that habitat could be smaller than if the habitat was rare. By contrast, larger reserves will be required to protect those habitats (and consequently the species within them) which are rare and fragmented. On a similar note, larger reserves will be necessary in places that are heavily impacted by human uses compared to less impacted places. This is because, populations in reserves will become more isolated as habitat degradation increases in surrounding regions.

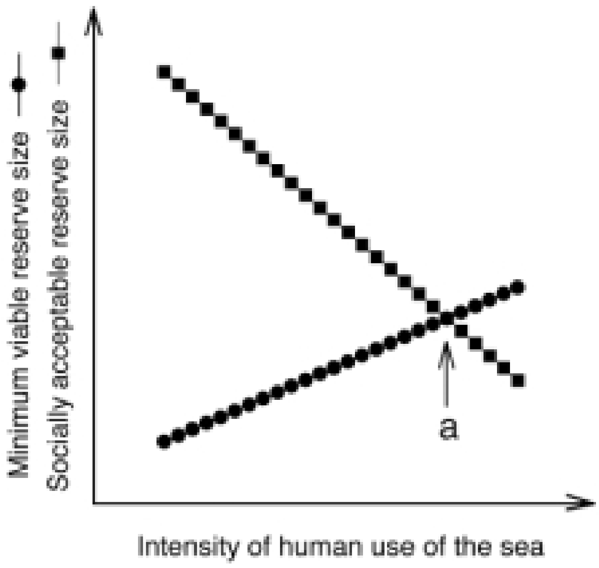


***Figure 12:* The size of reserves acceptable to local people is likely to fall as human use of an area intensifies. At the same time, the size of reserve needed to support viable populations is likely to increase as human impact on the sea increases. If the maximum acceptable reserve size falls below the minimum viable reserve size (indicated by arrow), then there are two options. Either efforts should be made to educate and persuade local people of the need for a larger reserve, or failing this, some form of compensation might be offered to those whose livelihoods will be most directly impacted by the reserve over the short-term. Modified from Roberts (in press a).**

The practicality of enforcing no-take regulations is also affected by reserve size. If protected areas within a network are too small and fragmented it will be difficult for users to identify their boundaries and they may be impossible to police. Alternatively if a reserve covers too great an extent of an intensively used area, it may be so unpopular that people will refuse to comply with the regulations imposed.

The success of management, conservation and fishing are all influenced by the size and design of marine reserves. It is in the interests of people from all parties to protect viable populations of marine organisms. Hence this common need can be used as the basis for compromise for how reserve networks should be set up. As a rule of thumb, marine reserves need to be as large as conservationists can secure under local constraints imposed by fishers and other users. If that is not large enough to support viable populations of species, then there are two options (Figure 12). The first is to make greater efforts in educating local people about the importance of securing adequate protection. The second is to offer incentives, such as compensation (Section 11), to help persuade people to accept larger reserves.

Key points:

- Very small reserves have shown striking benefits from protection. However, while the magnitude of effects is not strongly affected by the size of a reserve, overall effects are dependent on the combined area of reserves.
- Mobile species will gain less protection from small reserves than large. The larger a reserve is, the greater the range of species that will benefit.
- It is important that reserves are large enough to protect areas of habitat that will be viable over the long-term.
- Large reserves will be less susceptible to catastrophic disturbances than small, but networks of small reserves covering the same total area may reduce risks further.
- Large reserves are more difficult to implement than small and may be harder to enforce.
- From the viewpoint of fisheries, networks consisting of many smaller reserves may be better than a few very large protected areas. They will spread benefits more widely over a management area.

Further reading: Ballantine 1997; Roberts et al. in press b, c.

14. How much of the sea should be protected from fishing?

Of the less than half a percent of the world's ocean currently covered by MPAs, only a tiny fraction is closed to fishing. Nobody knows the exact amount of sea covered by fully-protected reserves, but it is likely to be less than one ten thousandth of the total marine realm! It may therefore seem academic to ask what proportion of the sea ought to be protected when the answer so clearly is "a great deal more". At the moment it is often a battle to get anywhere at all fully-protected. Any size of reserve, any place counts as an achievement.

A few years ago we published a paper entitled "How small can a marine reserve be and still be effective?" (based on the Anse Chastanet reserve, see Case Study). Our point was that even very tiny reserves can produce striking results. However, we realized that the message might be taken in the wrong way when we received a request for a copy of the paper from a politician! To some people, dramatic results from small reserves may suggest we don't really need to protect so much after all. In reality, such effects do not mean small area closures are satisfactory. We should view current successes as an indication of the even greater potential that fully-protected zones could have if they covered more of the sea. Even though scientists don't feel they have sufficient information to provide a precise answer to the question of how much area to protect, they are now confident enough to say we need more fully-protected marine reserves, we need them now, and for starters we should aim for 20% by the year 2020! More than 1600 scientists and conservationists recently backed this target in a statement entitled 'Troubled Waters: A Call to Action.' Why have they come up with this figure?

Arguments made for protecting the sea fall into several categories: (1) ethical, (2) minimizing the risk of overfishing and stock collapse, (3) maximizing fishery yields, (4) ensuring sufficient connectivity among MPAs to sustain biodiversity, and (5) providing resilience against human and natural catastrophes. We look at these arguments in turn and consider how much of the sea should be protected according to each.

Ethics: People treat the sea very differently from land. While property rights constrain access and exploitation on land, the principle of 'freedom of the seas' has led to freedom of exploitation in recent centuries. Today there is almost nowhere that isn't fished in some way. There is a growing dissatisfaction with the different treatment given to land and sea. Many people argue, on ethical grounds, that some places should not be exploited. However, even those sympathetic to this view don't necessarily want ethics to replace science as a rationale for management decisions. Using ethics alone to argue for a minimum proportion of the world's seas to be protected is very difficult. However, a scientist called Bill Ballantine has taken up this challenge and argued that a figure of 10% protected should be our lowest moral obligation, since this amount is significant as a whole, but will entail little cost compared with the 90% left open for exploitation. He sees this figure as a "call to arms" for marine conservation, rather than claiming it to be underpinned by rigorous scientific arguments.

Risk minimisation: Having areas protected from fishing reduces the likelihood that a fishery will collapse due to over-exploitation. If you protect some individuals from fishing at least they will still be around to produce others for the future. If you catch too many animals in a fishing area, you run the risk that those left will be insufficient to restock a fishery. This is because most species of fish reproduce unpredictably. Some years a few fish can produce lots of offspring, whilst in other years many fish produce much fewer. Recognizing this natural variability, fishery managers aim to keep fish stocks above levels where there would be too few fish available to reliably replenish the ones which have been caught. Early calculations suggested that, on average, it is necessary to retain at least 20% of the level of an unexploited stock to do this (Goodyear 1993).

Two serious sources of uncertainty derail attempts to achieve this target. The first problem is that nobody actually knows what the true unexploited stock size is. This makes it very difficult to protect 20% of it! The second is that estimates of fishing mortality may be wildly inaccurate, especially when species end up as by-catch in other fisheries. Scientists use complicated models, but often overly simple reasoning to try and set target catches to minimize the risk of over-exploitation. After that politicians often do their best to overrule scientific advice, which makes matters even worse! The common sense reasoning behind fully-protected reserves for risk minimisation is sound. Protecting a fraction of a population from exploitation or harm should help managers reach target stock levels more often. It only starts to get complicated when you try and work out what that fraction should be. More recent research suggests larger targets of at least 35% of unexploited stock size should be protected. Most models suggest that protecting a large proportion of the sea, between 20 and 50%, will greatly reduce risks of stock over-exploitation.

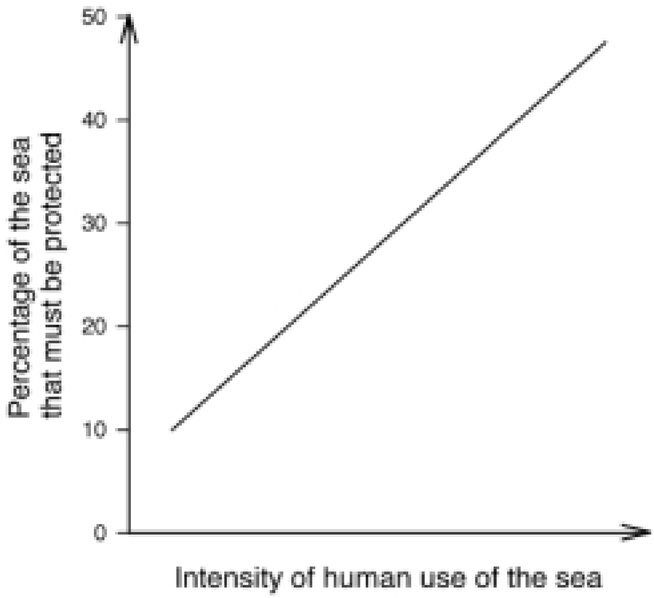


***Figure 13:* The total area of the sea that needs protecting is likely to increase as the degree of human impact outside reserves increases. This is because populations in reserves will become more dependent on those in other reserves for their replenishment, while fisheries will become more dependent on replenishment by offspring from protected populations.**

Catch enhancement: Fully-protected reserves are more than just an insurance policy - they are predicted to enhance fish catches, provided species are overexploited to begin with. If an area is only fished very lightly a reserve will not necessarily bring any benefit for catches (although it may benefit species harmed by fishing activities, such as bottom-living invertebrates). Most models suggest that catches will improve as more and more area is protected. However, a point will be reached where the advantages of having areas closed to fishing will be balanced by the disadvantage of not having a sufficiently large area in which to fish. How much benefit reserves give and how big an area they should cover will depend on the intensity of fishing involved and the vulnerability of target species to over-fishing. For example, it has been estimated for red snapper in the Gulf of Mexico that 15-29% of the fishing grounds should be set aside as no-take zones (Holland & Brazee 1996, Table 2). For mixed-species reef fisheries in the Caribbean, reserve areas that maximized catches were found to be 21% for a moderately fished area in Belize, 36% for a heavily exploited area in St. Lucia, and 40% for an intensely fished area in Jamaica (Pezzey et al. 2000, Table 2). Most studies conclude that protecting between 20 and 40% of fishing grounds will maximize catches.

Connectivity: Connectivity is the degree to which populations of organisms interact over distance. In order for reserves to benefit fishing areas, larvae and adults need to be exported. This export is also the means by which protected populations in different reserves can interact with each other. In general, creating a larger number of small reserves will provide greater connectivity benefits than fewer large ones, because the distances between reserves will be less. However, smaller reserves make less good targets for dispersing creatures to 'hit'. What is important is how much of the sea is protected. As the proportion rises, levels of connectivity among reserves will increase. The greatest gains in connectivity are made at the low end of the spectrum of protection, between 0 and 30% of the sea in reserves. After this, increases in connectivity are less rapid. Of course, species differ widely in their dispersal abilities and so high levels of connectivity (dense reserve networks covering significant fractions of the sea) will be needed to assure the persistence of the full spectrum of biodiversity.

Resilience against human and natural catastrophes: Just as fully-protected reserves can function as an insurance policy against collapse of fish stocks due to over-fishing, they can also help protect species and habitats from catastrophic disturbances. Most places are subject to disturbances of one kind or other - tropical regions often experience hurricanes, while virtually nowhere is safe from the possibility of an oil spill, for example. Allison et al. (in press) point out that if we want to protect a certain fraction of the sea in an undamaged state, it will be necessary to account for the fact that some places will be recovering from disturbance at any given time. It follows that the proportion of a region that needs to be in reserves should be greater than the fraction of the habitat that we want to safeguard in an undisturbed state, since some areas of habitat are always recovering from disturbance. This extra proportion, or buffer, will vary. Places subject to frequent disturbances, which affect large areas, and take a long time to recover, will need the greatest degree of buffering. However, if places outside fully-protected reserves are well managed then the buffer can be small.

Considering the above arguments, is aiming to protect 20% of the sea sensible? It is clear that a range of values are supported by the different lines of evidence. However, all of these arguments converge upon the importance of large-scale protection, with maximum benefits generally falling in the range of 20 to 40% of the sea in reserves. How much we need to protect depends on the degree of human impact. Under situations of low impact, protecting 5% might do perfectly well, whereas under high impact conditions, 30% might still not be enough. The main reasons for conservationists and scientists backing a target of 20% closure are: (1) this figure can be justified on the basis of the best biological information currently available, (2) such closures are expected to provide significant economic benefits to fisheries, and (3) it is a realistic figure to implement. However, we shouldn't look upon 20% as a fixed goal, but rather as an average, with some areas and habitats needing less protection and others more.

Key points:

- The sea receives very different treatment to land in terms of conservation. While most people accept that some terrestrial habitats should be protected, they feel the sea should be open to exploitation. These attitudes are inconsistent and greater protection of the sea is needed to redress the balance.
- More than 1600 international scientists and conservationists have backed a call for 20% of the seas to be protected from fishing by the year 2020.
- Theoretical modeling work suggests that protecting 20 - 50% of the sea from fishing will greatly reduce the risks of overexploitation and fishery collapse.
- Protection of 20 - 40% is likely to substantially increase long-term yields of over-exploited species.
- Protecting significant fractions of the sea from fishing will help sustain biological diversity, ecosystem functioning, and provide resilience against human and natural catastrophes.
- Figures of 20%, or greater protection, represent long-term targets. Reserve protection will begin small and develop over time. Every little counts.

Further reading: Allison et al. in press. Details of other studies referred to in this section can be found in Roberts in press d.

Table 2: ***Results of studies examining how much of the sea should be protected from fishing.***

Objective: Ethics
Ballantine 1997: Has argued for a target of 10% of all of the marine habitats in New Zealand to be protected. The key principle at stake is that we should not fish everywhere. Some areas should be set aside as refuges from exploitation for ethical reasons. Ten percent, he says, "has a long traditional use as a figure that signifies importance without serious hurt". It contrasts favorably with the 90% left open to exploitation and is conservative compared to the protected land area of New Zealand. However, he accepts that it represents a call to arms for conservation rather than being scientifically-based.
Objective: Risk minimization
Lauck et al. 1998: Examined the combined effects of variation in stock productivity, and errors in estimating fish mortality and population size, on the probability of managers successfully maintaining populations above target levels. In a simple model they showed that, in the face of the inevitable uncertainty in fishing mortality, reserves covering between 31 and 70% of fishing grounds would be needed to maintain populations above 60% of their unexploited size (argued to be an economic optimum) over a 40 year time horizon. The area of reserve required increased with fishing intensity. Furthermore, the greater the uncertainty in fishing mortality (which is equivalent to decreasing management control), the larger the reserves required.
Clark et al. 1995: Created a model of a randomly fluctuating fish population and looked at the likelihood of extinction. Reserves greatly increased the likely time to extinction over that of an exploited population with no reserve. The relationship between reserve size and reduction in extinction risk was sigmoidal. A reserve of 25% increased time to extinction by 8 times, one of 50% by 40 times and one of 75% reduced extinction risk to the level of an unexploited population. Large reserves, covering 40%+ of the management area, would offer an effective hedge against uncertainties in population size and exploitation rates.
Roughgarden 1998: Recommended maintaining exploited populations at 75% of their unexploited size in order to avoid **recruitment overfishing.**
Mangel 2000: Looked at the use of reserves as a tool to maintain fish populations above target levels. Found that if a stock was initially heavily fished (i.e. starts at 35% of its unfished size) reserves of 20 and 30% of the management area guaranteed persistence above this level for 20 and 100 years, respectively. The greater the minimum size of target species' population desired, the longer the planning horizon, and the higher the degree of variability in fishing mortality (= less control over fishing), the larger is the area that reserves need to cover in order to maintain target populations. Reserves increased cumulative yields from the fishery when populations were initially heavily exploited.
Goodyear 1993: Used fishery models to estimate that maintaining fish populations above 20% of their unexploited size would avoid recruitment overfishing.
Mace and Sissenwine 1993: Calculated for 91 fish populations (representing 27 species) in North America and Europe, that maintaining levels of 20% **spawning potential ratio** (one fifth of the unexploited population size) would prevent recruitment overfishing. Maintaining populations above 35% of their unexploited size would avoid recruitment overfishing for 80% of them. However, safe minimum population levels ranged up to 70% of unexploited population size for some species, meaning that they are vulnerable to only a small reduction in population size by fishing.
Mace 1994: Argued that, where the nature of the relationship between population size and recruitment is unknown, a precautionary approach would aim to maintain populations above 40% of their unexploited size.
Sumaila 1998: Used a model to examine effects of different reserve areas on **economic yields** from the Barents Sea cod fishery. Reserves reduced economic yield from the fishery but increased cod population size. The system was also modeled with an ecological shock - a ten year period of recruitment failure. Reserves supported populations through this recruitment failure and were found to be economically beneficial when there were moderate levels of movement of cod from reserves to fishing grounds (40 to 60% of cod leaving the reserve in a year). This allowed reserve benefits to be captured by the fishery. The largest reserves modeled, covering 70% of the management area, offered the greatest future security for stocks, but had the highest cost in terms of reduced current yields. How large reserves should be depends on the degree

to which populations are subject to external shocks, and the degree of risk managers are willing to accept. In general, reserves covering 30 to 50% of the area provided significant protection for stocks without greatly reducing current economic benefits.

Man et al. 1995: Modeled the persistence of an exploited **metapopulation** distributed across a series of habitat patches. Reserves (protected patches) became highly beneficial to population persistence as the local extinction rate in patches increased (due to increasing fishing intensities). This is because reserves provided a source of offspring to replenish fished out patches. Reserves became beneficial as exploitation rates increased, reaching a maximum of 50% of the patches protected at the highest levels of fishing. However, over a wide range of fishing intensities, optimal reserve fractions ranged between 20 and 40%.

Objectives: Risk minimization and bycatch avoidance

Soh et al. 1998, in press: Modeled the effects of closing hotspot areas (places where catch rates are particularly high) for catches of two species of rockfish in the Gulf of Alaska. The fishery for these species is unselective and currently there are high levels of discards of over-quota fish, ranging from 15 to over 60% of catches. Three areas of reserves were simulated, covering approximately 4, 9 and 16% of the trawlable shelf area of the region. Because reserves allowed all catches to be landed, rather than fishers having to discard fish, none of the reserve areas resulted in reduced catches. Reserves played a key role in increasing biomass of both species over a 20 year time horizon, whereas without reserves, biomass declined. The authors concluded that placing reserves in hotspots of adult fish biomass would enable even the smallest areas simulated to significantly improve on current management.

Objectives: Risk minimization and yield maximization

Foran and Fujita 1999: Modeled the value of reserves on rebuilding egg output by stocks of Pacific Ocean perch (Sebastes alutus), and catches, under optimistic and pessimistic assumptions of recruitment. They found that the benefits of reserves were sensitive to levels of recruitment. For example, a 10% **reserve system** would decrease long-term catches by 8% if recruitment is good, while the same reserve would increase catches by 15% if recruitment was poor. As the fraction protected increased, so fishing rates outside reserves had to be increased to maintain yields. The maximum long-term catch was from a reserve area of 25% and a moderately heavy level of fishing outside. The highest catch levels can be maintained using a range of total reserve areas provided fishing effort outside can be adjusted to appropriate levels. Reserves increased the resilience of the stock to higher levels of fishing and therefore provide a risk averse management approach.

Guenette and Pitcher 1999: Used a dynamic model which included weight-**fecundity** and **stock-recruitment relationships** to examine the effects of reserves on cod *(Gadus morhua)*. They found that reserves did not increase yields until cod were exploited at higher levels than necessary to achieve **maximum sustainable yield.** At higher fishing intensities, reserves prevented collapse in catch, with 30% reserves maintaining the highest yields of the four reserve areas modeled (10, 30, 50 and 70%). Larger reserves (> 30% protected) provided more robust biomass of spawning fish and reduced the number of years with poor recruitment compared to a no reserve regime. Increasing transfer rates of fish from reserves to fishing grounds decreased the benefits from reserves. However, even for highly mobile fish, reserves should be able to maintain higher spawning stocks than without them.

Objective: Yield maximization

Pezzey et al. 2000: Developed a model showing that the reserve area that maximized catches in coral reef fisheries varied between 0 and 50% of the total area, depending on the intensity of fishing outside reserves. As fishing intensity increases, so greater fractions of the fishing grounds must be protected to sustain catches. They calculated that reserves covering 21%, 36% and 40% would be required to sustain yields in the fisheries of Belize, St. Lucia and Jamaica, representing a gradient from moderate to intensive exploitation.

Sladek Nowlis and Roberts 1997, 1999: Using a single-species model, applied to four different species, showed that the fraction of a management area required in reserves depends on intensity of exploitation. Reserves were only effective in increasing catches when species were overfished. As fishing intensity increases, larger and larger reserves are required to sustain catches. In the most intensively exploited areas of the Caribbean, reserves covering 75-80% would be needed to maximize catches. However, at more moderate fishing intensities, reserves covering 40% of the management area would offer major benefits to yields.

Sladek Nowlis in press: Modeled the effects of reserves on catches of the Caribbean white grunt *(Haemulon plumieri).* At moderate fishing intensities (20% of animals that are vulnerable to capture removed per year) catches peaked with reserves covering 30% of the management area.
Sladek Nowlis and Yoklavich 1998: Used a population model to examine the potential for reserves to enhance catches of a Pacific rockfish, the Boccacio *(Sebastes paucispinis).* They found that reserves could produce moderate to great enhancements in catch depending on how overfished the species was to begin with. Optimal reserve areas, those producing the greatest long term catches, ranged from roughly 20 to 27% of the management area as fishing intensities grew.
Holland and Brazee 1996: Simulated the effects of reserves on catches from the red snapper *(Lutjanus campechanus)* fishery in the Gulf of Mexico. They found that reserves would not benefit catches until the species was overfished. For a range of heavy exploitation rates, optimal reserve areas (those that maximized catches) increased from 15 to 29% of the area as fishing pressure increased. However, in terms of present economic benefits, optimal reserve areas were reduced from these values as the rate of discounting of the future increased (in other words as the relative value afforded to present compared to future catches grows).
Hannesson 1999: Used a model to examine effects of reserves on spawning stock size, catches and costs of fishing for a mobile species like the cod *(Gadus morhua).* He assumed **open access** fishing outside reserves and found that reserves would have to be very large (70-80% of the management area) in order to produce catches and spawning stock levels equivalent to those of an optimally controlled fishery (one where stock size is held at 60% of the unexploited level). However, optimal control is an unrealizable economic abstraction and, compared to open access, reserves fared well. When covering between 50 and 80% of the area they produced increases in spawning stocks of 40 - 130%. Catches were greater than open access over a range of 10 - 80% of the area protected. The area that needs to be protected reduces when controls on fishing are implemented in remaining fishing grounds. However, reserves increased the costs of fishing and tended to promote overcapacity. The model ignored possible increases in catch from increased reproduction by the stock.
Polacheck 1990: Used a **yield per recruit model** (one which looks at the weight of fish caught for every individual recruited to the fishery) for George's Bank cod *(Gadus morhua)* to examine reserve effects on spawning stock biomass and yield in relation to reserve area, fishing pressure and rate of movement of fish from reserves to fishing grounds. Reserves were very effective at increasing spawning stock biomass. However, they decreased catches unless there were moderate rates of movement of fish from reserves to fishing grounds (although the model did not consider possible enhancements in catch that might be provided by increased reproduction by protected stocks). Reserves became more effective as fishing intensities increased, and the area of reserve required to increase catch grew as the mobility of the fish increased. For transfer rates from reserve to fishing grounds of 50% of the population per year, reserve areas of between 10 and 40% of the fishing grounds increased catches, the area needed rising over this range as fishing intensities increased.
DeMartini 1993: Used a yield per recruit model to examine effects of reserves on catches of fish on Pacific coral reefs. Reserves substantially increased spawning stock biomass for three model fish species with differing levels of mobility. Spawning stock increases were greatest for the least mobile species, and reserves became more beneficial as fishing intensities increased. However, reserves almost always decreased yield per recruit. Nevertheless, increases in spawning stock size reduce risk of overexploitation, and reserves ranging from 20 to 50% of the management area would offer significant levels of insurance against overfishing, although at increasing cost to present catches. Like Polacheck (1990), DeMartini ignored the possible benefits from increased reproduction by protected stocks. If included, reserves could potentially have increased catches (see Sladek Nowlis and Roberts 1997, 1999).
Hastings and Botsford 1999: Found that, for a wide range of biological conditions, marine reserves could offer equivalent yields to conventional fishery management tools. For species that reproduce over long lifespans, the fraction of area that needs to be protected as reserves is smaller than the fraction of the adult population that needs to be protected under conventional management. This is because animals can reproduce over longer periods in reserves than fishing grounds. For example, maintaining reproductive output at 35% of the unexploited level might require less than 35% of the area to be held in reserves.
Botsford et al. in press: Modeled the effects of reserves on catches of California red sea urchins *(Strongylocentrotus franciscanus).* They showed that reserves would benefit catches where the slope of the

stock versus recruitment curve is shallow (i.e. the species is vulnerable to recruitment overfishing). By contrast, if the slope is steep, and the species is therefore resilient to recruitment overfishing, reserves would reduce catches (although still increasing spawning stocks). However, the shape of the stock-recruitment curve is uncertain for most fished species, including this urchin. They found that, over the range of vulnerability where reserves would increase catches, the fraction of the management area in reserves that would maximize catches varied from 8 to 33%. For the most probable level of vulnerability for the sea urchin, they concluded that reserves covering 17% of the coast could increase long-term catches by 18%.
Attwood and Bennett 1995: Modeled the effects of reserves on catches of three species of surf zone fish that are targeted by recreational anglers in South Africa. Reserves would increase catches for two of the species, while reducing risk of recruitment overfishing of the third by increasing spawning stocks. Modeled catches of Galjoen *(Dichistius capensis)* peaked at 65% of the fishing grounds in reserves, while those for blacktail *(Diplodus sargus)* peaked at around 25-30% of the coast protected. The results suggested a combined management strategy would be successful for the three species, with one third of the area protected, distributed into reserves between 7 and 22km long across the coast of South Africa.
Quinn et al. 1993: Used a population model to explore the role of reserves in managing the fishery for the red sea urchin *(Strongylyocentrotus franciscanus)* in California. This species is subject to strong **Allee effects** at reproduction and at recruitment. They require high adult densities for successful fertilization of eggs, and juveniles recruit to areas of high adult density and survive best under an adult 'spine canopy' where they are better protected from predators. The authors simulated the effects of reserves on population sizes and catch rates for no reserves and three reserve areas: 17, 33 and 50% of the coast. Population sizes and sustained catches were greatest with 50% of the coast protected for all except the lightest level of fishing examined. This result was partly due to the spacing of reserves in relation to dispersal distance of the sea urchins. At the lowest fraction of the coast protected, reserves were too far apart for offspring to disperse from one to another.
Daan1993: Simulated the effects of creating reserves in the North Sea on the fishing mortality of cod *(Gadus morhua).* He found that creating reserves covering 10% of the area would lead to reduction of mortality of only 5% at the lowest net rate of movement of cod from reserves to fishing grounds. Protecting 25% could reduce mortality by 10-14%. However, cod were assumed to be homogeneously distributed across the region as was fishing effort. A more realistic simulation would probably have found greater benefits from protecting the same fractions of the area but in places where cod are more aggregated and catches higher.
Objective: Biodiversity representation
Turpie et al. 2000: Divided the South African coast into fifty two 50km sections to explore designs for systems of marine reserves that would represent all species of marine fish present, and all biogeographic areas. **Analyses of complementarity** were used to design the most space-efficient systems of reserves. A system covering 10% of the coast could be designed that would represent 97.5% of the species. However, this would not represent 15 narrowly distributed species found only in South Africa. A reserve system covering 29% of the coast would represent all of the species. Representing all species in the core regions of their ranges, a commonly-stated conservation goal that aims to maximize the chances of populations persisting in the long-term, would require 36% of the coast to be protected.
Bustamante et al. 1999: Developed a design for a representative system of fully-protected zones for coastal habitats in the Galapagos Marine Reserve. This reserve covers the entire archipelago. Their objectives were to protect all of the 'tourism visiting sites' in the archipelago, all areas of high biological importance, and to represent all the different coastal habitat types in each of the five biogeographic zones encompassed by the islands. To achieve this, they calculated it would be necessary to protect 36% of the coastline from fishing.
Halfpenny and Roberts in press: Designed a reserve system for the continental shelf seas of north-western Europe which aimed to represent all habitats and biogeographic regions present, and to replicate them in different reserves. Two systems covering 10% of the region were designed and were successful in achieving sufficient replication for most, but not all of the biogeographic regions and habitats.
Objective: Maintenance of genetic variation
Trexler and Travis 2000: Modeled the ability of fully-protected reserves to prevent or reverse undesirable effects of fishing on the genetic composition of fish stocks, and promote genetic diversity. They found that, under the most likely selective regimes (genetic responses to the effects of fishing), a reserve covering just

1% of the management area would have marked conservation benefits. Benefits increased rapidly with the proportion of the area in reserves. A 10% reserve decreased **directional selection** by 60%, while a 20% reserve would eliminate the selective effects of fishing from the population entirely.
Objective: Increase connectivity among reserves
Roberts in press d: Used a simple model in which reserve size and the fraction of the management area covered by reserves were varied to explore levels of connectivity among reserves. Connectivity rapidly increased (as measured by decreasing inter-reserve distances) as the proportion protected increased. For any given reserve proportion, connectivity also increased as the size of individual reserves was decreased. Connectivity increases were asymptotic, with the greatest decreases in inter-reserve distance manifested over the range of 5-30% of the management area protected. Reserves got 76% closer to each other over this range of protection. He also examined connectivity as the ‘target size’ of reserves for dispersing offspring, expressed as the number of degrees of horizon covered by reserves. Target size increased steeply as the proportion of the management area protected grew, and was four times greater at 30% of the area in reserves compared to 5%.

15. Where should reserves be located?

Wherever they are located, reserves will disrupt someone's activities and so the question of where to put them is perhaps the most controversial of all. There are very few cases where sites for reserves have been chosen strategically to meet a series of clear objectives. Instead, the haphazard forces of opportunism have dominated. Today's reserves have been created to protect special features, such as spectacular seascapes, unusual habitats or rare species. They have also been created to mitigate threats, for example to exclude oil and gas exploration. Alternatively, ecosystems may already have been severely degraded or populations or species driven to the edge of extinction, and reserves have been established to restore them. In other cases, people have simply seized the opportunity to protect places that are little-used at present, and thus there is little resistance to reserve implementation.

The many examples of working reserves illustrated in Section 5, and the 76 studies reviewed by Halpern (in press), suggest that haphazardly chosen reserves tend to perform well. Getting reserves set up whenever and wherever opportunities arise is clearly a successful strategy (Roberts in press c). However, many people have concerns with this approach, raising several objections. They argue that sites picked opportunistically may not protect the full spectrum of biodiversity. Sites chosen on the basis of least-resistance might be less good biologically. A focus on threat mitigation might lead to selection of less successful places for reserves. Picking poor reserves means that a greater total area will be required to achieve the same ends. Furthermore, placing reserves in poor sites might undermine the case for expanded protection since these will not perform as well as better sites. Finally, haphazardly chosen sites may be harder to defend against critics and so implementation is more easily derailed.

The Olympic Coast National Marine Sanctuary in the USA. Many reserves, like this one, have been chosen because they contain spectacular scenery, are remote and may be little-used. Protecting them can offer many benefits, but expanded and more objective approaches are needed to develop the comprehensive networks urgently required.

Several authors have published papers and guides describing ways in which we can improve on opportunism (Kelleher & Kenchington 1992, Salm & Price 1995, Agardy 1997, Ballantine 1997, Hockey & Branch 1997, Nilsson 1998). They list a series of criteria that can be used to choose reserves, covering a spectrum of biological, social and economic concerns. Although none of these authors suggests how to prioritize among the criteria they offer, social and economic criteria have often dominated the process of reserve selection (Table 3). Implementing reserves is a social process and so it is hardly surprising that such concerns often weigh most heavily. Roberts et al. (in press b, c) argue that allowing socio-economic criteria to prevail could come at the expense of biological functioning. In other words, strategic selection processes that offer equal or greater weight to socio-economic concerns from the outset may lead to sub-standard reserves. The same fears also apply to opportunistically chosen reserves.

Table 3: ***Social and economic criteria used to select the locations of marine protected areas (reproduced from Roberts et al. in press b).***

Economic Value
▸ Number of fishers dependent on the area ▸ Value for tourism ▸ Potential contribution of protection to enhancing or maintaining economic value
Social Value
▸ Ease of access ▸ Maintenance of traditional fishing methods ▸ Presence of cultural artefacts/wrecks ▸ Heritage value ▸ Recreational value ▸ Educational value ▸ Aesthetic appeal
Scientific Value
▸ Amount of previous scientific work undertaken ▸ Regularity of survey or monitoring work done ▸ Presence of current research projects ▸ Educational value
Feasibility/Practicality
▸ Social/political acceptability ▸ Access for education/tourism ▸ Compatible with existing uses ▸ Ease of management ▸ Ease of enforcement

Roberts et al. make the point that if reserves are to have lasting economic and social value, they must be effective biologically. There is a minimum level of function necessary, a biological bottom-line. They argue for the need to adopt approaches that go beyond mere representation of species and habitats, and safeguard ecological processes underpinning biodiversity and productivity. Such processes are critical to all the goals for reserves but are often left out. Biodiversity will not be conserved without looking after those processes, nor will fisheries prosper. Long-term stability can only be achieved by protecting whole marine communities. Hence Roberts et al. contend that biological criteria should be applied first in choosing sites for reserves. However, they fully recognize the importance of socio-economic interests in implementing reserves and so have developed a process that aims to preserve the biological bottom-line while still offering **stakeholders** a range of alternatives to choose from. They provide a series of criteria based on biology, which strongly affect or are affected by underlying biological attributes (Table 4).

The criteria are divided into four categories: representation, excluding, screening and modifying. Many authors stress the importance of protecting the full range of species and habitats. The two representation criteria are designed to achieve this. Of course, no single reserve can represent all species and habitats in a region, and so representation criteria are applied to develop networks of reserves. In fact, while many of the criteria can be used to select individual reserves, or develop **zoning** plans for multiple-use MPAs, they are specifically designed to be useful in developing networks. Even where the objective is to establish only a single reserve,

Table 4:** **Ecological criteria for the selection of marine reserves and design of reserve networks. Developed by Roberts et al. in press b, c. Adapted from NRC in press.

Representation criteria - aim to represent the full spectrum of biodiversity

- *Biogeographic representation* - all biogeographic regions should be represented and reserves should be replicated in each.
- *Habitat representation and heterogeneity* - all habitats should be represented and replicate habitats protected in different reserves within biogeographic regions. This criterion acts as a proxy for species diversity but requires less data.

Excluding criteria

- *Level of human threat* - very high levels of human threat will exclude a site from consideration, but threats that can be mitigated could increase priority for protection. For example, a strong motivation for establishing fully-protected reserves is to mitigate the threat posed by overfishing.
- *Level of threat from natural catastrophes* - sites that are foci for extreme natural disturbances should be avoided - e.g. areas regularly subject to low levels of dissolved oxygen (e.g. the area offshore of the Mississippi delta in the Gulf of Mexico).

Screening criteria

- *Size of site* - candidate sites should be large enough to support viable habitats. A viable habitat is one that supports populations of the component species that can persist long-term. See Section 13 for further details.
- *Connectivity* - sites should interconnect with others through dispersal and migration of the organisms within them. Networks of reserves must interconnect. The closer reserves are, the more likely there is to be connectivity. However, if reserves are too close together, there is an increased risk that catastrophic disturbances will affect more than one. See Section 16 for further details.

Modifying criteria

- *Presence of vulnerable habitats* - vulnerable habitats attract higher priority for protection. Such habitats are typically those where the structure of the habitat is dependent on biological growth rather than simply physical processes. For example, coral reefs, oyster beds and salt marshes are all vulnerable.
- *Presence of vulnerable life stages* - vulnerable life stages, such as spawning sites or nursery grounds, attract high priority.
- *Presence of exploitable species* - this is a pre-requisite for reserves to have any value in supporting fisheries.
- *Presence of species or populations of special interest* - restricted-range, relict, endangered or globally rare species, for example, increase the value of a site, as would populations that are genetically distinctive.
- *Ecosystem functioning and linkages* - areas that link with and support other systems, for example through export of nutrients, have a greater value than those that do not; similarly, sites that depend on links with other systems are vulnerable unless those places are also protected.
- *Provision of ecological services for people* - services such as coastal protection, or water purification add value to a site.

candidate sites are examined in the context of how they complement reserves that already exist.

Roberts et al. (in press c) outline the process for applying their criteria as follows: (1) define the area of interest for management, (2) define goals for the network, (3) divide the area into possible reserve units (there are many ways to do this, such as grids, sections of coast, habitats etc.), (4) evaluate each unit according to the criteria (selecting among and weighting the modifying criteria when necessary to ensure they are appropriate to the goals), (5) decide how to quantify the information needed for scoring sites according to each criterion, (6) assemble information on units (species or habitats present, levels of threat etc.), (7) score sites according to each criterion, (8) select among candidate sites for inclusion in the network, and (9) map out the different, biologically-adequate networks that are possible and feed results into a socio-economic decision making process to choose among alternative network designs.

It may seem that, by applying biologically-based scientific criteria first, this process separates scientific from stakeholder input. However, Roberts et al. (in press c) emphasize that stakeholders should be intimately involved throughout this process. As well as being a scientific tool, the process is a sociological tool, enabling stakeholders to understand how biological attributes of candidate sites are critical to achieving their objectives for a reserve or network. Experience in terrestrial reserve selection shows that working through criteria that are clearly matched to objectives for reserves can help resolve conflicts among different stakeholder groups.

There are several advantages to choosing reserves through an objective process like this compared to more *ad hoc* approaches. It provides a rigorous, transparent procedure to produce candidate reserve designs that are scientifically sound. It generates multiple designs for biologically-adequate networks that can then be fed into socio-economic evaluations, thereby maintaining biological function throughout the decision making process. Working through the process helps stakeholders to understand and accept the choices made. Finally, it is easier to defend decisions made using such a process and this may be decisive in helping proposals pass through to final implementation.

Whatever process is used to choose reserves or design networks, it is worth bearing in mind messages from practical experience. In the San Juan Islands of Washington State in the USA, people sought to place reserves in sites where there was little cost to fishers. Fishers identified places that were once highly productive fishing spots but no longer were due to overexploitation. This was very effective in designing a network of reserves that could be implemented quickly with little controversy. There is a risk with this approach as habitat damage or change may have altered the productive characteristics of those sites, rendering them less capable of supporting high production. However, it is a good way to get the ball rolling and set up pilot reserves that pave the way for extended networks. Ultimately, it may be best to mix this approach with others that select sites that are still productive.

Although networks are likely to function best for conservation if they include only the best sites, such networks will meet with stiff opposition as those places will probably be intensively used. Practical networks will include a mix of high, medium and low use areas as sites for reserves. Although they will probably be the easiest to implement, it is important not to choose the most marginal habitats or degraded sites for early or pilot MPAs. They are likely to take longer to show benefits than more intact sites, and their ultimate performance may be less good. On the other hand, inclusion of such sites in portfolios of reserves is a good strategy. Provided there are still source populations around and habitats have not been degraded beyond repair, such sites may show the most striking changes upon protection. They can make a powerful case for the benefits that protection can bring.

If threats are serious, don’t delay reserve selection due to lack of information. The tendency among scientists (and one that is often exploited by opponents of reserves) is to delay action until there is more data upon which to make a decision. However, there can be a large cost to this. The longer you delay before you act the more options you foreclose. Reserves will not resurrect species that have completely disappeared. Similarly, while habitat damage may be done quickly, recovery may take decades or even centuries. For example, deep sea coral beds are now threatened by trawling gear that can be used over rough ground. Such habitats can be destroyed by a handful of trawl passes but could take centuries to recover. The quicker you act to protect, the less will be lost and the greater the ultimate benefits of protection. However, even when protection is urgently warranted, do use the full range of information available to select reserve sites.

Isolated reserves will be more vulnerable to human impacts and environmental changes than reserves that are connected with others by dispersal. Reserves need to be closely spaced in order for populations of species that disperse poorly to interact. Don’t leave large gaps in networks.

Early reserves can be designated with less information than when networks are more complete. While there are many objective approaches to choosing reserves, there is still a very important role for opportunism. We are so early on in the process of protecting the seas that almost anywhere that well-respected reserves can be established will be valuable.

Key points:

- Selection processes must be practical, working with the limited data available on marine communities, ecological processes and human uses of the sea. If threats are serious, don't delay reserve selection due to lack of information but do use the full range of information available.
- We need to put biology up front in selecting reserves, but with a process that leaves flexibility for socio-economic considerations to be taken into account. Reserves that are inadequate biologically will fail to meet conservation or fishery management objectives.
- Reserves should be designed to fulfil many objectives. In particular, it is critical to marry fishery and conservation goals as far as possible. Previous separation of these objectives has been counter-productive, leading to the creation of complex masses of overlapping, often conflicting measures that offer the impression of protection, but not the reality. Design principles which favour conservation are almost always compatible with those for fishery management.
- Isolated reserves will be insufficient to conserve marine ecosystems over the long-term. We must adopt approaches that can be used to help design interactive networks of reserves.
- Select the best sites available for pilot reserves, but it is also worth including places where populations have been seriously depleted in pilot reserve networks. Such areas could show the most dramatic improvements following protection.

Further reading: Kelleher & Kenchington 1992; Salm & Price 1995; Agardy 1997; Ballantine 1997; Hockey & Branch 1997; Nilsson 1998; Roberts in press c; Roberts et al. in press b, c.

16. Why is it important to network reserves?

Marine habitats, like this mangrove and seagrass bed in Puerto Rico, are closely interconnected. Many commercially important species require different habitats at different stages in their life cycles. For example some coral reef fish use mangroves or seagrass beds as nursery grounds. Such connections must be considered in the design of marine reserve networks.

Some of the reasons for networking reserves have already been described in Section 14, on connectivity. A large proportion of marine species, and almost all of those we exploit, have a pelagic (= open sea) dispersal phase. Their eggs or larvae are released into open water where they develop over periods of days to a few months. Where they go during dispersal is one of the great mysteries of the sea. Some species may drift passively with currents, while others may be able to control dispersal in ways we still do not understand. It is because of this dispersal phase that populations in the sea are believed to be more 'open' than those of terrestrial species. This means that replenishment of populations depends heavily on reproduction that has taken place somewhere else. In 'closed' populations, such as those of many mammals, replenishment originates mainly from local reproduction.

An important consequence of open population dynamics is that reserves may be unable to support self-sustaining populations. Instead, recruitment to them may originate from somewhere else, perhaps many kilometres away. Figure 14 shows potential areas of dispersal for six sites in the Caribbean and is based on the assumption that offspring drift passively on ocean currents. This figure suggests offspring can potentially be carried very long distances from the places they were spawned, typically tens to hundreds of kilometres. It also suggests that potential supply of offspring could vary from place to place by more than ten times. Some sites may

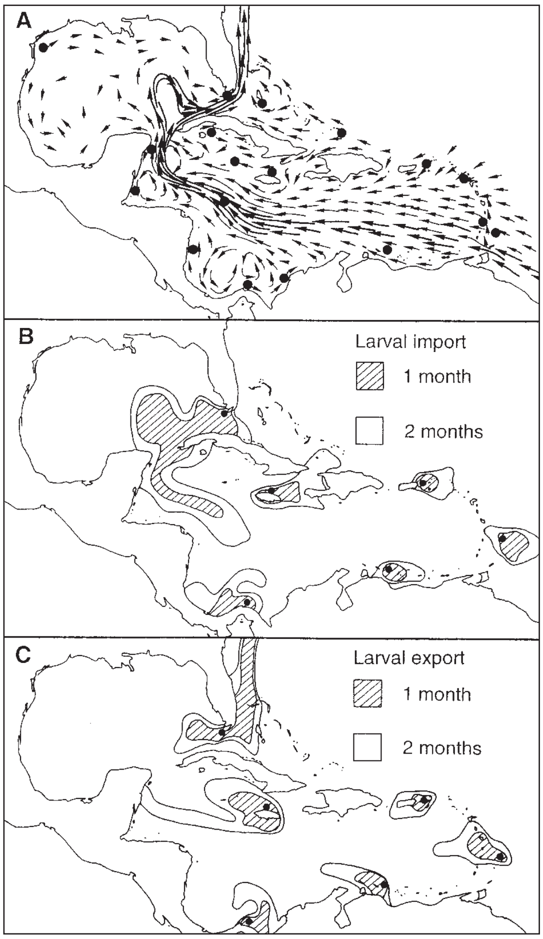


***Figure 14:* Surface currents may help determine where the eggs, larvae, seeds and spores of marine organisms disperse to (a). The shaded regions show the areas to which offspring of animals produced at a site (marked with a black circle) could potentially disperse (b), and could arrive at a site from (c), if eggs and larvae of marine organisms are transported passively by ocean currents. Ocean currents represent important vectors that could link populations among reserves, and so might be used to help guide network design. Managers in Australia and America are beginning to consider the effects of currents when deciding where to place reserves. Reproduced from Roberts 1997b, with permission.**

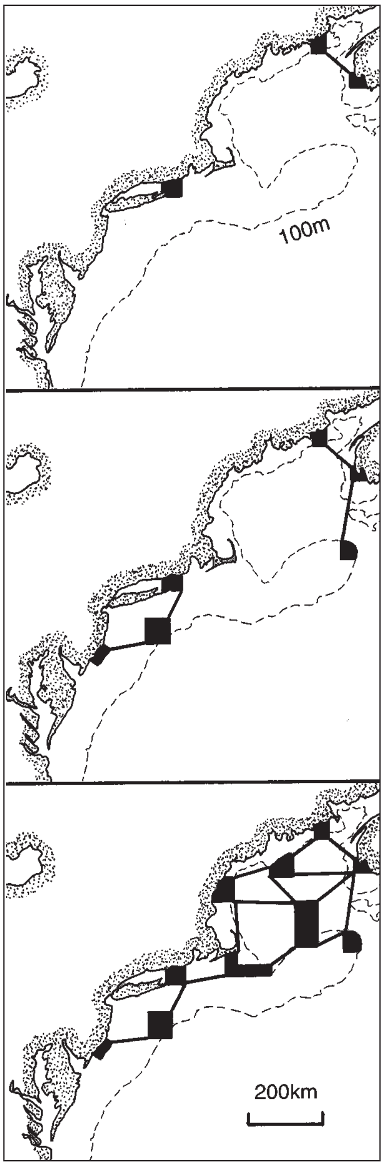


Figure 15: ***Ballantine (1997) has pointed out that connectivity among reserves increases rapidly, as measured by diminishing inter-reserve distances, as the number of reserves in a regional network increases. In this example, illustrating hypothetical reserve networks in the north-east coast of the USA, reserves closer together than 150km are connected by a line. The number of links increases much more rapidly than the number of reserves present. Doubling the number of reserves more than doubles the number of links.***

receive far more recruits than others because upstream source populations are larger. Most places have the potential to supply offspring to other sites, as well as receive them from elsewhere.

Not all offspring are simply washed away by currents, and many seem to have evolved ways of not going with the flow. For example, isolated seamounts or atolls could not support populations unless many of their recruits were retained locally. Some late stage fish larvae that have nearly completed their dispersal have excellent swimming abilities and can easily match or exceed the rates of prevailing currents. This gives them the opportunity to control dispersal. Consequently, the potential dispersal areas in Figure 14 represent probable upper bounds to dispersal distances. What we still do not know for almost any marine species, is how far their offspring really disperse. Dispersal is still a black box where the lid has been prized open only a fraction. Until we know a lot more, it is reasonable to assume that the longer a species' offspring stays in the open sea, the further they can potentially disperse and the less likely they will be retained locally. This means that reserves will be unlikely to support self-recruiting populations of long-distance dispersers.

Having said this, some marine species, especially among bottom-living invertebrates, disperse only short distances. Reserves are much more likely to support self-recruiting populations of these species. Thus, even isolated reserves will benefit a wide range of species. In fact, most of what we know about reserve performance is based on studies of isolated reserves and so clearly they have manifold benefits. However, many species in these reserves may be recruiting from unprotected populations. This leaves those species vulnerable to depletion of source populations. Numerous species can persist in fishing areas, but some vulnerable species have been regionally extirpated by broad-scale intensive fishing (see Section 3). For such organisms to persist, recruitment to reserves will have to come from other reserves, and this will require networks of protected areas. Isolated reserves will only be able to protect a limited fraction of marine biodiversity.

To be considered part of a network, reserves must be sufficiently close for their populations to interact (see Section 14). Since all species disperse in different ways and for different periods, interaction distances will vary. However, we need to site reserves close enough for relatively short-distance dispersers to get from one to another. The number of species whose populations can interact will decline as the distance between reserves grows. Ideally, reserves should be established in dense networks in which inter-reserve distances are typically less than a few tens of kilometres.

Key points:

- Isolated reserves have many benefits but will only be able to protect a limited fraction of marine biodiversity.
- Large numbers of marine species have open water dispersal phases and can potentially be transported long distances from where they were spawned.
- Individual reserves may be able to sustain self-recruiting populations of species that disperse short distances, but networks will be necessary to protect many of the species that disperse long-distances.
- Reserves in networks need to be close enough for protected populations to interact through dispersal, ideally being closer together than a few tens of kilometres.

Further reading: Carr & Reed 1993; Roberts 1997b, 1998b.

17. Should marine reserves be temporary, rotated or permanent?

Fishing is often called harvesting, and this suggests a parallel with agriculture. Perhaps for this reason, people often think that marine reserves can be rotated in the same way as crops in different fields. Crop rotation, and the fallowing of fields, support soil fertility and help maintain high levels of production. However, marine reserves function in a completely different way and need to be permanent fixtures. There are only very limited circumstances under which rotation might bring any benefits.

On land, rotation of crops and fallowing free up nutrients on which crop production depends. By contrast, fisheries depend on animal production (often of predators from high in the food web). Their fertility depends on population build-up and a shift in population structure towards older and larger individuals. To increase fertility, all you have to do is provide protection from fishing. Take that away and the gain is lost. Once fishing is resumed in marine reserves, stocks of animals which had accumulated over time will rapidly be depleted. While this provides a bumper catch over the short-term, it is bad news for tomorrow. Animals which had the opportunity to grow really big in reserves will not persist where there is fishing, and are usually cleaned out within a few months of it being resumed. When these big animals are lost the benefits provided by reserves in terms of increased egg production also disappear. You can't have production without producers and you can't keep producers without a permanent commitment to protect them.

The coral reef grouper* Plectropomus maculatus, *a commercially valuable species of reef fish, here photographed in the Red Sea. A related species, the leopard grouper* (Plectropomus leopardus) *is one of the most valuable fishery species on the Great Barrier Reef in Australia. As an experiment, Boult Reef was closed to fishing for three and a half years to allow their population to build up. After re-opening, intensive fishing removed 25% of the stock within only two weeks (Beinssen 1988). The benefits of protection take time to accrue but are rapidly eliminated by rotating reserves.

Marine reserves are much like a bank account where savings gain interest and so make money for the owner. As long you spend no more than the interest, the capital will remain to produce more. However, if the capital is plundered the interest will be lost. A permanent reserve is like having permanent capital which provides dependable interest. As soon as you reopen a reserve to fishing you lose the security that the capital provided. Just as it is hard to save money in the first place, there are costs to fishers in setting up marine reserves. However, reserves provide benefits to fishers which make the sacrifice of investment worthwhile. If reserves are permanent the hardship of closure will only come once and the benefits, when they begin, will be continuous.

When marine reserves are first established, lost fishing grounds are the biggest problem for fishers. They still want to fill their nets but with less area available this becomes harder and catches may fall. If a reserve is maintained permanently, short-term costs will turn to long-term benefits, while if fishing is reintroduced the clock will be set back to a time of hardship. Permanent closures maximize benefits and minimize costs, whereas rotations or temporary closures achieve nothing in the long-term. Temporary closures produce temporary benefits and so fail to fulfill the true potential of marine reserves. The only circumstance where temporary closures may be beneficial is for single-species fisheries on animals that are short-lived and need high densities to successfully reproduce. They include animals like sea urchins or sea cucumbers. For them, rotating fishing areas may be the best way of maximizing catches provided that, at any one time, some areas have always been protected for several years. However, such single-species closures should not be confused with fully-protected reserves.

Habitat recovery following protection is slower than population recovery and may take decades to complete. However, while recovery is slow, damage is often rapid, especially by heavy mobile fishing gears like trawls. Rotating reserves will swiftly set the clock back on habitat recovery, greatly diminishing their value as conservation tools.

There are several other reasons why marine reserves should be permanent. Firstly the amount of time and effort involved in setting them up is considerable. This cannot be side-stepped because without support by local fishers and other users, reserves will never have a chance to work in the first place. It is simply not worth all the educating, learning and debating for a gain today which is gone tomorrow. This contributes nothing to conservation or sustainable livelihoods for fishers.

It also costs money to set up marine reserves. For example, patrol boats are needed, and signs or buoys identifying boundaries need to be installed. Much of the advocacy work is done voluntarily, but some people must be paid to operate marine reserves and to enforce them. It is pointless to waste money providing a temporary solution when a permanent one costs little more.

One final cost of setting up a marine reserve is the time it takes fishers and others to get to know where it is. It can be quite tricky to learn where the boundaries of a reserve lie, especially where a protected area has many different zones. Unscrupulous fishers may use ignorance of boundaries as an excuse for poaching in the early days following establishment. However, compliance should increase as reserves become more widely known. This in itself is good enough reason not to rotate the locations of reserves. Rotations would create confusion and undermine effectiveness.

The only situation where it might be sensible to relocate a reserve would be if that reserve had been poorly placed, for example if it was put in an area of poor habitat. However, even under these circumstances the costs involved with moving the reserve might exceed the benefits. Areas sub-optimal in certain respects might not be so in every way. If this is the case, a better alternative might be to set up an additional reserve rather than sacrifice protection of the original.

Key points:

- Agricultural systems on land benefit from crop rotation and fallowing because this frees up nutrients on which crops depend. Marine reserves function differently, and fertility builds up only as animal populations expand and individuals survive long enough to grow large.
- Reopening a reserve to fishing will create a short-term benefit to catches but will squander the productivity that the reserve sustains.
- Reserves should be viewed as permanent fixtures in which capital stocks accumulate that can feed their ‘interest’ into fishing grounds.
- Habitat recovery is typically slow while damage is swift. Rotating reserves will regularly undo benefits of protection, thereby reducing their conservation value.
- Reserves are difficult and expensive to establish and take time for users to become accustomed to. It makes little sense to make these investments for temporary measures that offer little long-term benefit either to fisheries or conservation. Reserves are a permanent commitment.

18. Will fully-protected reserves work in temperate waters?

Industrialized nations, especially in the temperate north, have been very slow to embrace the idea of fully-protected reserves. Frequently, the argument is made that reserves may be useful at protecting species on habitats like coral reefs, but are inappropriate for temperate regions because the species and ecosystems there are different. Most often, we hear this argument from fishery scientists who consider fish more like mathematical abstractions than wild animals.

It is certainly true that many of the best studied marine reserves are in tropical seas - the Philippines, Florida Keys or Caribbean, for example. Yet there are many reserves in warm-temperate and temperate regions, even in a few places with industrial fisheries. Examples include New Zealand, South Africa, Chile, and the west and north-east coasts of the USA. All temperate reserves that have been effectively enforced have shown measurable benefits to species and habitats, even if some were not immediately obvious.

Temperate countries with industrialized fisheries have been slow to realize the potential of reserves. Nevertheless the influence of fishing extends far beyond exploited species alone and reserves can offer critically important protection to species like these burrowing anemones* (Cerianthus borealis) *in the Stellwagen Bank National Marine Sanctuary, Gulf of Maine, and thousands of other species like them. Photograph by Peter Auster.

Why are the views of temperate scientists so often polarized against reserves? Partly because there are very few examples in the regions where they work (although there are often single-species closed areas that provide insights into what full-protection might offer). A second explanation is a bias towards the small fraction of species that are important to industrial fisheries such as cod, haddock *(Melanogrammus aeglefinus)* or sardines *(Sardina pilchardus)*. It so happens that many of the key target species in temperate regions undertake lengthy migrations and so will move in and out of fixed location reserves as they pass from place to place. Use of reserves has tended to be dismissed for such species. However, Section 9 shows how migratory and mobile species can benefit from reserves. However, large numbers of temperate species have similar life histories to tropical ones and so will benefit from reserves in much the same way. For example temperate molluscs and echinoderm species are just like coral reef fish in being sedentary as adults and having widely dispersing offspring. Many other exploited species, including crustaceans, fish, barnacles and sea squirts, also have limited mobility as adults and will be afforded good protection by reserves.

Fishery scientists also tend to view the world from the narrow perspective of exploited species. There are very few countries where fishery managers are held to account for species that are not directly targeted by fishing. This is a puzzling omission from their working remit since other industries are expected to operate in ways that will minimize environmental damage. For example, highways are built only after impact assessments and lengthy public consultation. The impacts of fishing on **non-target species** are rarely ever considered by fishery managers, unless those species are also valuable in their own right. The occasional exceptions involve charismatic species like dolphins or seals, but if you are a bristle worm, blenny or basket star, you do not feature on the radar screen of fishery agencies. This is wrong.

Marine reserves are conservation tools. They will protect reproductive populations of many exploited species, in both temperate and tropical regions, and thus provide benefits to fisheries. However, they will also protect the tens of thousands of species that we do not exploit for food, and will conserve fragile habitats that would otherwise be rendered into rubble and sand by fishing. The currencies we should use to judge reserve performance go far beyond exploited species alone. By these criteria, marine reserves are just as effective and just as necessary in temperate regions as they are in the tropics.

Key points:

- Countries with industrialized fisheries have been slow to implement fully-protected reserves, believing (without evidence) that they will not work as well as in the tropics. This view is commonly expressed by those whose remit is to manage exploited species.
- Fully-protected marine reserves have been established in many temperate regions and have performed well.
- Temperate regions have been heavily altered by decades or centuries of intensive fishing. Their habitats and species desperately need the protection that reserves could offer.

Further reading: Dayton et al. 1995; Dayton 1998; Roberts 1997a; Roberts in press a; Castilla 1999; Murawksi et al. in press; Norse et al. in press.

19. Tourism and marine reserves

Marine reserves hold the same attraction for visitors to the coast as national parks do to tourists traveling inland. People expect the marine life to be better in reserves. They think it will be more exciting or unusual and assume it will be well protected. In reality this is often untrue. Signs that prohibit tourists from spear fishing or collecting may not apply to locals, yet if anyone is allowed to extract marine life, reserves will not provide the better diving and snorkelling that tourists are searching for. Tourism can greatly benefit from fully-protected marine reserves and in return bring prosperity to an area. Below, we show how this is achieved. We also consider how tourists can damage marine reserves, and how their activities should be managed to avoid this from happening.

When an area is closed to fishing it soon starts to accumulate large fish. All those that would have been caught by fishers survive and many are able to grow to sizes rarely seen in fishing grounds. In the Ras Mohammed Marine Park in Egypt, lunartail groupers *(Variola louti)* were three times the size of those in fished areas. In the Hol Chan Marine Reserve in Belize, the biggest groupers we saw were all in the central, no-take zone. This is important because people love to see big fish. Obviously all species have a size limit, but the biggest individuals of large species can be truly spectacular and make for 'high voltage' diving! Such fish become the "stars" of marine reserves and a great tourist attraction. Even fear does not seem to suppress people's desire to see big fish. On coral reefs, many divers who say they are afraid of sharks still want to see them underwater. (In temperate waters, where a few sharks have a more dangerous reputation, people are less enthusiastic!)

The Caribbean hogfish,* Lachnolaimus maximus, *is a wrasse whose curiosity has been its downfall. It is an easy target to spear fishers and will readily enter traps. Consequently it has been decimated throughout large parts of its range. Fully-protected reserves offer some of the few remaining places where tourists can get a close look at this endearing species.

As well as protecting huge individual fish, marine reserves also allow big schools of big fish to form. To divers and snorkellers big schools of any sized fish are impressive but without marine reserves big schools of little fish are all they are ever likely to see. Again, by providing protection from fishing, marine reserves allow an underwater spectacle to develop which draws in visitors.

Marine reserves also provide the opportunity for tourists to see species of fish they would not otherwise encounter. These include species such as the Caribbean hogfish *(Lachnolaimus maximus)* which are so vulnerable to overfishing they can disappear even from places that are only lightly fished. Marine reserves provide such species with a last refuge. If they have totally disappeared from a locality it can take time for reserves to be recolonised, but eventually biodiversity should increase. Many tourists are keen to see rare and unusual species, and reserves offer better prospects for doing so than fished areas. Another benefit of protection from fishing is that many species become easier to approach, especially in places where spearfishing was once a problem. People who do not fish pose less of a threat to animals and so the animals may be less disturbed by their presence.

Another benefit of protecting areas from fishing is prevention of the collateral habitat damage it can cause. Obviously some forms of fishing are more destructive than others. For example, dynamite blasting does horrendous damage to coral reefs whereas hook and line fishing causes little harm to the reef structure (although carelessly discarded or lost lines are unsightly). In places where habitat protection is a particularly important role of reserves, this service will also be a valuable asset to tourism.

Tourists need not even enter the water to benefit from reserves. For example, in many places boat trips to watch marine mammals or birds have become popular. Fully-protected reserves could enhance food availability for these animals allowing their populations to prosper, and people would be more likely to encounter them. In calm seas tourists who can't swim are still able to view marine life through a glass-bottom boat. Reserves can provide pleasure and an education for all sorts of tourists throughout the world.

As marine reserves attract tourists they also provide economic opportunities for local communities. For fishers, tourism offers the prospect of an alternative livelihood which is easier, safer and often better paid than fishing. They can use their boats to take people out to sea. Depending on the area, this might be for diving or snorkelling, bird watching, marine mammal spotting, visiting sites of local interest, or just plain cruising. Some turn their boats into water taxis. Of course some fishers want to retain their traditional livelihoods rather than embrace tourism in this way. However, as opportunities from tourism are open to many in the community, fishers can also benefit indirectly through others in their families. For example, jobs are created in hotels and restaurants, in local shops and in the diving industry. Once tourism starts to develop, its influence affects everyone and most people are happy to accept it.

Tourism can offer an important means of financing reserves, and can help to keep more damaging forms of development, such as industry, away from sensitive environments. However, as this early morning scene of diving boats loading up in southern Sinai in Egypt suggests, so many tourists can be attracted to an area that they start to cause harm. Some sites in the Ras Mohammed National Park are dived more than 50,000 times a year, well beyond sustainable limits. It is important that sites are monitored and managed to ensure that tourism does not cause harm.

However, tourists often damage the environment they come to enjoy, and some habitats are more vulnerable than others. Amongst marine ecosystems, coral reefs are particularly susceptible to the impacts of tourism and such effects can be very wide ranging. For example, sediment released during hotel construction can smother and kill corals, as can algal growth boosted by nutrient input from tourist sewage facilities. Boats carrying tourists out to the reef can cause serious damage if they drop anchor. In only a short time, careless anchoring can devastate a reef that may contain corals which are hundreds of years old. Tourists themselves can also do considerable damage by breaking corals whilst diving and snorkelling. Apart from making the reef less attractive, such damage may encourage the spread of coral diseases by providing lesions through which infection can occur.

Fortunately some of these problems are easy to solve. For example mooring buoys can prevent anchor damage, breakage by tourists has been proven to be reduced through education (Medio et al. 1997), and better building practices can help ameliorate the impacts of construction. What is important is to ensure that tourism development is properly regulated so that it does not exceed the sustainable capacity of the environment. Nowhere is this more crucial than in marine reserves. The popularity of reserves means that they are the places most likely to become over-crowded with tourists. Not only will high densities of divers and snorkellers threaten the habitats they visit, but if lots of boating traffic congregates in one particular area, conditions can become hazardous for them. The Hol Chan Marine Reserve in Belize has suffered from this problem. It is a honeypot site for fish, but the coral there has been damaged by the hordes of snorkellers and divers that use the site. Hol Chan's success in attracting tourists has helped lead towards creation of other reserves in Belize, which may help reduce some of the pressure on it.

The possible downside of tourism, damage caused by excessive use, calls for cooperation among agencies in creating reserves. For example, in the USA, many Fishery Management Councils are considering creating reserves for fishery management purposes. Their concerns usually centre only around designating a box and enforcing protection from fishing. However, once reserves have been created, build up of fish stocks and habitat recovery will almost certainly lead to a broadening and intensification of uses. Such effects require a more integrated approach to management and warrant close cooperation from the outset among agencies responsible for marine resources.

Despite the problems associated with tourism, most people feel that good points outweigh bad. With careful management it is possible to achieve a balance that is favourable to both environment and tourists. Consequently tourism is something that both conservationists and fishers are encouraging. The fact that marine reserves help stimulate tourism can thus be considered one of their major assets.

Key points:

- Fully-protected marine reserves can be highly attractive to tourists. Protection leads to the development of more interesting and spectacular biological communities than exist in unprotected areas.
- Tourism can be a major asset to reserves, helping finance their management, offering alternative employment for fishers and others, so easing pressure on exploited resources.
- Excessive visitation of reserves, and the development that accompanies tourism, can be damaging. It is important to monitor and manage reserves to ensure that sustainable levels of tourism are not exceeded.

Further reading: Hawkins & Roberts 1994, 1997; Hawkins et al. 1999.

20. What other activities can be permitted in fully-protected reserves?

Up to now we have concentrated on the importance of closing marine reserves to fishing. Fishing undoubtedly has pervasive and often severe impacts on marine species and habitats, but it is not the only human threat that causes concern. Reserves are intended to protect habitats and species from harm and so it makes no sense to designate an area off-limits to fishing while allowing the extraction of sand or gravel, or the dumping of sewage sludge or colliery spoil. In this book we use the term 'fully-protected' to denote reserves which are closed to all extractive or harmful human uses. Mining and dumping clearly destroy habitats and impact species, but activities like dredging or infilling may also cause lasting impacts. They too are inappropriate in reserves.

Frequently, when people discuss reserves, we hear some express the view that they should be closed to all human use, including the passage of boats. Some areas of the sea, such as the strict protection zones on Australia's Great Barrier Reef, are already closed to all uses except observational study by scientists. However, this level of protection is unlikely to be acceptable in areas which people use intensively. To be implemented, reserves need wide public support. As more uses are excluded, so the support base for reserves will dwindle and with it the probability of getting them established. It is important not to alienate user groups by imposing restrictions that are unnecessary.

Shipwreck on a coral reef. Particularly sensitive habitats, especially in areas hazardous to boats, may call for restrictions on shipping. For example, restrictions on large vessels and those carrying dangerous cargoes, have been enacted in the Great Barrier Reef Marine Park.

How much and what kinds of use are tolerable in reserves without compromising their role for conservation? Many activities only become harmful if they are performed intensively. In these cases the level of use needs to be controlled rather than the activity excluded. For example, most boat traffic and shipping generally pose little threat to deepwater marine reserves (unless vessels are carrying hazardous cargo). However, excessive use of boats with outboard engines, particularly two stroke engines from which oil is discharged into the water, could be harmful if concentrated into small areas. Oil sheens are toxic to the eggs and larvae of marine species floating at the water surface. Larger reserves with more dispersed boat traffic will suffer less from this problem than small and popular reserves. It may also be necessary to direct boat traffic away from sensitive areas, such as shallow reefs, bird colonies or areas used by marine mammals. The Gully, a reserve off the east coast of Canada is closed to shipping to protect whales from ship collisions. However, limits on use need rarely be extended to full-scale bans unless the reserve is very small and all of it is sensitive. Attempts to exclude all boat traffic are bound to antagonize and may be unworkable. It also conflicts with the possible objective of allowing recreational use as it may be impossible to access reserves without boats.

Proposals to set up a large, fully-protected reserve in the Dry Tortugas of the Florida Keys, ran into difficulties when recreational anglers objected that excluding them while allowing recreational scuba diving would be inconsistent and unfair. Anglers wanted to continue 'catch-and-release' fishing in the reserve, claiming that it had little impact on fish populations. 'Ecological reserves', as fully-protected reserves are called in the Florida Keys National Marine Sanctuary, are intended to prohibit all fishing but to allow non-extractive human uses such as scuba diving. Catch-and-release fishing is deemed 'extractive' because some fish die as a consequence of being caught. This will reduce the efficacy of reserve protection. However, anglers contend that scuba diving and snorkeling are also 'extractive' because divers and snorkelers kill corals, even if inadvertently (see Section 19). Their argument, while true to a point, was rejected by the Stakeholder Working Group convened to choose the location of the reserve (see Dry Tortugas Case Study). They decided the risks from recreational fishing were too great, and the principle of no fishing should prevail. Furthermore, there is no evidence that scuba diving has any impact on fish populations, while catch-and-release fishing could lead to the death of the largest and most reproductively active fish in a population. This would conflict with the objective of using the reserve to supply recruits to adjacent fisheries. Fully-protected reserves are also a good way of separating conflicting activities, such as scuba diving and fishing.

The impacts of scuba diving and snorkeling can be contained by mooring buoys, education and limits on numbers allowed to use sites (Section 19). Nevertheless, divers and snorkelers do cause harm and anglers have a point when they say that some areas should be closed to these activities. Some countries already have no-diving zones, such as Bonaire and St. Lucia. We would recommend that 10 or 20% of the total area of reserves be closed to scuba diving. Such areas form important control sites for studying the impact of diving. There are also some organisms that will be better off without disturbance from divers and the boats that carry them.

It is now common for stakeholders from many walks of life to be included in the processes of reserve establishment. Formerly such discussions were dominated by fishers, but the increasing breadth of participants reflects the fact that many other people have legitimate interests in the oceans. Committees now often have representatives from fishing, diving, boating, conservation, science and management groups. During deliberations on what uses should be permitted in proposed reserves the idea is sometimes put forward that scientists should also be excluded. This argument often arises out of a perceived asymmetry among who gains and who loses from reserves (at least in the short-term). There is a notion that the 'pain' of reserve creation should be shared by all, including scientists. However, science should never be completely excluded from reserves. Natural communities, undisturbed by other human uses, are vital for both fundamental and applied research. How else can we fully understand the impacts people have on ecosystems? There is a good case for restricting collection of samples from some reserves, but observational science is always needed. Research is essential for gauging whether reserves are effective (see Section 21). If science is excluded, fishers and others will be unable to judge the value of those reserves. Everybody has a vested interest in the outcome of research on reserves.

Key points:

- Fishing is not the only activity that affects marine ecosystems. It is important to protect reserves from other extractive uses and sources of harm.
- Many recreational, educational and scientific uses of reserves are compatible with full-protection. However, it is important to monitor reserves to ensure such uses are not causing harm.
- Strict protection, the exclusion of all human uses except observational science, is sensible for some zones if reserves are large enough. Such zones offer refuge for species that are easily damaged or disturbed by people and will help in assessing the impacts of use elsewhere in reserves.
- Science should never be completely excluded from reserves, since nothing will be learned from them if it is.

Further reading: Hawkins & Roberts 1997; Hawkins et al. 1999; Bohnsack 1998; Ballantine in press.

21. How do you assess if reserves are effective?

After establishing a reserve it is essential to monitor its performance. Too often, protected areas are set up without plans for monitoring or resources to support it. Such reserves are a wasted opportunity. We desperately need to learn more about how reserves work and must do so at every opportunity. Reserves cost money to establish and maintain and it is impossible to gauge the value of that investment unless they are properly studied. In some cases reserves are established on a trial basis, with a set period over which benefits must be proven or the reserve scrapped. Monitoring is essential to determine their success. It also provides valuable feed-back that can help bolster support for reserves within local communities. If things are seen to be improving, people will be more willing to continue their support.

Ideally, monitoring should begin before reserves are declared to provide a baseline of data for future changes. This is important because reserves are often created in places where conditions are better than average to begin with. Without baseline data such differences would confuse later comparisons with unprotected areas. Usually only one baseline survey is performed, whereas several would be better, as they would provide greater confidence in inferences made about the causes of change. This is especially important if only one reserve is being established. Studies with more than one reserve are considerably more powerful and all studies must have unprotected controls matched as closely as possible for environmental conditions.

Sampling of fish catches in southern Belize. Few studies have yet monitored the effects of reserves on fish stocks and fisheries. Monitoring programmes that target both fish and fisheries are urgently needed to examine the extent to which reserves can support catches, and promote long-term fishery sustainability. Photograph by Will Heyman.

Table 5 lists many indicators of reserve performance. At present most studies have only measured exploited populations. However, it is also important to monitor the habitats in which those species live. The best monitoring programmes target a broad range of species and mix a range of different measures. Basic monitoring can often be conducted effectively with observational techniques alone. This minimizes disturb-ance and does not compromise protection. Wherever possible, non-destructive techniques should be used in place of damaging ones. For example, filming the seabed with remotely operated vehicles would be better than bringing large chunks of the seabed to the deck of a boat! However, sometimes it is necessary for destructive monitoring, such as experimental fishing. In such cases it is important to devise approaches that maximize the value of observations while minimizing damage.

Monitoring is expensive in both time and money and organizations that manage protected areas may not have sufficient resources to do all their own monitoring. Ideally, provision for monitoring costs needs to be built into management budgets, perhaps coming from user fees. However, if this is not possible, managers can easily team up with university-based research groups. Scientists are always looking for good field sites to study, and research into reserve function is a growth industry. Scientists can raise research money for detailed monitoring studies that can help support management. If this approach is taken, managers and scientists should agree terms at the outset. Monitoring will be of little value unless the results are reported back to managers on a regular basis. It is also important for managers to bear in

Table 5: ***Measures that may be incorporated into monitoring programmes. This list is not exhaustive but gives an idea of the kind of measures that have proven useful in existing programmes.***

Indicators of the status of exploited populations

- Species composition - categorized for example by the maximum size or trophic level of the organisms present. Intensive fishing leads to progressive loss of large species, and those from high trophic levels.
- Abundance - usually measured as density. Fishing tends to reduce population densities of target species.
- Size distribution of individuals present. Fishing tends to skew size distributions toward smaller individuals.
- Biomass - calculated from size and abundance estimates using length-weight relationships. Fishing tends to reduce biomass. Increased biomass is usually the earliest indication that reserves are working.
- Sex ratios and size at first sex change of sex-changing species. For species that change from female to male as they grow, fishing skews sex-ratios in favour of females, and often leads to earlier sex change at smaller sizes.
- Indicators of particular kinds of fishing. For example, butterflyfish abundance on Caribbean coral reefs is depressed by trap fishing; presence of fish with wounds can indicate spearfishing; presence of discarded or lost fishing gear can indicate whether fishing is continuing in a reserve.

Measures of habitat condition

- Cover, population density and size structure of indicator organisms. For example, on coral reefs, corals and algae are important indicator groups of reef condition. In other systems, some of the best indicator species may be found among those that are long-lived, slow growing and easily damaged.
- Structural complexity. Fishing gears tend to reduce structural complexity with consequent impacts on species that depend on physical habitat structure for shelter.
- Damage measures. These include, for example, broken colonies or injured (and possibly recovered) animals, dynamite fishing craters, trawl tracks, or anchor scars.

Indicators of stress

- Disease frequencies - frequencies may be higher in stressed populations.
- Symptoms of stress - e.g. bleaching is an obvious sign of stress for reef corals.
- Reproductive output - stressed organisms may produce fewer offspring.
- Growth - stressed organisms may grow more slowly.

mind that a typical research grant only lasts three years, whereas monitoring is a long-term commitment. However, enterprising scientists should be able to maintain long-term research programmes through a succession of short-term grants.

Key points:

- It is essential to monitor the performance of reserves, but few management bodies have sufficient resources to do this properly. Lack of resources can often be overcome by teaming up with university researchers, but this will not provide a complete solution. Reserve managers must also develop a local monitoring capability.
- Monitoring should be broadly based and able to detect expected as well as unexpected outcomes of protection.
- Monitoring should encompass both environmental and human responses to protection, and should be done inside and outside reserves.
- Monitoring provides important data to inform management and provides feedback to local communities that can help reinforce their support for reserves.
- We need to use the opportunity offered by every reserve to learn more about how they function and how to improve performance.

Further reading: Richards & Davis 1988; Brosnan 1993; Davis 1993; Davis et al. 1997; UNEP/AIMS 1993; Rogers et al. 1994; Clarke & Warwick 1994; Roberts 1995.

22. Will reserves simplify fishery management?

In many developing countries, marine reserves are one of the only fishery management tools that will work. It is virtually impossible to apply conventional methods (species-by-species restrictions on catch or effort) to the complex fisheries of nations in the tropics. Such approaches simply aren't practical where landings consist of many species caught using a wide array of fishing gears, where fishers are numerous, boats small, there are multiple landing sites and resources for fishery management are negligible. Reserves will certainly simplify management in these circumstances. What can they offer in places where resources for management are more lavish and fisheries less complex?

Managers in developed countries have many resources at their command: people to check gears and to measure and monitor landings, patrol boats, satellite tracking systems for boats etc. Despite this impressive armoury, fishery management is imprecise, often wildly so. To calculate how many fish it is safe to catch, you first have to estimate how many there are. It is not easy to count fish in cold water with poor visibility. You can't just stand on the top of a cliff, scan the horizon and count shoals of fish wandering across watery plains. Instead you have to sample them with nets, hooks or traps. Often managers rely on fishers to do the sampling for them, because it is expensive to do their own surveys. But fishers don't fish at random. They seek out the cities of the cod world - places where they can obtain the greatest catches in the shortest time. This makes it very difficult to calculate abundance, and estimates are often wide of the mark by 20% or more.

For example, after estimating the abundance of yellowtail flounder *(Pleuronectes ferrugineus)*, imagine you want to ensure that only one third of the reproductively active population are removed from the sea in a year. You must devise restraints on fishing power that will enable you to deliver this target. So you set a minimum mesh size on trawls that you hope will allow immature fish to escape, and set a total allowable catch that corresponds to one third of the estimated adult stock, and then you monitor landings to see when that is reached. Unfortunately, life is not this simple. Once the trawls start to fill up with fish, juveniles cannot escape from the nets and so form part of the by-catch. Because they are discarded dead at sea rather than landed you don't know how many have been killed. The flounder is not as valuable as cod which are also caught in the same trawls, and so at the beginning of the season, boats fill up with cod and dump flounder. It is not until later in the season that fishers start to land their quota of flounder. All of this means that far more flounder are killed than the target set. The problem is that fishery managers don't know how many more - it could be 10% or it could be 60%! The tools used to deliver management targets are blunt, even in the most technologically sophisticated fisheries.

Scientists have called these problems 'irreducible uncertainties'. They are errors in estimation that cannot be reduced given the resources available. To operate safely, fishery managers need to buy insurance against this uncertainty, and reserves can provide it. Mark Mangel, of the University of California, and his colleagues have found that fishery managers would find it much easier to keep fish populations above minimum target levels if they had reserves. Furthermore, if mistakes are made and fishing does drive stocks to very low levels, recovery can take place faster if there are protected populations. Reserves virtually eliminate the risk of complete population collapse.

Theoreticians also point to another benefit of reserves - they can reduce year-to-year fluctuations in fish populations and catches. Fish populations are highly variable, and fishing can push them to levels where recruitment will not maintain abundance. Models suggest that reserves will keep populations above levels at which recruitment is limiting and so make fisheries easier to manage and future income more predictable for fishers.

Reserves can also help solve some other thorny management problems. For example, fisheries often run into conflict when boats targetting one species catch another that supports different fishers. Reserves placed in areas with severe by-catch problems can help reduce those conflicts. Finally, reserves could help overcome the problem of political interference in management, or at least lessen its impact on management success. Managers rarely have the pleasure of seeing their recommendations implemented in full. Instead, they are watered down in political bargaining processes that ultimately do no favours to fish populations or fishers. Fully-protected reserves (not single-species closures) are difficult to set up, but that also makes them difficult to remove. A **system** of reserves that supports fishery management offers a back stop against political risk taking that should leave fish populations somewhere well above zero if things go wrong.

Key points:

- Fisheries operate with 'irreducible uncertainties', errors in estimates of target species population size, catch, fishing effort and fish mortality that cannot be reduced given the resources available.
- Given such uncertainties, fishery managers need to 'buy' insurance, and reserves can provide it. Reserves could virtually eliminate the possibility of complete fishery stock collapse.
- Theoretical work suggests that reserves could reduce year-to-year variability in catches, so making fisheries easier to manage.
- Reserves can help reduce conflicts among different fishery sectors by preventing damaging by-catch.

Further reading: Sladek Nowlis & Roberts 1999; Roberts 1997a, in press d.

23. How can you best gain support for reserves?

Establishing reserves is a highly charged issue and the process is easily derailed. It is therefore very important to muster support for reserves by building as many allies as possible.

Natural allies of reserves: Public opinion generally favours greater protection for the environment. Unfortunately, the public are rarely properly engaged in public debate about reserves. They are not usually perceived as legitimate users of the sea in the way that fishers, or port authorities, or tour boat operators are. This view is gradually changing and people now recognize that even those who only visit the sea occasionally, or even never at all, have valid concerns that should be aired. However, public opinion is still being rejected in some quarters. For example, the Gulf of Mexico Fishery Management Council in the USA recently tried to reject public comments on proposals for a marine reserve in the Gulf of Mexico, because they came from people who had no obvious connection with the fishing industry.

Since reserve establishment is unlikely to affect their livelihoods, there is less incentive for the general public to become closely involved in debates surrounding reserve establishment. Dan Suman, a social scientist from the University of Miami, found there was wide support among the general public for proposals to set up the Florida Keys National Marine Sanctuary. However, few of them ever attended public hearings because they thought that their interests would be represented by the National Oceanic and Atmospheric Administration. But this organization was the convener of the hearings and there to listen to views rather than represent them. Consequently, instead of achieving a representation of public opinion, the hearings were dominated by special interest groups that were often hostile in their opposition to protection.

Children are becoming more and more environmentally aware and can be especially strong allies of reserves. Bill Ballantine, in his efforts to establish marine reserves in New Zealand, produced education materials for schools and spoke at every secondary school in the country! He recognized the importance of teaching the next generation about the value of the sea and the need for greater protection. If children support marine reserves they may encourage their parents to attend meetings concerned with setting them up.

Tourist operators also tend to be allies of reserves. Tourism depends on a high quality environment and tourists are particularly attracted to places with protected areas where they expect the environment to be spectacular and well looked after. Hence the tourism industry has an interest in promoting environmental protection.
Conservation organizations are obvious allies. They can help at the local level directly and mobilize support amongst their wider membership. Some conservation organizations, such as the World Wildlife Fund can help by acting as 'honest brokers', facilitating the establishment of participatory management bodies when negotiations begin to founder. In the Galapagos, for example, they helped set up the group that agreed on protective measures for the Galapagos Marine Park. However, for the role of an honest broker to be pursued, it is important that conservation groups act only in an advisory, not a decision-making role.

Possible obstacles to establishing reserves: In the initial stages of consultation on reserves, fishers usually oppose proposals. This is not because they are anti-resource protection, but more to do with their outlook on life, their experience of past management regulations, and their natural suspicion towards regulators. Fishing is a tough, often dangerous occupation and fishers are fiercely independent. They see themselves as hunters living by wit and skill, and are reluctant to have that freedom curtailed by restrictions on where they can go, what they can catch and how much they can take. The growing raft of regulations to which they are subjected stem from their success as hunters and the failure of others to regulate effectively. Regulations limit the extent to which good fishers can earn a better living than bad ones. Ineffective regulations undermine confidence that any proposals put forward by the authorities will be successful. Why should reserves be any different?

Fishers begin to support reserves when they understand how they work. Reserves make much better sense to them than mathematical abstractions used to underpin many other kinds of regulation. For example, if you want to protect fish before they spawn, it seems far more appropriate to stop fishing in some places rather than trying to separate breeders from non-breeders with different kinds of gear. It also makes sense to protect nursery areas where by-catch of juveniles is unavoidable, and to protect some habitats from being flattened by trawls. But what seems most sensible of all is to leave a sizable proportion of fish in the sea to supply future catches rather than push luck to the limits with dangerously optimistic catch targets. In England, the Cornish Fish Producers Organization, the largest in the country, supports fully-protected reserves because they believe these offer the best prospects for the future of the industry.

Fishers will often support reserve proposals where they see populations being fished unsustainably. They don't like catching animals before they have reproduced, and they don't like to see populations being cleaned out from places where they are especially vulnerable, such as spawning aggregation sites. However, fishers are in competition with each other and while such areas remain open they will continue to fish them, even if they know it will damage the fishery in the long run. However, if everyone is excluded from an area, then the pressure to exploit unsustainably is removed. Fishers are very concerned that regulations are equitable and will often support fully-protected reserves over partial closures which they feel create 'winners' and 'losers' within the industry.

Fishers may be more willing to support reserves, and even play a part in their enforcement, when they feel their livelihoods are being threatened by outsiders. In many places, fisheries are being exploited by itinerant fishers as well as locals. For example, throughout South East Asia, boats have been systematically fishing out groupers and other highly sought after fish for the live food fish trade. As they have no stake in the long-term prosperity of local fish stocks, their objective is to extract as many fish as possible with no regard to sustainability. They simply move on when stocks are exhausted. Fully-protected reserves, especially when established as zones within larger marine protected areas, offer a means of keeping out itinerant fishers. This benefit could help gain the support of local fishers for reserve establishment.

Convincing fishers to support reserves is never an easy job. This book is designed to collate good examples of reserves from all over the world which will help persuade people of their value. One of the best ways to overcome skepticism is to bring in speakers from places where reserves are working. In the US Virgin Islands, doubtful fishers became more receptive to reserves when a representative from the St. Lucia Fisheries Department told them how successful reserves had been in St. Lucia. Alternatively, fishers can be taken to places with reserves and speak to people themselves. For example, when Jamaican fishers were taken to the Hol Chan Marine Reserve in Belize, they were deeply impressed by what had been achieved (see Case Study). While fishers may not be persuaded by examples from elsewhere, they may be willing to support a 'pilot-scale' reserve in their own area. There is nothing better to persuade people that reserves are worth taking seriously. Finally, the offer of some form of compensation or the development of economic alternatives may be effective in gaining support (see Section 11).

Perhaps surprisingly, fishery scientists in developed countries often oppose the use of reserves in fishery management. This is perplexing given the difficulties they have in delivering management targets in the face of uncertain population sizes of target species and uncertain levels of fishing mortality (see Sections 4 and 22). Reserves could be a great asset to them so why the initial prickles? Gary Davis, a research scientist with the Channel Islands National Park in California, believes the

16th century writer Machiavelli has the answer. To paraphrase him, "There is nothing more difficult than to change the order of things"! Reserves are alien to the way most fishery scientists think. If for years you have pursued a course of ever greater refinement of mathematical population models in order to manage species one by one, then at first the simplicity of reserves might make them seem like a blunt tool - a bit like asking a surgeon to exchange a scalpel for a pair of garden shears. Replacing the fine calculus of birth, growth and death, comes the brute offence of an all-encompassing closure. But that is exactly why reserves are so important - they are all-encompassing and in being so they put the 'ecosystem' into management. Too many fishery managers seem to have forgotten that their targets live in an environment which provides them with food, shelter, and places to reproduce. Within that environment they rub shoulders with other species, hunting and being hunted. It is futile to try to manage species as if the environment will always take care of itself and as if catching one species will not also affect others. Only a tiny fraction of fishery models in use today take any account of the ecosystem context of managed species, and this is a grave omission.

Fortunately, it is becoming easier to convince fishery scientists of the value of reserves. The literature on reserves is burgeoning and most of it strongly supports their use. Distinguished panels, such as the US National Research Council Committee on Sustaining Marine Fisheries, have argued for greater use of reserves in management. Many questions about how reserves will help in fishery management remain unresolved, but we will not find the answers unless reserves are established and tested. Fishery scientists can hardly object to that!

Key points:

- Reserves are never easy to set up and require broad support for proposals to get off the ground.
- Natural allies of reserves include the wider public, tourism operators and conservation organizations. However, the public are often poorly represented in discussions and need to be actively engaged to mobilize their support.
- Fishers often oppose reserve proposals to begin with, fearing that they will impose further costs upon them. However, once they understand how reserves work, and have seen examples from elsewhere, they often become firm supporters.
- Fishery scientists often oppose reserves, although they offer many advantages over conventional management approaches. However, the current flood of information on reserves is likely to soften their reluctance to use this new tool.

Further reading: Bohnsack 1997; Roberts in press d; NRC 1998.

24. How can you reach agreement to establish reserves?

Establishing reserves is never easy. Proposals to restrict use of the sea will always be controversial. In fact, a rough rule-of-thumb is that the closer you get to implementing a reserve, the more controversial it will become! Perhaps the worst possible way to try to implement a reserve is to have a government body produce a plan and take it to local communities for comment before implementation. Yet this is the model most often followed in the past. Even if the body produces a plan that is basically right and does it for good reasons, people are unlikely to accept reserves proposed in this way. This is human nature! While such a process may lead to legally mandated reserves with clearly mapped boundaries, it is highly unlikely to result in real protection. All over the world paper parks have been created in this way. If reserves are to have any chance, local communities must be an integral part of the process from the outset.

There is a cost to community involvement. Richard Stoffle, an American anthropologist who has many years experience working on natural resource management with local communities, put it succinctly when he said that "the cost of cooperation and community involvement in management is that the process slows down and the endgame has to be left open". You cannot have pre-determined outcomes if there is to be meaningful community involvement. Consultations should be open-ended. Table 6 summarizes good and bad practice in community consultation.

So how do you identify stakeholders to involve in consultations? Obviously, people who use the sea directly must be involved: fishers, tourism companies, aquaculturists, port authorities, coastguard etc. However, it is important to involve others with interests in the sea, for example those who discharge or process pollutants, residents and visitors to the coast, and even people who do not live close to the coast at all and may never visit. We increasingly recognize that there are existence values to natural resources. The very existence of beautiful coastal areas and of the animals and plants that live there has value. People can see them on television, enjoy photographs of them, or cherish the fact that others can experience them directly.

While it may be relatively straightforward to identify stakeholder groups, it is much harder to effectively represent their views in negotiations. Billy Causey, superintendant of the Florida Keys National Marine Sanctuary, considers this one of the

Table 6:* *Good and bad practices in consultation. By Bob Earll. Reprinted with permission from Fisheries and the Environment, Working on a Common Agenda. 1999. Marine Forum. Candle Cottage, Kempley, Gloucester, UK.

Issue	Bad practice	Good practice
Process	Not transparent	Transparent
Timing	Rushed and late	A realistic timescale
Participation	Not welcomed	Active and welcomed
Information	Limited or non-existent	Sufficient to respond
Decisions	Closed - already made	Still open
Outcomes	Unclear or predetermined Probably lose	Not determined, with options Probably win-win
Appeal process	No appeal or only via legal means	Appeal procedure clear
Consultees' perception	That input will not make any difference	That input would be worthwhile

Box 1: Methods of Conflict Resolution

Four methods can be used in resolving disputes related to the establishment or use of marine reserves:

Self-negotiation: Conflicting parties decide, on their own initiative, to resolve a dispute, and seek a mutually agreeable solution without any external assistance.

Facilitation: Parties in a conflict interact and communicate directly, seeking solutions with the help of one or several facilitators.

Mediation: In this process there is no direct communication between conflicting groups. A mediator relays their options and proposals and helps them find common ground. Participants formulate their own conclusions.

External arbitration: An arbitrator seeks the views of all parties then tests solutions and options. It is then up to the arbitrator to formulate a mutually acceptable solution.

The following describes what happened when marine reserves were established in Soufrière, St. Lucia, West Indies. One of the reasons for wanting reserves in St. Lucia was to resolve growing conflicts between different users (see Soufrière Marine Management Area Case Study). It was initially intended that all negotiations would be facilitated but as it turned out a combination of methods were used. Mediation helped sort out the most difficult issues, whilst some problems between fishers and dive operators were overcome by self-negotiation. When negotiations were facilitated, the following procedure was generally adopted. Before a session began, facilitators would draw up a list of objectives and design a structure for the day's discussion. These were then discussed with participants, and amended if necessary. The first discussions would examine the current situation and the problems it was causing, so allowing people to see things from other perspectives. Once problems were established the next stage was to identify their causes, followed by potential solutions for the most simple ones. Success built on success as participants realized it was possible to reach agreement. However, some issues were more difficult to resolve than others and this was the stage at which mediation was required.

By Yves Renard, Caribbean Natural Resources Institute, Vieux Fort, St. Lucia, West Indies. First published in Caribbean Park and Protected Area Bulletin 5(2) August 1995. Edited version reproduced with permission from CANARI.

most important but most difficult aspects of community involvement in reserve creation. Stakeholder groups can participate in reserve designation through open meetings, surveys, responses to circulated proposals and so forth. All these approaches were used during the process of establishing the Florida Keys National Marine Sanctuary, but there were still problems. The approaches were too cumbersome and in the end failed to motivate some stakeholder groups. Furthermore, well-organized and vocal minority groups tended to "hijack" public meetings. For these reasons, **participatory management** groups make a good alternative.

Participatory management groups have been successfully used in many places, and the Galapagos and Dry Tortugas Case Studies describe two examples. Such groups are assembled to represent stakeholders and negotiate on their behalf. However, it is critical to select people who will fairly represent the interests of each stakeholder group. For example, fisheries are often split into different sectors, say hook and line fishers, seine netters, and trawl fishers. It is rarely possible to find a single person who can represent all these interests and so it may be necessary to appoint several. Representatives from conservation organizations are usually able to represent natural resource values of people who do not directly use those resources. Everybody on the participatory management group must have the trust of their constituents if the outcome of negotiations is to be accepted outside the group.

Participatory management groups negotiate to find acceptable solutions to resource management problems (see Box 1 for a description of negotiating strategies). Those problems might be relatively narrowly defined, such as where to put a reserve, or more broadly defined, such as whether reserves are needed in the first place. People on the group negotiate to seek an acceptable consensus. Cynics have defined consensus as a position where nobody is happy, but the process of negotiation can bring the views of parties much closer together. Solutions that may be rejected at the outset of negotiations can become acceptable when people start to understand each others' views better. It is important to get participatory management groups to agree on principles and objectives before discussing how to achieve them. This makes it easier to agree on solutions.

There are many benefits to following this approach. Different stakeholder groups often find they share many common values and objectives, and are able to resolve their differences. The process for selecting reserve locations described in Section 15 can be used as a framework for stakeholder input to choice of reserves. It requires stakeholders to articulate their objectives then follow through a process leading to solutions for them. Whilst going through this process, groups can learn about the biology underling reserve function. Participatory management is particularly effective for reducing conflicts among resource users, and reserves are very valuable in helping resolve conflicts.

Participatory management groups are only effective if they know that their recommendations will be taken seriously. There is no point using the process to try to obtain token support for a pre-determined agenda. Furthermore, reserves are even less likely to be successful if the advice of such a group was sought and subsequently ignored. In the Galapagos, discussions within the participatory management group were greatly facilitated by a parallel legal effort which gave them the authority to determine management of the newly established marine reserve.

The process of establishing reserves through participatory management has many social as well as environmental benefits. Stuart Green, a fishery scientist advising on the establishment of reserves in the Philippines, says the effect of reserves on people has been almost as important as it has been on fish (see Barangay Lomboy and Cahayag Fish Sanctuary Case Study). Setting up reserves brings communities together as people develop and pursue a common agenda. The role of managing reserves can often be undertaken by the participatory management bodies that set them up. This will involve regular community meetings and provide frequent opportunities for discussion at which other community problems can be aired and resolved. Reserves also offer a focus for education about natural resources and their management.

Although community participation adds time and money to the task, it is more cost-effective in the long run. If reserves are set up in this way they are likely to have greater compliance and support, which means better protection at less expense.

Key points:

- Reserves are unlikely to be successful unless they are established with active involvement of stakeholders.
- There are many ways to obtain stakeholder input to negotiations, and a variety of approaches should be taken. However, participatory management groups made up of stakeholder representatives have proved very successful.
- Particular care must be taken in developing participatory management groups to ensure that representatives have the trust of the groups they represent.
- The process of participatory management has many social benefits as well as providing consensus on how to manage resources.
- Meaningful stakeholder involvement slows the process of reserve establishment but will lead to more cost effective, long-term protection.

Further reading: Bohnsack 1997.

Box 2: Key lessons for the creation of effective marine reserves

1. ***Marine reserves should be designed to achieve specific objectives, which should evolve according to changing circumstances if necessary.*** Objectives are important. They provide critical input to the selection and design of reserves. However, it is important not to be a slave to objectives stated at the outset. Reserves produce many surprises that may call for their revision. Large fishery closures established on the George's Bank off the US east coast in 1994 were designed to help recover populations of groundfish such as cod and haddock. Few people expected the spectacular rebound of scallops within them, yet the closures clearly became important in restocking local scallop fisheries.

2. ***Marine reserves must be tailored to local conditions, attitudes, and needs.*** What works in one place may not be as successful in others. For example, community-based management has worked well at the village level in places such as the Philippines where there is a strong sense of community and use of the sea is primarily by locals. However, different forms of community involvement are needed for places with large transient populations, such as holiday resorts in the Florida Keys.

3. ***Stakeholders must be involved at all stages of marine reserve planning and management.*** Marine reserves established by government order in St. Lucia in the 1980s failed because there was inadequate community participation in the process. Only when officials went back to the drawing board in the early 1990s and initiated detailed discussions with local stakeholders, did the process get back on track. St. Lucia now has a strong coastal zone management programme based around multiple-use MPAs.

4. ***Marine reserves often benefit from having a legal base.*** Reserves that have strong community support can function without a legal basis, but they are vulnerable to loss of protection. Voluntary marine reserves have been established by local supporters around the coast of Britain out of frustration with the inadequacy of the process to establish statutory protection. However, they offer little real protection to the marine life within them.

5. ***All marine reserves need a management plan.*** Although it was first established in 1986, the Galapagos Marine Resources Reserve (as it was then known) did not have a management plan until the early 1990s. This undermined efforts to provide protection.

6. ***Local communities should have a role in enforcement.*** If local people feel they have no role in the management of reserves, they are less likely to support them. Enforcement by government alone can foster local resentment, leading to the development of an 'us versus them' mentality. Furthermore, governments can rarely afford to implement the level of patrolling necessary to secure protection.

7. ***Marine reserves require sufficient, well-trained personnel.*** The most successful MPAs are those that are watched over and cared for, whether it is by paid staff or volunteers. Sumilon Island reserve in the Philippines was enforced by a single watchman on the beach, the Hol Chan and Saba Marine Parks in the Caribbean are patrolled daily. Lack of staff to implement protection is one of the most pervasive reasons for failure of reserves. In Florida, the Experimental Oculina Research Reserve was established to protect fragile deep water corals from damage by trawling. Unfortunately, the coastguard, who were given the responsibility of enforcing protection, were fully occupied patrolling for drug runners and the reserve has done little to stem habitat destruction.

8. ***Marine reserves must be financially sustainable.*** International donor organizations are very good at injecting large amounts of money for short periods of time to get reserves up and running. They are much less good at ensuring those reserves become self-supporting, despite the fact that parks are worth little more than the paper their regulations are written on without it.

9. ***Marine reserves should be established within a framework of integrated coastal management.*** Most marine reserves stop at the high tide line, despite widespread recognition that land and sea are interlinked. The sea is downstream of all that happens on land and what happens there can impact on marine resources. On the island of Bonaire, in the Caribbean, coral reefs are being damaged by nutrients released into the sea from coastal developments. Uncontrolled nutrient pollution will undermine the best efforts of the park to protect those reefs, but the manager can do little more than lobby for better treatment of waste water.

10. ***Marine reserve management effectiveness should be monitored and evaluated.*** Few reserves are adequately monitored yet this is the only way to establish how successful they are. Although the Virgin Islands

National Park on St. John in the Caribbean was established in 1956, it wasn't until the 1990s that monitoring of fish populations began, revealing that the park had presided over their long-term depletion by fishing. If monitoring had been instituted early on, the park would have discovered the problem long before it became so severe.

11. ***You cannot separate the need for conservation from the issues of resource use.*** Throughout the world, millions of people depend on the sea for a livelihood. They will not support reserves if they feel that their livelihoods are threatened by them, even if this is a misperception. Ecological reserves in the proposed management plan for the Florida Keys National Marine Sanctuary were vehemently opposed by fishers who failed to appreciate how those reserves could contribute to sustaining their livelihoods. It is vital that such concerns are clearly addressed from the outset and resource users have a direct input to the crafting of proposals.

12. ***Socioeconomic considerations usually determine the success or failure of reserves.*** Many reserves never make it from proposal to implementation because they are opposed on the grounds that they will adversely affect some user group. For example, an ecological reserve was proposed offshore of Key Largo in the Florida Keys but was shot out of the water by wealthy local residents who were concerned that they would be unable to land fish at their local jetties. Some reserves are implemented and subsequently fail because a few user groups refuse to accept them and lobby for their removal. The most successful reserves are those where benefits of reserve creation are fed directly back into local communities and help compensate those whose livelihoods have been affected.

13. ***An imperfect reserve is better than no reserve.*** As human impacts in the sea grow, so also does the urgency of protecting them. Canadian authorities have been working for years to identify the best sites for marine protected areas, in the process developing detailed maps of marine habitats and resources. Although their aim of creating a comprehensive and representative network of MPAs is laudable, many years passed before the first reserves were established, while depletion and damage to marine resources continued apace. Less deliberation and quicker action might have offered greater benefits, even if the sites chosen were not perfect.

Compiled from experiences worldwide by Kelleher and Recchia (1998), World Wildlife Fund (1998) and annotated with examples by the authors.

25. Who should manage reserves?

Governments are ultimately responsible for natural resource management. Therefore it might seem logical that they should be in charge of looking after protected areas like marine reserves. Although governments often take this view, they can be very ineffective in this role. There are three root causes for their failure. Firstly, government bureaucracies often think that protection is achieved once a reserve has been legally declared. They fail to appreciate that legislation must be backed up by significant resources to establish and patrol a reserve in the field, and to support and educate users. Without this back up, reserves are nothing more than paper parks. Secondly, governments are too distant from local users. Governmental control often becomes polarized into an issue of ‘them’ against ‘us’ no matter how closely allied environmental and community goals may be. Finally, top down control over natural resources is prone to corruption, with officials being bought-off to overlook violations.

Following the top-down model, reserves are sometimes set up and managed by fishery agencies. In some situations, for example offshore areas, fishery agencies may be the only ones capable of implementing protection. However, they are poor at managing activities other than fishing that may impact reserves. Additionally, nearshore reserves subject to intensive use require constant surveillance, far beyond the levels most fishery agencies can provide.

The Saba Marine Park encircles the entire island of Saba in the eastern Caribbean and is run by a non-governmental organization. NGOs can be highly effective in managing marine reserves. They are able to keep natural resource management separate from politics, can devote much time and effort to public education, and can act as a conduit for funding from private and public sources alike.

At the other end of the spectrum is community-based management. This provides local people with control over resources and has many strengths. Because reserves are only effective where they have the support of local users, community-based management firmly places the onus of protection on those users. The best reserves are policed by users themselves, rather than regulations being enforced by some “official” agency. For example, no-fishing regulations are maintained by education and peer pressure in the Edmonds Underwater Park in Washington State, USA (see Case Study). Community initiatives can be very useful for building broad local support for environmental management. They also provide an effective vehicle for feeding benefits from reserves back into the community.

However, there are drawbacks to community-based management. To be effective it requires a strong sense of community and there need to be strong institutions with the authority to punish those who disregard regulations. Without them it will founder. For example it may not work as well in places with very large populations, or where thousands of outsiders use the reserves. Nor is it likely to work in places with a high turnover of residents, such as itinerant fishing communities. Problems can also arise if reserve management is too dependent on volunteers. If people lose enthusiasm or withdraw their support, the whole system can easily break down. In such cases, there is a middle way. Management is probably most effective where there is strong community involvement but this is backed up with legal instruments that enshrine protection. Such co-management arrangements are also greatly strengthened by the establishment of non-governmental (but government supported) bodies to manage the reserves.

What kinds of body should manage reserves? In the Netherlands Antilles, a group of islands in the Caribbean, non-governmental organizations (NGOs) have been set up to manage marine parks that, in some cases, encircle the entire island. NGOs have the blessing of the government, but should be able to pursue their resource management goals unhindered by party politics. They are also more likely to receive financial support from users and other organizations (see Section 27). These NGOs have the time and mandate to become deeply involved in community education. They can also help broker disputes over uses of the sea, and can generate resources to defend an area against threats from development. Many other places are following this lead and establishing similar management authorities to oversee marine reserves.

Key points:

- Governmental agencies are often ineffective as reserve managers. They usually lack sufficient resources to properly implement protection, and locals are often suspicious of top-down control over their resources.
- Community-based management offers an alternative to government control. To be effective it requires a strong sense of community and strong institutions capable of implementing regulations.
- Co-management has also proven successful. Here management of reserves is sanctioned by government and implemented by local communities with their support.
- Reserves are often best managed by locally-based NGOs, sometimes established specifically for the purpose. They combine close involvement with the community and government approved legal authority. They provide a good vehicle for channeling financial support to the reserve.

Further reading: White et al. 1994.

26. How should reserves be enforced?

The benefits from reserves depend intimately upon the efficacy of protection from fishing and harmful activities. It takes only a small amount of illegal fishing to remove a large fraction of the most vulnerable species (see Section 17), and to erode reserve benefits. This is no excuse to avoid areas where compliance will be imperfect, but it will prevent reserves achieving their full potential (Figure 16). Furthermore, the risk of poaching will tend to increase as time goes on and populations in reserves rise farther and farther above those in surrounding areas (see Case Study of Anse Chastanet Reserve).

The better respected reserves are by users, the more successful they will be. Respect is based on a combination of compliance and enforcement, with compliance being most important. Compliance will be high in communities where people have been fully involved in the process of reserve establishment. It will probably be lowest in places where reserves have been imposed without local consultation (see Case Study of the Soufrière Marine Management Area). This is why community involvement from the onset of the reserve creation process is so critical to success. If people feel ownership for resources in their area, and think that their views were taken into account when reserves were sited, they will be far more likely to support them. Although the process may take time, creating reserves with community involvement will ultimately cost less and be more effective.

Illegal fishing in the Galapagos Marine Park. The man in the red gloves is about to go spear fishing, but instead of holding his breath he will breathe through a hose connected to the compressor on the boat. This will allow him plenty of time to target choice individuals. With the odds stacked so strongly in the fisher's favour it's not long before this method of fishing eliminates big individuals of favoured species, then smaller ones, then less favoured species, and so it continues. Hookah fishing, as it is called, or fishing with scuba gear are much too efficient and should be banned throughout the world. These men are also fishing in one of the Park's proposed fully-protected zones, Gordon's Rocks.

Fishers are key community members to involve in reserve establishment. Reserves exclude fishers from places they have traditionally fished. Overnight they can be turned from law-abiding citizens into criminals if they continue to fish those areas. Fishers need to realize that reserves are in their best interests and not another attempt to force them out of a living. Close consultation during establishment is the only way to avoid misunderstanding and all fishers must be properly represented in negotiations. When a reserve was being set up at Discovery Bay in Jamaica, seasonal fishers who came from inland areas were omitted from consultations, and this led to problems later on.

No matter how much fishers are involved in establishing reserves, there will always be a few die-hards who refuse to accept them. In the Florida Keys, regulators estimate that only 5-10% of fishers land 90% of the unlawful catch. Such people are often well known in the community and can be targeted in efforts to gain their support. Nevertheless, if some people are seen to benefit by fishing in reserves at the expense of everybody else's sacrifice, it will foster resentment and may undermine reserve success (see Barangay Lomboy and Cahayag Fish Sanctuary Case

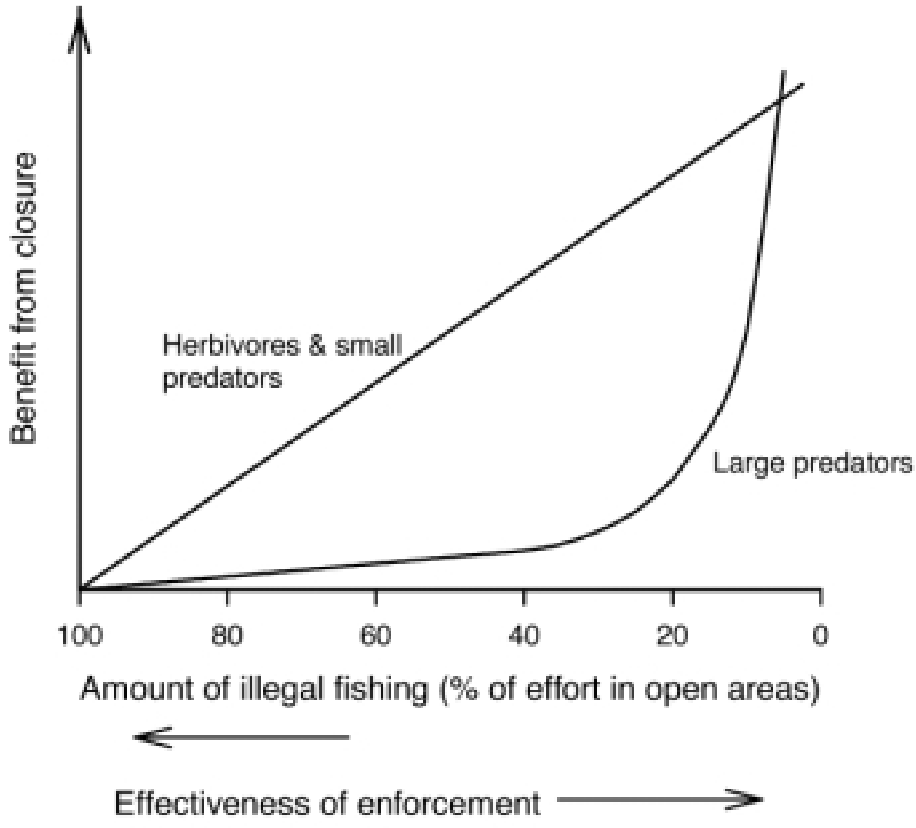


***Figure 16:* Relationship between effectiveness of reserve protection (enforcement/compliance) and benefits. For species very vulnerable to overfishing, benefits are low until a high level of protection is achieved. Such species include large, long-lived, late reproducing fishes such as snappers, groupers and rockfish. The shape of this curve was derived from empirical data collected by Jennings and Polunin (1996) and Munro (1983). For species more resilient to overfishing (typically smaller, shorter-lived, and early reproducing fish), benefits build up more steadily as the level of protection increases. Such species include members of families like surgeonfish, parrotfish, grunts and porgies. Redrawn from Roberts (in press c).**

Study). People who place personal gain ahead of community welfare must be liable to prosecution. However, the question of who should apply those penalties is difficult. In some places, marine park wardens have powers of arrest and may even carry guns. If park wardens do all the enforcing, they might be perceived as anti-community and become a focus for local resentment, especially in small communities. For this reason, some authorities, like the Soufrière Marine Management Area in St. Lucia, try to restrict their role to education. They work to build compliance, leaving any arrests and punishment to the marine police. However, there is a risk that by giving wardens no powers of arrest, persistent offenders will feel confident to defy them. There is no right or wrong answer here, just a mix of pros and cons that must be resolved for every individual case.

Even without powers of arrest, organizations managing reserves play a vital role in encouraging compliance. Regular patrols provide a presence on the water that makes reserve boundaries tangible, and educating users helps build up support. Jim Bohnsack, a long-time advocate of reserves and scientist with the National Marine Fisheries Service in the USA, believes there are three phases in the management of reserves. Initially it is necessary to have a strong presence in the field, and a large amount of effort must be invested in education and enforcement. Early on people have to become familiar with boundaries, change habitual patterns of use and find new fishing sites. There will be little incentive to poach since resources inside the reserve will not have had much time to build up. After five or so years of protection and community education, fishers will begin to feel the benefits of reserves, and will have developed a sense of ownership through their own self-restraint. At this point, reserves may be virtually self-enforcing with peer pressure keeping people from fishing in them. However, in the third phase, after reserve populations have reached very high levels, the rewards from poaching could become worth the risk of detection. This is particularly likely in places where fish populations outside reserves are intensively exploited. In this phase it becomes necessary to step up surveillance, especially at night, and to impose stiff penalties on violators. Based on our experience of parks throughout the world, we have two comments on how marine park managers can improve the success of their surveillance. This first is to patrol at night (even if only sporadically), and the second is to vary patrol times.

Remarkably few parks employ these simple measures, believing they have good compliance when in fact fishers are actually simply avoiding reserves during patrols. Good fishers have no compunction about fishing at night, while most park patrols are strictly daytime activities!

Coastal reserves can be patrolled by small, shore-based boats and so are relatively straightforward to enforce. However, people often raise objections about the cost of patrolling offshore, or particularly large reserves. In these situations modern technology can facilitate reasonably low cost policing. In the north-eastern USA, the large offshore reserves on George's Bank were enforced by fitting satellite transponders to every boat in the fishery. These devices constantly relay the position of vessels to a land-based monitoring unit and so violations can be tracked remotely. Further refinements in technology could allow these devices to report when fishing gear is deployed. Satellite trackers are still unpopular with fishers, but the need for increased regulation over use of the seas makes their widespread use just a matter of time. Satellite monitoring makes offshore reserves a realistic proposition.

Hydrophone technology is also being developed to allow remote surveillance. Here an array of hydrophones are established to cover the reserve area and they are connected to a shore-based station that monitors boat traffic. Signals from the hydrophones can be used to identify characteristic noise signatures from boats. Hence unknown vessels can be detected in reserves and patrol boats sent out to check on their activities. This technology is being deployed in the Tubbataha Marine Park, a remote offshore reserve in the Philippines, and should prove useful in many other parts of the world. Such systems are relatively inexpensive and can help reduce the cost of patrolling.

Key points:

- Benefits from reserves depend closely on the efficacy of protection.
- The more users respect reserves, the more successful reserves will be. Education and community involvement help build support.
- Protection is achieved through a combination of compliance and enforcement. In their early stages, reserves are likely to need strong enforcement. After a time, communities may start to police reserves themselves and compliance will grow. Long-established reserves may once again need strong enforcement since the potential gains from poaching may be considerable.
- Modern technology offers growing opportunities for remote surveillance at reasonable cost.

27. How can reserves be financed?

Establishing and running reserves is expensive and few will be successful unless properly financed. McClanahan (1999) argued that most of the world's existing marine reserves are failing to achieve their objectives simply because there isn't enough money to manage them properly. Three key stages are involved. (1) Initial consultations and lobbying for reserves. This may be relatively inexpensive, but will depend very much on the local situation. (2) Start-up costs. These are typically high because consultations need to be held, site visits made, meetings organized, people hired, capital equipment purchased etc. (3) Running costs. Typically these are lower, but tend to be hardest to find. It is this stage that usually makes or breaks a reserve.

Sources of start-up funds depend on the objectives for reserves. For example, if a reserve is intended primarily as a fishery management tool then money should probably come from the government department responsible for fisheries. However, reserves are often set up with multiple objectives in mind, and fishery management agencies are often seriously underfunded. Management is also quite likely to be inadequate if left in the hands of fishery managers, since they usually lack the experience, the remit or even the will to take care of reserves (see Section 25). It is usually necessary to seek outside sources of support to get reserve proposals afloat. Conservation organizations, foundations with interests in the sea, philanthropists or development banks can often provide core support for establishment costs. They are most likely to help if there is clear evidence of the need for conservation, and a demonstration of at least some local interest, as well as governmental support for proposals. To do this there is generally an initial period of struggle - the wilderness years - with few resources but much enthusiasm and commitment among local individuals or organizations. The longer and harder people work, the more likely their proposals are to become reality. Don't be put off if your first attempts do not succeed. Many reserves have only been created after decades of effort working to gain support.

Although conservation organizations and foundations can be generous, their funding is temporary and reserves are vulnerable to loss of funding. Securing adequate

Bonaire Marine Park surrounds the entire island of Bonaire in the southern Caribbean. It became one of the first self-financing marine parks in the world through the introduction of user fees levied on visiting scuba divers. These fees are collected by diving centres and paid directly to the marine park, which operates as a non-governmental organization.

recurrent funding to cover operating costs is critical to long-term success. In the Caribbean, parks surrounding the islands of Bonaire and Saba in the Netherlands Antilles, became some of the first self-funding marine reserves in the world. The bulk of their funds now come from user fees levied on visiting scuba divers, snorkelers and yachts. Those are supplemented by sales of souvenirs from park shops, and 'friendship' organizations formed to channel support to the parks from concerned individuals (usually past visitors). The parks also continue to attract some grant support for monitoring and new initiatives, such as installation of moorings or extending protection to nearby areas.

Tourists represent an excellent source of income. Stephen Colwell, of the American NGO Coral Reef Alliance, noted in 1995 that scuba divers tend to have large incomes, took an average of one and a quarter dive trips per year, lasting an average of eight days, and spent over US$3,000 per trip. There are over eight million scuba divers in the world's industrialized countries and a further 600,000 or more are certified each year. They are constantly on the look out for high quality diving destinations. The mere act of designating a site as a reserve increases its attraction for divers, and the protection offered will pay further dividends over time as animal populations build up.

Several surveys have looked at the willingness of tourists to pay for resource protection, and many have looked specifically at scuba divers. They show that divers are willing to pay significant sums to protect marine habitats, of the order of US$20 - 30 per trip. Experience in the Caribbean suggests that while there is a considerable willingness to pay, there is less willingness to charge! Tourist operators tend to be reluctant to charge extra, feeling that it will undermine their competitive edge. This is short-sighted, since the competitive edge would be much greater with effective resource protection. In most cases, such as in Bonaire, their reluctance has been overcome by close collaboration with the park in deciding how user fees are to be spent.

Surveys also revealed that an important factor affecting willingness to pay was where the money would go. In all cases, tourists were willing to pay higher user fees if they knew that their money would go directly towards running the reserves instead of via the government. People don't trust governments to return money to marine parks. Given this attitude, and the success of NGOs in running reserves, it makes sense to create an independent management body with powers to collect revenue directly. Furthermore, if fees or taxes are collected by governments, international banks may put pressure on them not to earmark funds for conservation but to plough them into loan repayments. Thus, governments also have an incentive to establish partner organizations with powers to collect fees.

Protected areas may also be funded through environmental trust funds. They may be established with donations or loans from international development organizations, in debt-for-nature swaps, or through taxation. Such trusts are very useful in generating core funding of operating costs, and will usually complement other sources of revenue, such as user fees. In Egypt's South Sinai, a large area of coast lies within the Ras Mohammed Marine Park. However, only a relatively small percentage of tourists (roughly 1 in 5) visit places where user fees are charged directly. The rest benefit from the activities of the park and they should also contribute to the running of the park. Egypt has introduced an "Environmental Cost Recovery Charge" on all visitors that is levied by hotels for every night they stay. These fees are collected by the Environmental Affairs Agency direct from hotels and placed into the Agency's Environmental Fund that is overseen by a board of trustees. Such environmental taxes provide a very useful instrument for collecting revenue for environmental management of broad regions, even where tourist use is focused on localized 'honeypot' sites.

Some reserves will not be able to support themselves from tourism. In these cases, funding may be partly obtained from government sources, especially where a reserve clearly contributes towards a country's commitments to conserve biodiversity. Some reserves will have to rely heavily on government support. Offshore reserves, for example, will probably always require funding from government sources. Alternatively, they might be supported through redistribution of revenue from reserves adjacent to the coast, where this is sufficient. It is critical that financing mechanisms are clearly worked out in reserve proposals and management plans. Sustainable funding is essential for success.

Key points:

- One of the most common causes for failure of marine protected areas is a lack of resources to implement protection.
- Start up costs for reserves can often be obtained through co-financing between government and private sources.
- User fees, environmental taxes on tourists, or environmental trust funds can help to provide long-term sustainable income to cover running costs.
- There is no single formula that can be applied everywhere and funding mechanisms must be developed that are appropriate for each reserve. Variety and ingenuity are the keys!

Further reading: Hooten & Hatziolos 1995; Dixon et al. 1993.

28. Conclusions

The sea was once considered a vast and seemingly endless resource to be used freely by all. But human impacts on the oceans are growing faster than ever and we must now move rapidly to protect them or risk losing precious assets. Marine protected areas provide the most powerful tool but they currently cover a trivial fraction of the sea, and the majority that do exist are poorly managed. Most people think that pollution is the greatest threat to marine ecosystems, whereas the most dramatic agent of change is fishing. Fishing has transformed the seas. We have become victims of our own success in exploiting marine life. Technology allows us to fish virtually everywhere up to depths of more than a kilometre deep. In this new millennium, the only refuges for marine life will be those we deliberately create.

Protecting areas of the sea from fishing has shown dramatic benefits, leading to swift and spectacular increases in abundance, biomass and average size of exploited species. Reserves create mosaics of conditions that favour those species most affected by fishing, and so help sustain biological diversity and ecosystem functioning. Reserves are most valuable and their performance is greatest if they are fully protected from fishing, and other extractive or harmful uses. Ideally every marine protected area should have at least one zone that is afforded full protection. However, anywhere that offers protection against some harmful activities will have value in a network of reserves that includes a large element of full protection elsewhere. Furthermore, reserve networks are most effective when supplemented by other forms of management.

Pilot-scale reserves have been remarkably effective but they are not sufficient. The combined effects of reserves are proportional to the total area protected. A significant proportion of the seas need to be closed to fishing to support fisheries, safeguard biodiversity and secure ecosystem functioning. Present research suggests that benefits to fisheries will be maximized with protection of between one to two fifths of the sea. Such a proportion would also confer great conservation benefits. While the amount we should protect is still being actively debated, what is in no doubt is that we need a great deal more protection than we currently have. It will take time to achieve this and fishers need not be concerned by the large figures being discussed. Reserve networks will be built gradually, starting with small areas protected. If reserves perform as they are expected to, fishers will be among the first to benefit and are likely to become enthusiastic advocates for expanded protection.

Reserves will be most effective when established in networks, and those networks will perform best when reserves are sufficiently close for protected populations to interact. Isolated reserves have shown many benefits, but populations within them will depend, to varying degrees, on species persisting in unprotected areas. Networks increase the likelihood that species will persist and fisheries will be sustained over the long-term. Practical experience suggests that precise reserve placement is probably not critical, especially if reserves are networked with others. However, simple rules-of-thumb can be applied in choosing places where reserves are likely to work well. Given that it will take time to build reserve networks, there will be greater fishery and conservation benefits if the first sites protected are biologically better than average. However, the best areas are often the most controversial, since they are usually heavily used by people. If your top candidate site gets mired in controversy, it could be more sensible to opt for an alternative, biologically-adequate site that can be implemented more quickly at less cost. Creation of a functioning reserve often reduces opposition and may make it easier to protect other sites nearby.

Reserves can and should be designed to simultaneously fulfil multiple objectives. Experience has shown that individual reserves can offer many benefits, such as enhancing fisheries, protecting biodiversity, providing economic opportunities and reducing conflicts. Not all sites serve all purposes, but all sites can serve more than one. It doesn't make sense to draw the objectives of reserves too narrowly. A sectoral approach to marine management is bound to fail, as it has in places like California. Instead, we must integrate the objectives of all stakeholders in the design of reserve networks to meet their combined goals. This does not mean reserve networks have to be designed from the top down, or that local people will not have a say in where to place reserves. However, it does mean proposals for new reserves should be considered in the context of others that already exist - how will it complement and support them, and vice versa.

Successful reserves require a great deal of effort to establish followed by long-term commitment from local communities and decision makers to maintain effective protection. Time after time, experience has shown that reserves are unlikely to be successful unless there is close involvement of all stakeholders throughout the full establishment process. In the long-run, reserves stand or fall depending on their support. Sometimes it may seem expedient to establish reserves quickly and with limited consultation. However, this is likely to store up problems for the future. Full stakeholder participation does not guarantee success, but lack of it almost invariably leads to failure.

There is now ample scientific justification for implementing new reserves and reserve networks at significant scales. Reserves should be well studied, so that experience can help refine design principles and expectations for the expanded tranche of reserve establishment we are heading toward. Pilot reserves must be monitored more broadly in the future. As well as looking at trends in the abundance of exploited species, monitoring should embrace a wide array of non-target species and **ecosystem processes.** It should also include study of the fishery effects of reserves, and of human responses to reserve creation. Armed with knowledge from practical experience, we can refine the process of reserve implementation to increase the likelihood of success.

There will always be uncertainty regarding the best location and configuration for reserves and what fraction of the sea we should protect. Such uncertainty often delays implementation as people argue we should not act until we know more. However, we are surrounded by compelling evidence of what happens if we don't protect marine ecosystems. The very act of creating reserves is a means of reducing our uncertainty as to whether species, habitats and productive fisheries will survive far into this millennium.

29. Getting hold of further information

If this book has given you an appetite for more detailed information on marine reserves, we can recommend several good sources. It is important to use up-to-date information since the evidence for marine reserve effects is growing so rapidly. Thus, while the information presented in earlier studies on the effects of reserves is reliable, the strength of the arguments for use of reserves was less compelling than it is today.

This book will be available to download from the world wide web from a site accessible through www.panda.org.endangeredseas/. We plan to periodically update the contents of the web version of the book, adding new sections and case studies. Other materials on marine reserves will also be available from the site.

The U.S. National Research Council Committee on Marine Protected Areas has published a report on marine protected areas. Copies can be obtained by writing to: National Academy Press, 2101 Constitution Avenue, NW, Washington, DC 20418, USA. www.nap.edu/books/0309072867/html/

The Marine Reserves Working Group of the U.S. National Center for Ecological Analysis and Synthesis has been making significant advances in developing the theory that underpins the design and establishment of reserves. They will publish many of their findings in a special issue of the journal *Ecological Applications* in 2001. Further details of the project and its publications can be obtained by logging on to www.nceas.ucsb.edu and following the links to project "Developing the theory of marine reserves" which is listed under "Jane Lubchenco, Stephen Palumbi and Stephen Gaines".

There is also a collection of excellent papers on marine reserves and their effects in an issue of the *Bulletin of Marine Science*, to be published in mid-2000. These papers originate from the Mote symposium on "Essential Fish Habitat and Marine Reserves" held in Sarasota, Florida in late 1998.

The Natural Resources Defense Council have published a booklet titled "Keeping Oceans Wild – How Marine Reserves Protect Our Living Seas". This features success stories, especially from the USA. It is available from www.nrdc.org.

There are a number of recent overview papers and books on marine reserves that offer an excellent place to get started in learning more. They include:

Agardy, M. T. 1997. Marine protected areas and ocean conservation. Academic Press, San Diego, California.

Allison, G. W., J. Lubchenco and M. H. Carr. 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecological Applications 8(Supplement): S79-S92.

Bohnsack, J. A. 1996. Maintenance and recovery of reef fishery productivity. Pages 283-313 in N. V. C. Polunin and C. M. Roberts, editors. Reef Fisheries. Chapman & Hall, London, UK.

Kelleher, G. and R. Kenchington. 1992. Guidelines for Establishing Marine Protected Areas. A Marine Conservation and Development Report. IUCN, Gland, Switzerland. Available to download from the web on: www.iucn.org/cgi-bin/byteserver.pl/themes/marine/pdf/guidelns.pdf.

Murray, S. N. et al. 1999. No-take reserve networks: sustaining fishery populations and marine ecosystems. Fisheries 24(11): 11-25.

Roberts, C. M. 1997a. Ecological advice for the global fisheries crisis. Trends in Ecology and Evolution 12: 35-38.

MPA News is an excellent newsletter on marine protected areas that is published by the University of Washington School of Marine Affairs in Saettle, Washington, USA. It is full of comment and thoughtful advice on all aspects of marine protected areas. It is available on the web at www.mpanews.org. Subscribe by emailing mpanews@u.washington.edu with ‘subscribe’ in the subject line of the message, and your name, mailing address and telephone number in the body of the message.

We will be happy to provide readers with copies of any of the papers referred to in this book that we have written or co-authored. They can be obtained by sending a request to Julie Hawkins, Environment Department, University of York, York, YO10 5DD, UK. email: cr10@york.ac.uk; Fax: +44 1904 432998.

A. Saba Marine Park, Netherlands Antilles

No-take restrictions protect tourism asset

The volcanic island of Saba lies in the eastern Caribbean and rises precipitously to 900m. It covers only 11km^2 and has a low population of approximately 1,800 residents. Both factors are significant in enabling Saba to have a marine park which surrounds the entire island and a no-take fishing zone which is almost 100% effective! The marine park is operated by a non-governmental organization and has the distinction of being the world's first self-funding marine park. Plans for the park began in 1984 in response to the island government's request for help in managing its marine resources. It took just under three years to develop a fully zoned management plan and raise funds to establish the park. During that time there was intense consultation with the island's fishers to alleviate their concerns about why the park was being set up and how it would affect them. By the time the park was opened it had gained almost universal support and that popularity has never faltered. What is it that has made the Saba Marine Park so successful?

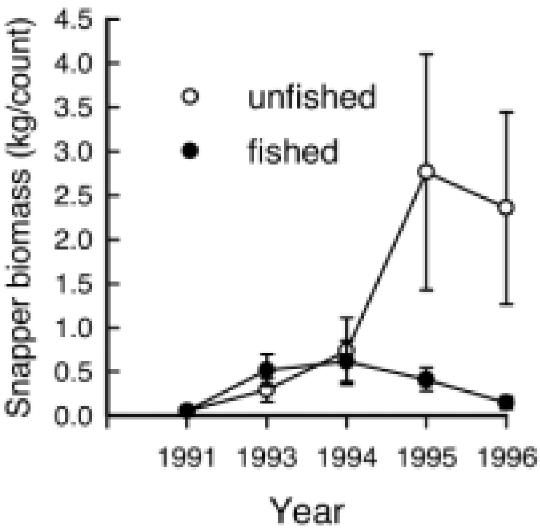


***Figure 17:* There was a steep initial increase in biomass of snappers in the fully-protected zones of the Saba Marine Park following protection, followed by a leveling off (perhaps a consequence of several major storms that passed nearby in 1995). Even though the reefs of Saba are only lightly fished, the fully-protected zones offer important protection to the most vulnerable species, like snappers. Roberts and Hawkins, unpublished data.**

The principal objective of the marine park was to maintain a healthy marine environment to attract tourists and boost the island's economy. Right from the start local people wanted to follow the route of ecotourism, where tourists would benefit the island but not begin to take it over or degrade the environment. In Saba these ideals of ecotourism have been realized. Some of the key reasons are that the island has no real sandy beaches and no access for cruise ship tourism. People visit Saba to dive or hike and because the landscapes both below and above water are so spectacular they are prepared to pay a high price to do so. The mass tourism that miles of white sand beaches tend to attract has not been a significant problem and there has been little pressure for greater development on the island. In fact, most locals feel they are doing pretty well with things as they are and don't need too much change in their lives. This sort of attitude is all part of the charm and appeal of Saba.

The island's fishers have a similar attitude towards catching fish. Although there are several commercial boats, modern intensive fishing has never developed on the island. In fact, for some time before the marine park was established, fishing had become a predominantly part-time activity. Most of it is for open water fish caught by trolling with hook and line, well offshore of the coral reefs. Nowadays there is very little net or trap fishing, although in former times the Sabans relied heavily on these methods. Today reef species are mostly targeted by a small number of spearfishers. Only locals are allowed to do this and they must dive using a snorkel. No-one is allowed to do any type of fishing in the no-take area (although, initially, fishing from the shore with hook and line was permitted, few used the opportunity). Hence, because fishing pressure in Saba was low when the marine park was established the primary objective was to protect tourism assets rather than offer a means of salvation for fishers. Nevertheless, no-take zones were an integral part of the management plan. They were set up to enhance the numbers and size of fish on the reefs, primarily for the benefit of divers. Any advantages to the fishers would be an additional bonus.

The relationship between divers and the marine park is mutually beneficial. The park provides mooring buoys for dive boats and protects the underwater environment which the divers have come to enjoy. It provides regular slide shows at hotels and on live-aboard boats to tell people about the park and how they should behave to conserve the reefs. Meanwhile divers help fund the park through user fees which are automatically added to their dive costs and collected for the park by the diving centres. Other money for the park comes from yacht mooring fees and a "Friends of Saba Marine Park" foundation which is supported by past visitors to the island. Park wardens make daily patrols to collect mooring fees from yachts and enforce no-take regulations. Very few violations have ever been committed by locals over the park's entire history.

Saba is a tiny island but is much loved by tourists seeking out beautiful natural environments above and below water.

Fish and coral communities at 14 sites within the marine park have been regularly monitored since 1991. Even though the fishing pressure on Saba was, and has remained light since then, there has been a rapid build up of fish biomass inside no-take zones. This rise has been most striking in two families which are particularly vulnerable to over-fishing, the snappers and groupers. Figure 17 reveals an exponential increase in the biomass of snappers following protection, although numbers fell slightly in 1996, probably as a result of three hurricanes which passed by the island between the 1995 and 1996 surveys. A second effect on the fish communities has been an increase in biodiversity in both no-take and fishing areas, due to increases in the abundances of fish throughout the whole marine park. Tourism development on Saba has led to an easing of fishing pressure in areas outside the no-take zones too.

Results from monitoring of coral communities show that, despite a 42% increase in the number of dives made in the park between 1988 and 1994 coral cover in the park held steady, unlike many parts of the Caribbean where it declined during this period. Furthermore overall levels of diver damage appear to be declining. This suggests that the marine park's efforts at diver education and the practice of all boats having to use mooring buoys rather than drop anchors is promoting reef conservation. However, one serious problem on Saba that threatens some of the near shore reefs, is sedimentation. Over-grazing by goats is causing high levels of sediment run-off throughout the island, while dust released from a rock crushing plant was causing localized damage to reefs nearby (until the plant closed following a hurricane in 1999). Unfortunately, the marine park's jurisdiction ends at the high water line and as yet it has been unable to properly address land-based problems. Ultimately, the success of the park will depend on controlling land-based activities as well as those in the sea.

Key lessons:

- Reserves run by NGOs can be highly successful.
- Income from tourists can provide much of the running costs for a marine park.
- Zoning of activities has minimized conflict and promoted a healthy marine environment.
- It is important to link management of the land and sea.

References: Roberts, C.M. and J.P. Hawkins, unpublished data; van't Hof 1991; Polunin & Roberts 1993; Web site: www.sabapark.com/

B. Hol Chan Marine Reserve, Belize

Success of pilot reserve stimulates development of a national reserve network

The Hol Chan Marine Reserve is situated approximately 4km south of San Pedro, a small but prosperous tourist town on Ambergris Caye, an island in the northern section of Belize's barrier reef. It was established in 1987 in response to a growing concern for the area's marine environment. Overfishing had seriously depleted valuable conch and lobster fisheries, and caused the disappearance of several species of large, easily caught fish. Mangroves were being cleared for development and increasing numbers of tourists were starting to have visible impacts on the reef, for example by breaking corals and collecting marine curios.

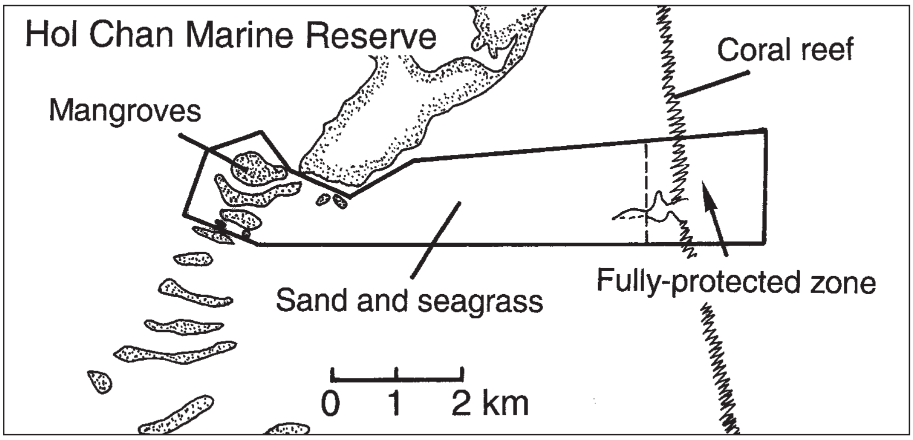


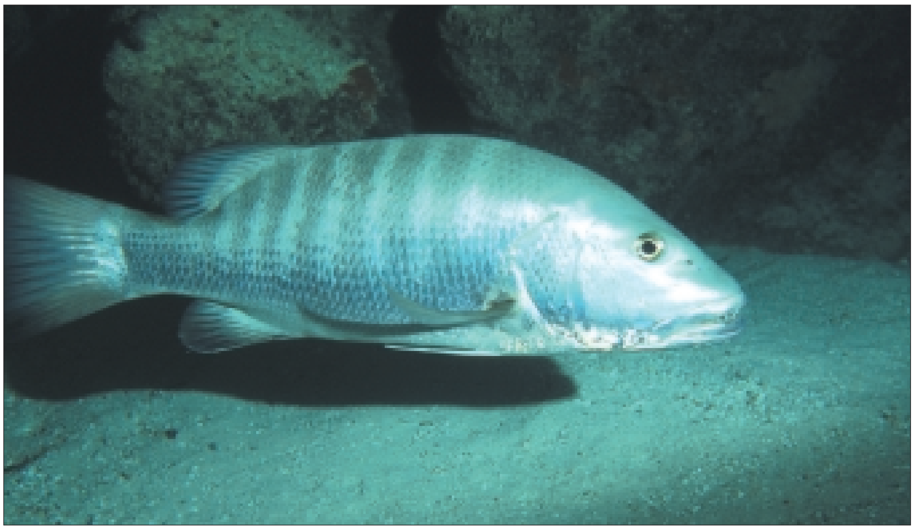
***Figure 18:* The Hol Chan Marine Reserve was one of the first in Belize to benefit from a fully-protected zone. However, only the coral reef and a small area of seagrass are encompassed by the fully-protected zone. The extensive mangroves, sand flats and seagrass beds in the remainder of the reserve receive less protection.**

The marine reserve was set up to encompass coral reef, seagrass and mangrove habitats and was zoned for different uses (Figure 18). Fishing activities are restricted throughout the reserve, but only banned in Zone A, a small fully-protected area of 2.6km^2. The fully-protected zone is centred around a channel that connects the lagoon with the outer reef. Even before it was protected, this channel was an excellent place for fish and because of this had become a key attraction for tourists. Although the channel was also a good spot for fishing it was felt to be more valuable as a tourist asset, and deserving of full protection.

'Walls' of fish can now be found inside the fully-protected zone. In the channel itself, fish schools are so dense that they literally obscure the reef. Build-up of fish biomass was exceptionally fast, partly due to immigration of large animals like groupers to the site. Four years after protection began the total biomass of commercially important, reef-associated fish was 50% greater at the edges of the fully-protected zone than in surrounding fished areas. In the central channel it was six to ten times higher! On average, 25% of reef fish species had significantly higher abundance, size or biomass in the fully-protected zone. Several species once favoured by fishermen were not present in fishing grounds but were found in the fully-protected zone. They included the gray snapper *(Lutjanus griseus),* black margate *(Anisotremus surinamensis),* and saucereye porgy *(Calamus calamus).* All but one commercially important species of fish was bigger in the fully-protected zone than in fishing grounds.

Densities of conch and lobster are also higher inside the fully-protected zone. For these species in particular, people 'fish the line'. That is, they fish close to reserve boundaries to get better catches. Spillover occurs when individuals from more closely packed populations in the reserve emigrate into the less densely-packed fishing grounds.

The Hol Chan marine reserve has overall been a great success. In addition to protecting marine life, it now attracts over 35,000 visitors a year. Many local people have given up fishing to take tourists snorkeling and scuba diving and this has further reduced pressure on reef fisheries. However, it has increased the need to protect the reef from tourists. Because the reserve is small there are problems caused by overcrowding and too many boats in the water. Damage is especially noticeable in the Hol Chan channel which is the most popular place of all. Here many corals have been broken and abraded by tourists. It is thought that a localized outbreak of black band disease, which occurred in the reserve in the early 1990s, might have been due to corals damaged by tourists becoming more susceptible to infection.



A large cubera snapper* (Lutjanus cyanopterus) *in the central part of the Hol Chan Marine Reserve, in Belize.

Efforts are now being made to educate tourists on how not to damage the reef, and several other reserves with fully-protected zones have been established to help divert tourist pressure away from Hol Chan. This is important because tiny fully-protected zones, within larger marine reserves where fishing is allowed, still mean that the greater part of the sea is essentially unprotected. A national network of fully-protected areas that is currently being developed in Belize should provide widespread benefits of the sort that the Hol Chan reserve has already achieved.

Key lessons:

- Recovery of fish and invertebrate communities from over-fishing can be extremely rapid where areas of high quality habitat are made into fully-protected reserves.
- Fully-protected zones can swiftly become tourism assets. This provides lucrative opportunities for fishers to cater for tourists.
- If fully-protected zones are very small, they may become overused by tourists, leading to habitat damage.
- It is important to have fully-protected zones representing all the different habitats included within marine reserves.

References: Polunin & Roberts 1993; Roberts & Polunin 1993b, 1994; Carter & Sedberry 1997.

C. Edmonds Underwater Park, Washington State, USA

Artificial habitats and voluntary protection have spectacular effects on marine life

The Edmonds Underwater Park hugs a small section of the shore in Puget Sound near Seattle on the west coast of the USA. It covers just 6.8 hectares of seabed and 3.3 hectares of intertidal, and on one side is bounded by a ferry terminal. The park was established in 1970 to provide a safe, high quality site for recreational scuba diving. When first established it covered only 75m of shoreline to the north of the ferry terminal, but in 1998 the boundary was extended northwards so the park now encompasses 550m of shore.

The Edmonds Underwater Park is remarkable in many ways. It is one of the longest-standing no-take marine reserves in the world. The site was first designated under a City of Edmonds local law that prohibited removal of any marine life from the park. Remarkably, that law was never enforced by the City. Instead, protection has been maintained voluntarily, and has become self-enforcing over time. A group of volunteer Park Stewards, have provided the first line of protection, and through their efforts, people have developed a protection ethic for the site. Compliance with no fishing regulations is maintained through peer pressure, even as fish stocks have built up over time. Locals simply feel it would be anti-social to catch fish in the reserve. Recognizing the park's success, protection has recently been reinforced by passage of a state law to back up the city's no-fishing regulations.

Perhaps most surprising of all, the Edmonds Underwater Park consists almost entirely of artificial 'habitat'. The site was originally a dry dock that eventually fell into disrepair and began to attract divers. It was this dock that formed the kernel of the original, smaller area of the park. However, from 1972 onwards, additional features (human junk!) have been added and trails established to connect them. The 'habitat' now consists of all kinds of debris strewn accross the sandy bottom, from the ruins of an old mill to vehicles, sunken boats and cable. Despite this, the park

The Edmonds Underwater Park is intensively used for recreation. Although it is near the city of Seattle in Puget Sound, abuts a busy ferry terminal, and the 'habitat' within it consists mainly of human junk, the reserve supports spectacular populations of fish not seen in unprotected parts of the Sound.

sustains much greater densities of rockfish and lingcod than fished habitats in Puget Sound. For example, after 25 years of protection, Palsson and Pacunski (1995) estimated that densities of copper rockfish *(Sebastes caurinus)* ranged between 9 and 25 times greater in the park than at fished sites. Average sizes of these fish are also higher in the park. Such differences are revealing. They show just how great the impact of fishing has been on populations of exploited fish in Puget Sound. The scale of those impacts is brought into sharp relief by the fact that artificial habitats close to areas of extensive boat traffic and coastal development have outshone natural habitats. A park consisting of artificial habitats can hardly be considered an accurate baseline against which to measure human impacts on the sea. Populations on undisturbed natural habitats might reach even greater levels.

The greater abundance and size of fish in the park provide a boost to their reproductive output. Palsson and Pacunski (1995) calculated that lingcod *(Ophiodon elongatus)* in the reserve produced 20 times more offspring than those in fished populations, while copper rockfish produced 100 times more. Such differences are striking and, even though the park is small, they are regionally significant. This tiny scrap of protected area produce as many young copper rockfish as 50km of fished shoreline in Puget Sound! There is also tantalizing evidence for a local effect of recruitment enhancement in adjacent fishing grounds by the reserve. A survey by Ray Buckley found that recruitment of these species was much greater in areas to the north and south of the underwater park than at other sites examined in the Sound. Either, habitats nearby are forming a sink for recruitment, or perhaps more likely, they are benefitting from reproduction by fish in the park.

Edmonds Underwater Park has proven far more valuable than just a means of keeping scuba divers happy. Scientists have used the opportunity to study the effects of protection from fishing, and their findings provide a deeper understanding of human impacts on the sea and how marine reserves can help reverse them. Although the park is tiny, its spectacular underwater life now attracts some 40,000 visitors a year. Despite such high levels of use, the artificiality of its habitats, its close proximity to Seattle and the adjacent ferry terminal, the reserve works well! It gives us a much needed insight into what could be achieved if protection were offered to larger areas containing more natural habitat.

Key lessons:

- Reserves can work without statutory law enforcement if there is strong community support and education.
- Reserves that are protected from fishing can work well in unpromising places.
- Pilot reserves can teach us much about the extent of human impact on the marine environment.

References: Palsson & Pacunski 1995; Murray 1998.

D. Soufrière Marine Management Area, St. Lucia

Participatory management leads to rapid benefits from no-take reserve network

The Caribbean island of St. Lucia is renowned as a tropical paradise and the town of Soufrière, with its seven thousand inhabitants, lies in a prime location on the south-west coast. Its magnificent coastal scenery, sandy beaches and beautiful coral reefs attract thousands of tourists every year. However, in contrast to the growing prosperity of the tourism industry, life for the fishers of Soufrière was becoming increasingly difficult. Decades of population growth had led to intensifying fishing effort and dwindling catches. By the mid-1980s, a fisher might have to work all day to secure a handful of undersized fish that would have been dumped over the side twenty years before.

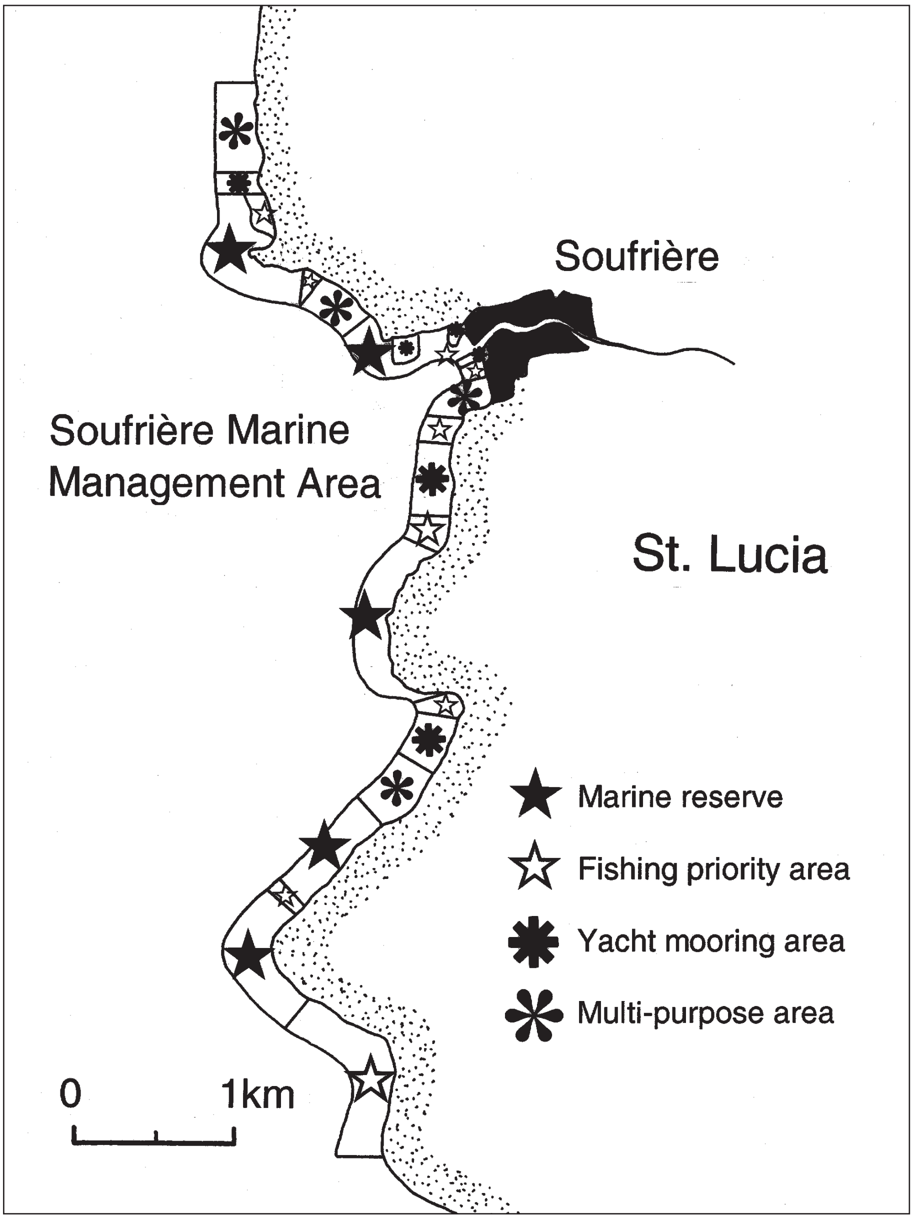


Figure 19. ***Zonation map of the Soufrière Marine Management Area, St. Lucia.***

Around this time, the St. Lucian government moved to establish a country-wide system of 19 marine reserves to protect marine habitats from impacts such as overfishing. However they failed to properly consult the fishers over their plans or to adequately fund this initiative. Unsurprisingly, this first scheme was doomed to failure and the reserves were ignored.

View across the bay of Soufrière and the Pitons in St. Lucia. This area forms the centre of the 11km long Soufrière Marine Management Area.

By the early 1990s, life had become even worse for the fishers of Soufrière. Their catches were still declining and they felt their attempts to fish were being hindered by an ever increasing number of tourists. Seine fishers complained that yachts were getting in the way of them hauling their nets, while trap fishers accused divers of deliberately damaging their gear. The time was ripe for change and, seizing the opportunity, the Department of Fisheries spearheaded a process of participatory community management for the seas around Soufrière. All local stakeholders including fishers, diving operators, hoteliers and representatives of the yachting community, were brought together to air their views and work out their problems. After three years of effort, the end result was a comprehensively zoned management plan for 11km of Soufrière's coastline: the Soufrière Marine Management Area (SMMA).

The management plan for the SMMA was implemented in 1995 and has two key objectives: (1) to rebuild fish stocks and restore fishery productivity, and (2) to separate conflicting activities. At the heart of this plan is a series of four no-take zones interspersed between fishing areas (Figure 19). The reserves cover roughly

35% of the area of coral reef habitat in the SMMA. By promoting the build up of fish stocks, the reserves were expected to contribute to fisheries, create a spectacular attraction for divers, and reduce conflict by separating tourism from fishing. People are still allowed to dive and fish outside marine reserves in 'multiple use areas' but fishers also have their own 'fishing priority areas', where they are the primary users. For yachters there are three designated areas for mooring, equipped with mooring buoys.

Healthy populations of herbivorous fish, like this stoplight parrotfish **(Sparisoma viride),** ***in Soufrière's fully-protected zones help prevent algae from overgrowing the reef.***

To be successful, measures such as these require a combination of strong management and community support. The SMMA is a non-governmental organization responsible for enforcing the management plan. It has a staff of seven people including four park wardens who make daily patrols by boat. Part of the running costs of the SMMA come from user fees paid by divers and yachters. Anyone found violating the no-fishing regulations can be fined or have their gear confiscated. In practice, continuous education and positive reinforcement have proved far more effective than punishment for maintaining no-take zones. However, not everything worked to plan. The trap fishers, who were formerly the main users of the no-take zones, felt they had not been properly represented in the negotiations leading to establishment of the SMMA. Some continued to fish in these zones, putting the whole system in jeopardy. In the end, a compromise was reached which allowed a few of the oldest fishers, people who had no alternative employment opportunities, to fish in part of one of the no-take zones. In addition, they were given one year's compensation of US$150 per month not to fish in the no-take zones. This helped tide them over the difficult period where they had lost fishing grounds but stocks in reserves had not yet built up sufficiently to improve catches in fishing areas. The compensation was very popular and eliminated almost all illegal fishing.

One of the most important factors in maintaining support for no-take zones has been to keep fishers and other stakeholders informed about how they are performing. Results of annual surveys of fish and corals collected by a team from the University of York in England show reserves are working very well indeed. After only three years of protection, the biomass of commercially important fish in no-take areas has tripled compared to what it was before the SMMA was established. Most importantly, it has doubled in adjacent fishing areas. In fact the fishermen have obviously noticed an effect from the reserves because the most popular fishing sites have begun to shift toward the boundaries of the no-take zones. Even in the no-take zone where some trap fishing was later allowed, the biomass was still higher than in sites with no protection. This is an important finding since it shows that even partial protection can still produce some benefits.

The increase in biomass has also been reflected in more bigger fish within protected areas, and no-take zones are becoming increasingly popular with divers and snorkelers. Protection from fishing has also benefited biodiversity, with a 20% increase throughout the entire management area in the number of fish species observed per count in annual censuses. This is a result of increased fish abundance, not the return of species that had been eliminated by fishing. Soufrière still lacks the large groupers and snappers that are common on unfished reefs elsewhere in the Caribbean. Hopefully they will eventually return if adequate protection is maintained.

One of the most immediate successes of Soufrière's management plan has been the reduced conflict between tourists and fishers. After all the long negotiations between the different users, a mutual respect for each other's territory has now been established. In fact, many people now have interests in both fishing and tourism as more fishers take advantage of the economic opportunities offered by tourism. Some turn their hands to construction and fish only part time while others turned their boats into water taxis and gave up fishing as a livelihood. However, fishing is in the blood in St. Lucia and many a tourist is kept waiting while their water taxi driver helps friends haul in a seine net in exchange for a small share of the catch!

Key lessons:

- Community participation is vital if no-take zones are to be effective. It is essential at the outset of the management plan to identify and include all the different stakeholders.
- If no-take zones cover a sufficiently large proportion of the area, are interspersed with fishing areas, and there is good compliance with no-take regulations, the benefits of marine reserves can build up very rapidly.

References: George 1996; Roberts, C.M. & J.P. Hawkins, unpublished data.
Web site: www.smma.org.lc/

E. Anse Chastanet, St. Lucia

Even tiny reserves can provide benefits if well protected

In the mid 1980s, the government of St. Lucia attempted to create an island-wide network of marine reserves to protect the country's coastal resources. On the whole, this proved unsuccessful due to a lack of funding and insufficient consultation with local users. More details about the initiative and its subsequent accomplishments are provided in the Soufrière Marine Management Area (SMMA) case study. Here we look in detail at one particular no-take area near the town of Soufrière on the west coast, the Anse Chastanet Reserve. This reserve was one of those designated as part of the government's original network, and was later incorporated into the SMMA in 1995.

In the original network design, the Anse Chastanet Reserve encompassed 12 hectares, and surrounded a headland which sheltered a beach backed by the luxury Anse Chastanet Hotel. This reserve would have remained a 'paper park', like most of the others, except that in 1992 the hotel instigated protection of a small area of reef used by its guests for snorkelling and diving. This area covered only 150 x 175m (2.6 hectares) and was marked off by buoyed ropes. Although it was much smaller than the government had intended, the fact that any protection existed at all was entirely due to efforts by the hotel. The buoyed off area provided a safe haven for swimming, snorkelling and diver training and also kept the fishers out. If fishers did try to use the area they were asked to leave by hotel staff and, together with the fact that so many dive boats and water taxis operated in the area, most fishers were persuaded that it wasn't worth the trouble to fish there. Hence, by the time the Soufrière Marine Management Area was set up in 1995, there had already been a *de facto* no-take zone operating at Anse Chastanet for three years.

View over the Anse Chastanet marine reserve, which lies within the Soufrière Marine Management Area. This picture encompasses most of the area that was protected by the Anse Chastanet hotel from 1992 to 1995, prior to the implementation of the Soufrière Marine Management Area.

Despite the reserve's tiny size, benefits from cessation of fishing accumulated rapidly. By 1995, biomass of commercially important fish species was more than double that present in adjacent areas of similar habitat (Figure 20). In particular the biomass of predatory snappers (Lutjanidae), a group highly vulnerable to the effects of over-fishing, was very high there. For both predators and herbivores alike, the reason the biomass was much greater inside the reserve than out was primarily because fish in the reserve were significantly larger than those outside. The abundance of fish was only significantly greater in the reserve for two families: parrotfish (Scaridae) and snappers.

One particularly telling feature of this reserve was that even species that had the capacity to be highly mobile benefitted from protection at Anse Chastanet. Three large species, the mutton snapper *(Lutjanus analis)*, and the Spanish grunt and Black Margate *(Haemulon macrostomum and Anisotremus surinamensis)* were found nowhere else along the Soufrière coast but were present within this tiny reserve. These species are easily caught by fishers but have managed to persist with the help of only a small, well-protected no-take zone.

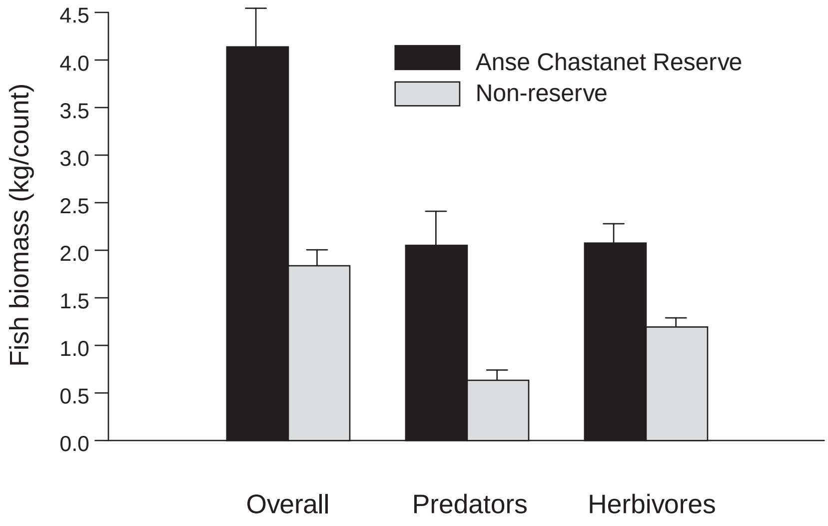


***Figure 20:* Differences in biomass of commercially important fishes between the Anse Chastanet reefs and similar adjacent fished reefs, after three years of effective protection in 1995.**

The Anse Chastanet reserve also shows the vulnerability of small protected areas. In 1996, after the full reserve system of the SMMA had been in operation for one year, the biomass of fish actually fell by 20% in the Anse Chastanet reserve. This was caused by “protest fishing” shortly after the SMMA was established and was done by those who opposed the idea of no-take zones. Some started setting their nets inside the reserve, others began fishing at night with hook and line, and one individual spear fisherman repeatedly violated the law. The protest didn’t last long and was confined to only a few fishers, but it had an impact.

By 1998 the social problems underlying opposition to the SMMA had been more or less resolved, and for nearly two years virtually full protection was re-established at the Anse Chastanet Reserve. During this time fish biomass recovered to a level higher than the peak reached in 1995 (Figure 21). Turtle Reef, a patch reef within the reserve, now supported the largest and most spectacular schools of snappers in St. Lucia. This shows that even if no-take compliance does break down, benefits can be recovered once protection is reinstated. How quickly this happens obviously depends on how bad violations were, how long they went on for and what state the fish stocks were in before the problems started. In the case of Anse Chastanet the poaching was sufficiently light and short-lived, and stocks good enough for recovery to be very rapid.

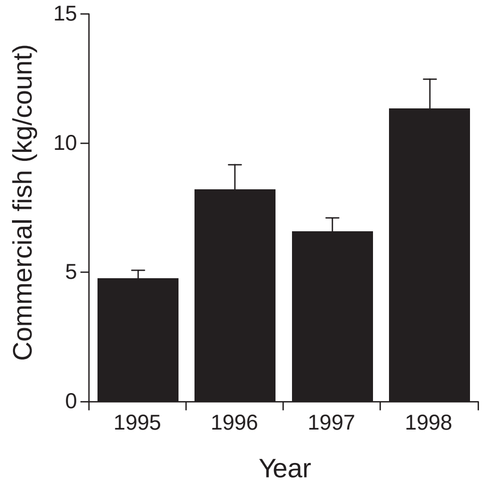


***Figure 21:* Changes in biomass of commercially important fishes inside the Anse Chastanet reserve over time. Biomass fell in the year after the creation of the Soufrière Marine Management Area due to protest fishing. However, protection was reinstated in late 1996 and has continued since then.**

Key lessons:

- Even a very small marine reserve can show rapid benefits when protected from fishing.
- Small reserves can protect surprisingly large and mobile species.
- Local initiatives, for example by hotels, can help protect marine habitats.
- Small reserves are especially vulnerable to poaching.

Reference: Roberts & Hawkins 1997. Web site: www.smma.org.lc/

F. De Hoop Marine Protected Area, South Africa

Reserve that links land and sea provides many benefits

De Hoop lies in the warm temperate zone of the Western Cape Province and is the most southerly marine reserve on the African continental shelf. It was proclaimed a marine protected area in January 1985. The reserve measures 50 km along the shore and extends three nautical miles seaward. The intertidal area comprises sandy beaches, wave-cut sandstone platforms and rocky headlands. Vast quantities of sand are continuously shifted from the land to the sea and vice versa, covering and uncovering reefs over periods varying from days to years. The sub-tidal habitat includes low profile sandstone reefs and soft sediment.

All habitats adjacent to the reserve are heavily exploited. The target fisheries include: (1) inter-tidal shellfish collection by subsistence and recreational fishers (targets at least six species), (2) beach seine fishery (targets mullet), (3) recreational shore-angling (targeting 30 species of fish), (4) squid fishery (targets spawning aggregations of *Loligo* species), (5) inshore trawl fishery (targets hake, horse mackerel, kingklip, and sole plus substantial by-catch), (6) line fishery (targets 17 fish species), (7) longline (targets hake), and (8) pelagic purse-seine (targets pilchards). The De Hoop reserve therefore provides valuable protection for over 60 directly exploited species.

De Hoop is Africa's most southerly marine protected area, encompassing rocky and sandy inter-tidal, subtidal sandstone reefs and soft-bottom environments. It is backed by an adjacent terrestrial protected area. Photograph by Colin Attwood.

For the past 14 years, scientists have studied how fish stocks in the surf zone of the reserve respond to protection and if it improves fishing in the adjacent areas. Since it is impossible to conduct dive surveys in the surf zone, abundance has been measured as catch per unit effort (CPUE). A research team also tagged and released fish to study their growth and movement patterns in relation to the reserve. There is good evidence that eight species of fish, most of them bream (Sparidae), have recovered well within De Hoop. Their CPUE was considerably greater in the protected area than in similar habitats outside (Figure 22), and the difference suggests that the total number of commercially important fish in De Hoop is at least ten times higher than in fishing grounds. Mean fish size and age is also greater in the reserve, although for some vulnerable species even small fish are uncommon in the fishing grounds. Any large fish of these species present in fishing grounds may have moved there from the reserve.

The tagging study demonstrates that fish leave De Hoop to move into fishing grounds. Some fish species show great site-fidelity but populations of others, such as galjoen *(Dichistius capensis)* and some bream, contain individuals that will migrate long distances. Other species undergo predictable migrations between spawning grounds and feeding areas. The De Hoop reserve is well placed to protect many species of juvenile fish which stay there to feed until they reach maturity. Examples among bream include white steenbras *(Lithognathus lithognathus)*, red steenbras *(Petrus rupestris)*, musselcracker *(Sparadon durbanensis)* and poenskop *(Cymatoceps nasutus)*. South Africa has over 40 species of bream, most of them endemic, and several such as the white steenbras are seriously over-exploited. Fully-protected marine reserves are vital to protect the diversity of this particular family.

In a comparison of the reef topography, sea bed and fish communities of De Hoop with an unprotected area over a period of 8 years, it emerged that protection from fishing was more important in determining fish abundance, than any other biological, geological or physical factor studied.

To help fishers appreciate how well marine reserves can function, 'guest' anglers have been taken out on field surveys, to see for themselves how effective protection can be. This has had enormous impact, causing them to change their attitudes and become supportive of marine protected areas.

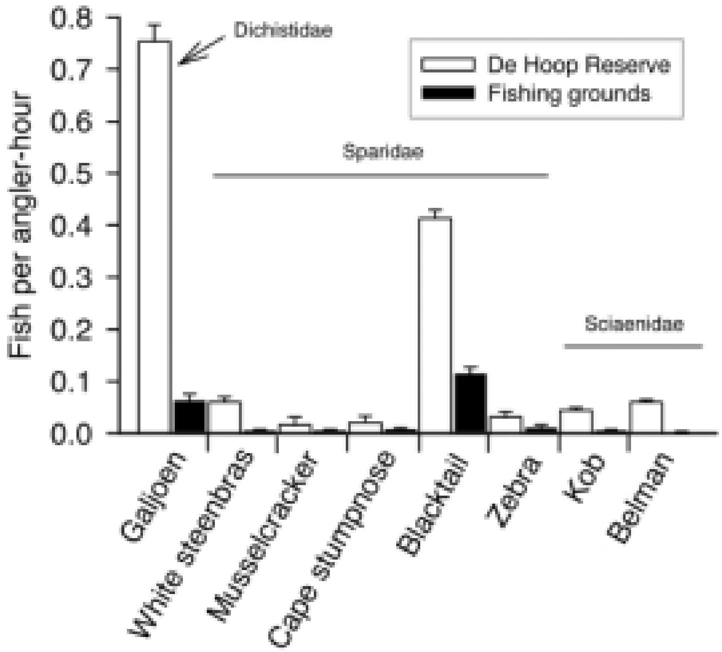


Figure 22: ***Catch per unit of fishing effort, a measure of fish abundance, of eight fish species was considerably greater in the De Hoop Marine Reserve than in similar habitats nearby that remained open to fishing. The samples were collected over a period spanning between 8 and 13 years of protection in the reserve. Samples inside the reserve were from experimental fishing by researchers, while those in unprotected areas came from analysis of recreational anglers catches. Colin Attwood, unpublished data; reproduced with permission.***

The De Hoop reserve also helps mitigate other problems threatening the coast. For example it is a monitoring site for plastic litter that is increasing throughout the region, and which mainly originates from fishing and shipping industries. It provides a buffer against coastal development which is proceeding rapidly in the area due to its popularity for recreation. In fact De Hoop is the seaward extension of a terrestrial reserve against which it abuts (in combination protecting an area of 50 x 15 km). The land reserve protects highly diverse but threatened vegetation, and includes remains of archaeological interest.

De Hoop is widely used for education and approximately 70 schools visit the reserve to learn about terrestrial and marine conservation. It is also one of the best shore-based whale-watching sites in the world, where people can observe the 200 or so southern right whales *(Eubalaena australis)* that return to mate and calve there every year. With so much to offer eco-tourists, De Hoop has become a popular attraction. It provides an excellent example of how terrestrial and marine conservation can be integrated.

Key lessons:

- Reserves are highly effective in protecting stocks of commercially important fish in South Africa, including endemic species.
- Fully protected marine reserves provide vital refuges for overexploited species.
- Species which don't normally move far will spillover to fishing grounds.
- Taking anglers out on research trips helps them to understand the effects of their activities and spread the message about reserve effectiveness through the fishing community.
- Adjacent marine and terrestrial reserves can complement each other to provide more effective biodiversity conservation.

References: Bennett & Attwood 1991; Attwood & Bennett 1994.

Case study co-authored by Colin Attwood, Sea Fisheries Research Institute, Private Bag X2, Roggebaai 8012, South Africa. Email: cattwood@sfri.wcape.gov.za

G. Barangay Lomboy and Cahayag fish sanctuary, Pangangan Island, Philippines

Unforeseen circumstances undermine reserve effectiveness

From 1960 to the 1980's coral reefs of Calape Bay in the Philippines were fished with dynamite. Every day there would be about twenty blasts with each one killing around 200 kilograms of fish. Local residents of the barangay Lomboy did their fishing with hook and line, not dynamite, but tolerated the practice because there were plenty of fish and the dynamiters left shares of their catches for the community. However, by the late 1980's locals were seeing their catches fall dramatically. Previously a hook and line fisher could expect to land about 15 kilos of fish a day, but that went down to two or three kilos or even nothing at all. People were beginning to realise the damaging consequences of blasting a reef with dynamite.

In early 1991 a group of conservationists visited Calape Bay and suggested a community-based fish sanctuary could help rectify some of the problems that dynamiting had caused. The Lomboy village head, Benjamin Cuadrasal, thought this was a good idea and tried to set one up in his barangay. However, he was met with considerable opposition, as most people did not appreciate the potential improvements a marine reserve would bring. They could not see beyond the problem of lost fishing area and were afraid a sanctuary would further reduce their catches. As elections were approaching, the village head did not pursue the idea.

Lomboy fishers construct a guardhouse for their marine sanctuary. Close surveillance is important to help prevent poaching. Photograph by Stuart Green.

It was not until several years later that government representatives from the Department of Environment and Natural Resources (DENR) started a coastal environment program (CEP) to set up marine reserves. The re-elected village head helped them run a series of community workshops and take people to provinces where fish sanctuaries were already in operation. These visits were incredibly successful in helping people understand the benefits a sanctuary could provide. In March 1995 the Lomboy-Cahayag Fish Sanctuary was established with the full support of local people. It covered 8.6 hectares and was located in a place that village elders remembered as a fish spawning ground.

Initially all went well and the sanctuary flourished. However, in 1996 an outsider set up two large fish corrals alongside the sanctuary boundary where he began to catch large amounts of fish. These corrals were not illegal and the owner refused to take them away. Locals could only watch as he continued to catch large quantities of fish, probably originating from their reserve. After one and a half years of bitter legal fighting the law was eventually amended to include a buffer zone around the sanctuary. Only certain types of fishing were to be allowed within this area, and these did not include maintaining a fish corral!

In 1997 a group was established to assess social and biological effects of the fish sanctuary. Results showed that between 1997 and 1998 hard coral cover increased from 7% to 17% inside the sanctuary whereas it decreased from 30% to 18% outside. There was also a marked decrease in sand from 48% to 9% inside the sanctuary and an increase in rock cover from 29% to 45% outside. However, there were few food fish in the sanctuary, some wrasse, parrotfish, eeltail catfish and fusiliers, but the community was dominated by damselfishes and fairy basslets.

When the community were told about these findings, it came to light that certain individuals had been fishing in the sanctuary. This had started during the corral problem, when despondency had caused people to be less vigilant about guarding the sanctuary. It had also tempted others to fish illegally at night. People justified this behaviour on the grounds that an outsider was already stealing their fish. As a result of these revelations a sanctuary management committee was formed. The committee aimed to increase vigilance against illegal fishing and promote support and raise funds for the sanctuary.

After the management committee was set up, the sanctuary began to show considerable improvements. Fish stocks increased in abundance and diversity and there are now more large individuals around (Uychiaoco et al. 1999). The community has learned not to take the sanctuary for granted and to tackle problems as they arise. It has become a “showcase” for communities interested in setting up their own sanctuary and a further three have been established in the area.

Key lessons:

- Communities must have a thorough understanding about the purpose of a marine reserve.
- Local leaders can help persuade people about reserve benefits, but their effectiveness will be constrained by political climates.
- Creating fish sanctuaries is not the end to a problem - they are the start of a never-ending, full time job.
- Thorough planning is essential prior to implementing a protected area.
- Local communities require regular feedback on the effectiveness of a reserve.

References: Uychiaoco et al. 1999.

Case study authored by Stuart J. Green, Coastal Resource Management Project, Provincial Coordinator - Bohol, Bohol Environment Management Office, Capital Site, Tagbilaran City, Philippines. Email: bosicadd@mozcom.com.

H. The Galápagos Marine Reserve, Ecuador

From management conflicts to community-based management

The unique biology and historical importance of the Galápagos Islands attract tourists from all over the world. They provide important revenue for Ecuador and are a source of great national pride. The Galápagos National Park was created in 1959, and the archipelago was designated as one of the first natural World Heritage Sites by the United Nations Educational, Scientific and Cultural Organization (UNESCO). A marine reserve was declared in 1986, but this had no management plan and received no protection.

The stark beauty of the Galapagos islands. If Charles Darwin had been able to scuba dive he would have found a spectacular and unique underwater biota just as impressive as that he described from land!

In 1992 a management plan was developed, but locals were not involved and it was never implemented. Part of the problem in getting management established was due to the fact that two different government agencies had responsibility for the marine reserve. Bureaucratic conflicts delayed progress in protection and over-exploitation increased during the 1980s. In particular, intensive and highly lucrative fisheries developed for shark fins and sea cucumbers which threatened to cause local extinctions and reduce marine biodiversity. Both fisheries were new to the Galápagos, but developed rapidly in response to huge demand from Asian markets.

In 1996 a participatory management approach was initiated which gave local stakeholders the opportunity to help develop a management agenda for the Galápagos Marine Reserve. At the same time a "Special Law" was devised to provide a legal basis for these agreements. In January 1998, through the Galápagos Special Law, the Ecuadorian parliament approved a series of important protective measures for the islands. The new law placed the marine reserve under the jurisdiction of the National Parks Service, and extended its limits to 40 nautical miles from the archipelago's baseline (a line joining the outermost points of the outer islands). Industrial fishing by mainland and foreign fleets was banned, and only locals could fish within the newly designated 140,000km^2 reserve. The law also required that 50 percent of revenue generated from tourists be invested in local biodiversity conservation.

The Galápagos Marine Reserve will now be zoned into areas permitting different activities. Examples of the categories to be used include "scientific use only", "no fishing but tourism and recreation allowed", and "fishing, tourism and recreation allowed". A new participatory management body will decide how much area should be included in each type of zone and where to put them. Following this, zones will be set up for an experimental two year period, with the possibility of extension to four years, while their effects on wildlife and people are evaluated. Following review of these outcomes and possible amendments to the scheme, the zoning is expected to be made permanent.

The zoning scheme provides a great deal of flexibility in the level of protection and type of management that can be applied. For example, staff at the Charles Darwin Research Station and Galápagos National Park Service have proposed a zoning scheme that will represent all habitats and biogeographic regions of the archipelago in the two categories of no-take zone. Their scheme would protect 36% of the total length of the coastline, up to a distance of two miles offshore, from fishing.

The way these zones are distributed will ensure that fishery benefits are spread around the entire archipelago. This should offer the prospect of recovery for overexploited stocks such as the Bacalao (*Mycteroperca olfax*, a large grouper) and sea cucumbers. Theoretical studies of reserves suggest that a closure of 36% will produce a high level of long-term benefit to fisheries. In the Galápagos, a large closure is particularly important because the islands are isolated and subject to extreme environmental variability. Both these factors call for a precautionary approach to management and the no-take zones will help provide resilience against environmental fluctuations. However, the proposed zoning scheme does not offer an equivalent level of protection to offshore areas, leaving important habitats unrepresented in zones giving the highest level of protection.

The design of a monitoring programme is still being developed, as are the measures by which success or failure will be judged. However, at present there are plans to assess reserve effectiveness after only two years of closure, with a mind to re-opening some if they fail to perform. Experience of establishing and monitoring reserves elsewhere in the world indicates that few biological effects can be convincingly demonstrated in only two years of protection. Although it is likely that fish populations will increase within no-take zones, it is very unlikely that catches will improve over such a short time. Furthermore, the zoning scheme is intended to

Fisheries are very species-specific in the Galapagos. Bacalao* (Mycteroperca olfax) *are highly sought after and becoming rarer, while yellow-tailed surgeonfish* (Prionurus laticlavius) *are not targeted and still extremely abundant.

secure the long-term sustainability of fisheries and conservation of biodiversity in the Galápagos and measures of short-term effects on ecosystems and society are unlikely to reflect the eventual benefits of such a scheme.

The zoning scheme also has one other problem: a lack of staff and resources to implement protection. This means that enforcement will be limited and much effort will be needed in community education to build compliance and support. However, the small population of the Galápagos and the significant advances in participatory management make this a realistic goal.

Key lessons

- If protection is to be effective, management agencies must have clear jurisdiction over resources.
- Management must have the flexibility to address unforeseen threats such as the development of new fisheries.
- Building consensus takes a real commitment of time and resources but as trust grows, diverse stakeholders can achieve complex tasks such as formulating management plans.

References: World Wildlife Fund 1998; Roberts 1999; Heylings & Cruz in press.

Further Information: Fundacion Natura and WWF produce an annual "Galápagos Report", available in Spanish and English, providing detailed assessments of the status of the islands' marine and terrestrial biodiversity. Visit the website of the Charles Darwin Research Station at www.polaris.net/sui/jpinson/pml/root.html, the Galápagos Coalition at www.law.emory.edu/PI/GALAPAGOS/ and the Galápagos Conservation Trust at www.law.emory.edu/PI/GALAPAGOS/TrustConservation.htm

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I. The Mombasa Marine National Park, Kenya

Fully-protected marine park restores ecosystem health and fisheries

The Mombasa Marine National Park covers $10km^2$ and was set up in Kenya in 1987. Despite legislation, it took several years for the park to become functional. Fishers remained in the area until 1991, and poaching continued to be a problem until 1992 when night-time patrols finally brought it under control. Hence, although

Kenyan fisher in a traditional dhow. In the area to the south of the Mombasa Marine National Park, only traditional fishing methods are permitted. Photograph by Tim McClanahan.

fishing pressure began to decline from about 1989 onwards, it was not until 1992 that the park became truly protected from fishing. When the marine park became fully-protected from fishing, restrictions were also implemented in the area immediately to the south, called the Mombasa Marine Reserve. Here fishing is limited to traditional techniques, with only traps, gill nets, and handlines allowed. However, once again the new regulations were slow to take hold and were not properly adhered to until 1994. Figure 23 shows a map of the area.

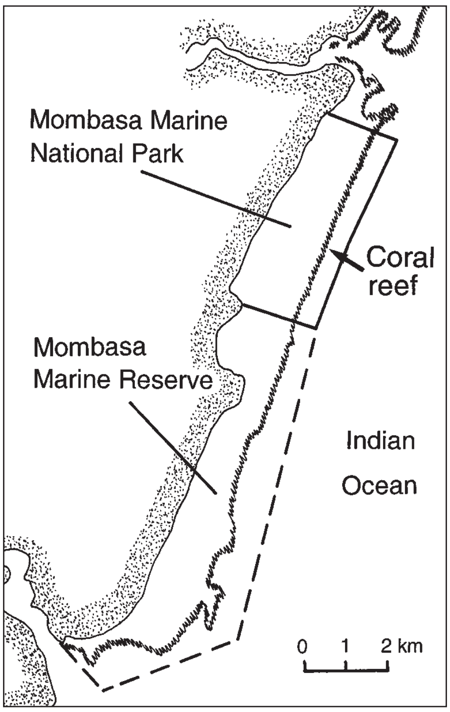

Figure 23:* *Map of the Mombasa Marine National Park in Kenya.

Between January 1991 and December 1994 the number of fishers using the Mombasa Marine Reserve fell by 68%, because they preferred to go elsewhere, or stop fishing altogether rather than crowd into the reserve. The number of fishers per unit area remained almost the same because 63% of their fishing area had been incorporated into the fully-protected park. As a consequence of this lost fishing ground, the catch of bottom-living fish fell by 35%. However, this drop was much less than the percentage decrease in fishing area because the overall catch per unit effort (CPUE) increased by 110%, from 20kg/person/month to 43kg/person/month. The increase for coral reef fishes alone was 74%.

Over time these initial increases in CPUE were not maintained, because in 1994 bans on the more effective fishing gears like spear guns were enforced. However, over time, as stocks improve CPUE for the remaining gears should increase to a level higher than before the park was protected.

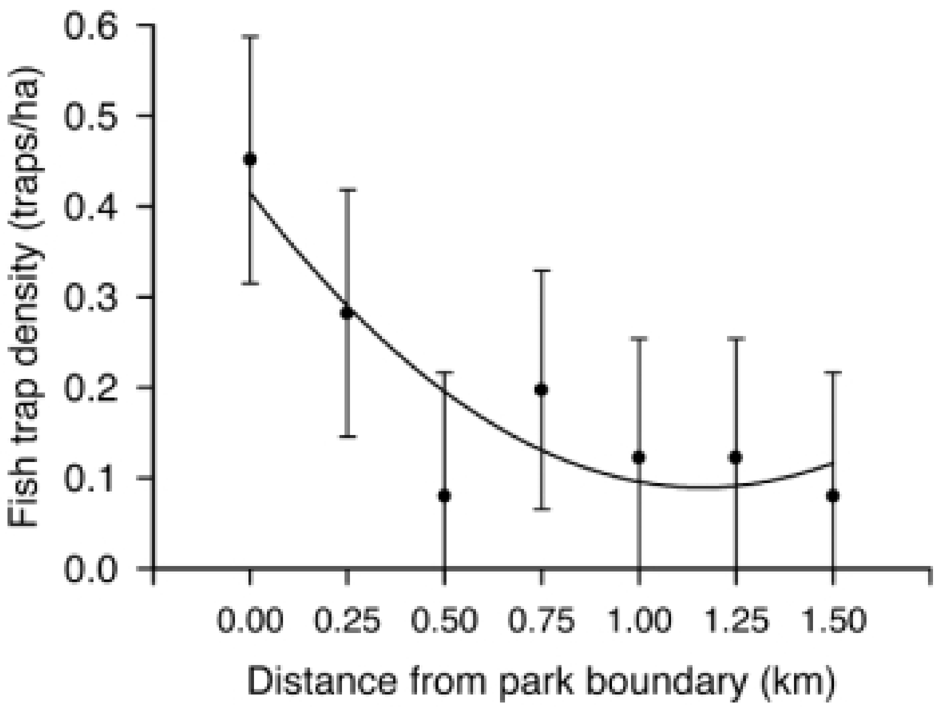

***Figure 24:* Since the creation of the Mombasa Marine National Park, catch per unit effort of fish traps has increased. The highest catches are now obtained close to the reserve boundary, suggesting spillover from reserve to fishing grounds. Redrawn from McClanahan & Kaunda-Arara (1996).**

In 1994, three years after full protection, fish biomass within the marine park was estimated to be approximately1600 kg/ha compared to only 300 kg/ha in fishing areas. Fishing areas lacked large sized fish in all families. At first glance, this differential suggests that fishers are not benefitting from the fully-protected zone, whereas in fact they are. At park boundaries CPUE in 1993 was 25% higher than elsewhere in the fishing grounds. Consequently, fishers are targeting these areas with higher densities of traps (Figure 24), and prime fishing spots close to the park boundary are restricted to the most senior fishers. Although densities of fish are not increasing in fishing grounds, the fact that CPUE is greater approaching reserve boundaries suggests that catches are being supplemented by spillover from the fully-protected zone. This spillover of fish does not penetrate far into fishing grounds because it is captured close to the boundary.

The benefits of marine protection in Kenya do not end with increased CPUE for fishers. Tim McClanahan, a scientist who has spent years studying African coral reefs, has concluded that fully-protected reserves are vitally important in preventing the destruction of Kenya's coral reefs by grazing sea urchins. In areas of high fishing pressure, populations of sea urchins are many times higher than in fully-protected zones. This is because intensive fishing removes key predators of sea urchins such as triggerfish and emperors. Without them sea urchin numbers can explode, leading to intensive grazing on the reef. Their scraping mouthparts erode the reef and reduce coral cover. At such grazing intensities the very framework of the reef begins to erode. Degraded reefs support fewer fish than healthy ones. Furthermore, high densities of urchins can also out-compete fish herbivores for food and so reduce the number of these fish that the reef can support. Hence, because of its indirect effect on sea urchins, intensive fishing has not only removed target species but led to processes which have further reduced the amount of fish to catch. Areas closed to fishing help restore a healthier ecosystem state and improve catches.

Key lessons:

- It is often necessary to patrol reserves at night to control illegal fishing.
- Catches are enhanced close to the boundaries of no-take zones through spillover.
- Closing areas to fishing protects against unforeseen, harmful effects of over-exploitation on marine ecosystems, and can help restore areas where such effects have occurred.

References: McClanahan 1994; McClanahan & Kaunda-Arara 1996.

J. The Leigh Marine Reserve, New Zealand

Pioneering reserve reveals the benefits of protection from fishing

The Leigh Marine Reserve is situated on the rocky coast of New Zealand's north island. It is a small reserve, covering 5.2km^2, and extends 800m from the shore. It was one of the world's first reserves to be closed to fishing and was protected in 1977 after more than a decade of community effort. The initiative was taken by scientists working in the Leigh Marine Laboratory. They had become concerned that spearfishers and people collecting along the shoreline and shallow sub-tidal habitats were having too great an impact on the ecology of the area. As well as threatening the environment, they felt these activities compromised their ability to do good science.

In 1965 the scientists from Leigh began a tireless campaign to gather support for a fully-protected marine reserve, targeting schools, diving clubs and the general public. Local divers were easily persuaded as they too felt that marine life was rapidly disappearing. Other support came more slowly and cautiously, with 17 official objections raised before protective legislation was finally passed. Concerns included (1) doubts about the scientists' integrity, (2) an unwillingness to believe that over-exploitation was actually happening, and (3) suspicions that local people would be unable to use the reserve for recreation. Twelve years of effort in community education could not completely take away all these niggling doubts and insecurities. It was not until the reserve had been up and running for a number of years that almost universal approval was achieved.

Setting up the Leigh reserve had been a contentious issue. However, once the legislation was finally passed, many people began to lose interest in it. Because it had primarily been established for scientific research, they felt it now had little to do with them. After a few years, scientists began recording changes in populations of commercially-important species within the reserve and this soon interested a lot of people. For example, the density and size of rock lobster *(Jasus edwardsii)* were increasing rapidly, while populations of snapper *(Pagrus auratus)* and red moki *(Cheilodactylus spectabilis)* were also doing well. By the mid 1980s, scientists concluded that the Leigh reserve was helping replenish fishing grounds for rock lobsters. Fishers started to preferentially set their traps along the reserve boundary, feeling this was the place they would get the best catches. They also began to report illegal poaching. This was a sure sign that people recognized the benefits of the reserve and would not tolerate others jeopardizing them.

Throughout the 1980s an increasing number of people began to visit the Leigh reserve. In the summer of 1984 it attracted around 14,000 tourists. By 1994 that number had risen to 100,000. As tourism grew, amenities such as dive shops, cafes, camp grounds, glass bottom boat operations and a marine education centre also developed. People were attracted to the reserve by stories of abundant, easily approachable marine life and went there to dive, snorkel and swim. However, because there is only one access point to the reserve, this spot often becomes over-crowded. It is also a place where people liked to feed fish. At the moment, scientists are not too worried that visitor use is threatening marine life or their research because tourists are highly concentrated into one specific area comprising about 5% of the reserve. However they do feel that tourists are affecting the behaviour of certain species of fish.

The Leigh Marine Reserve has become an inspiration to people worldwide. The experience at Leigh, and the campaigning efforts of one of its founders, Bill Ballantine, have made the scientific community and public aware of how important reserves are.

Key lessons:

- Even an extensive public education campaign cannot allay all misgivings about a fully- protected reserve.
- Support for a fully-protected reserve will increase once it is operational and people can discover their fears were unfounded.
- When fully-protected reserves start showing positive results, local fishers help police them voluntarily.
- Abundant, easily approachable marine life attracts visitors to reserves which boosts the local economy.

References: Walls 1998; Ballantine 1991; Babcock et al. 1999.

K. Marine Reserves in Tasmania, Australia: Governor Island, Maria Island, Tinderbox and Ninepin Point

Reserves reveal how fishing has transformed marine ecosystems of southern Australia

In late 1991, four fully-protected marine reserves were declared on the east and south-east coast of Tasmania, Australia. The largest, at Maria Island, covers 7km of coast. This reserve includes many marine habitats typical of the east coast and was established to conserve a broad range of biodiversity. Ninepin is smaller, only 1km long, and was designed to protect a single, unusual habitat. The two other reserves, Tinderbox and Governor Island are 2km and 1km long respectively, and were declared to promote recreation. Although the reserves were set up to fulfill a variety of objectives, a common expectation was that each would restore populations of overexploited species such as rock lobsters *(Jasus edwardsii)*, black-lip abalone *(Haliotis rubra)* and large fish.

Six years of protection have brought several changes to Maria Island Reserve. The number of fish species increased by 5%, whereas in nearby unprotected areas it fell by 23%. Most of the new species were large and had suffered badly from overfishing. They included the bastard trumpeter *(Latridopsis forsteri)*, ling *(Genypterus tigerinus)* and draughtboard shark *(Cephaloscyllium laticeps)*. Diversity of mobile invertebrates and algae also increased at Maria Island by 25% and 11% respectively, whilst falling by 7% and 5% in fishing grounds. However, there were no changes in the number of species for any of these three groups at Governor Island or Ninepin Point, while at Tinderbox, only the number of large fish species increased.

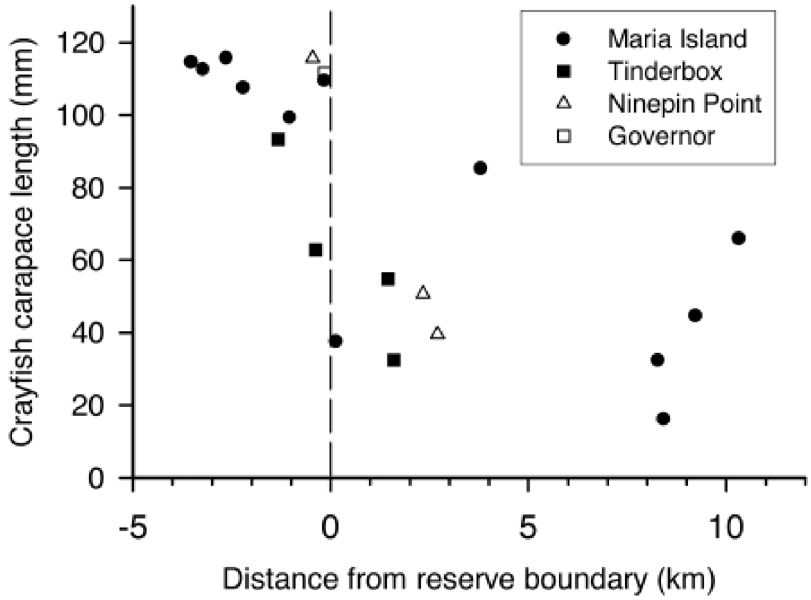

Figure 25:* Differences in size of rock lobsters** (Jasus edwardsii) ***inside four Tasmanian reserves and with increasing distance away from them. Five years of protection from fishing has led to marked increases in size of lobsters within reserves.

The most striking outcome of protection in Tasmania has been the build-up of large fish, (> 33cm). In the Maria Island Reserve, these increased from an average of 2.6 to 9.2 per 500m^2, a rise of over 240% in 6 years. Outside the reserve densities remained more or less constant at 1 per 500m^2. The same pattern was found at Tinderbox where large fish increased by 300%. At Ninepin the trend was upheld if long-fin pike *(Dinolestes lewini)* were considered reef-associated rather than pelagic. These pike were very abundant in this reserve, but rare in all of the others. However, at Governor Island there was no accumulation of large fish.

The species showing the greatest recovery was the bastard trumpeter at Maria Island. This species is virtually absent from unprotected areas, but following a large recruitment in 1994/1995, numbers in reserves showed an incredible 100 fold increase. This species is thought to spawn on deep offshore reefs, which if true, will result in a mass movement of fish outside the reserve when the young reach sexual maturity. It appears that as juveniles they do not move far, otherwise there would have been more dispersal outside the Maria Island Reserve. However, tagging studies suggest that some individuals will travel as far as 140km. In South Africa it has been shown that amongst galjoen *(Dichistius capensis)*, some individuals will disperse over great distances, while the majority of the population move little (Attwood & Bennett1994).

Rock lobsters also showed significant responses to protection. In Maria Island their numbers increased by 260% over 6 years compared to only 12% outside the reserve. They also grew in size. When the reserve was set up, carapaces of the biggest lobsters measured about 110mm, the minimum legal size in the fishery. After six years protection, some lobsters had carapaces measuring 200mm, whilst in fishing areas the biggest were still around 110mm. As a consequence of increased size, lobsters at Maria Island produced ten times more eggs than exploited stocks. The other reserves also contained much larger lobsters than fished areas (Figure 25), and at Tinderbox their abundance rose by 100%.

Size of black-lip abalone also increased in reserves. At Maria Island these grew from an average of 128 to 136mm but outside fell from 125 to118mm. It was only in reserves that any individual grew bigger than 160mm. However, the number of juvenile abalone did decline at Maria Island between 1992 and 1997, perhaps due to competition with larger abalone, or perhaps because of predation from the extra numbers of rock lobsters and large fish. Surprisingly, marine reserves did not enhance densities of the sea urchin *(Heliocidaris erythrogramma)*, which are exploited throughout the area.

It is unclear why several species did not grow big at Governor Island and Ninepin Point in the way they did at Maria Island and Tinderbox. Maria Island may have offered more effective protection because parts of it were surrounded by large stretches of sand which might have deterred fish movements. Another explanation is that the large number of nets and lobster pots set close to the reserve boundaries at Governor Island and Ninepin Point made protection less effective for mobile species in these very small reserves. The fact that rock lobsters were able to increase in size in all reserves suggests that this species does not move very far. In Tasmania, any lobster that wanders out of a reserve is highly likely to end its journey on a dinner plate!

Key lessons:

- The densities and sizes of commercially important species are limited by fishing on Tasmanian reefs.
- Reserves provide an important refuge for severely overexploited species.
- Monitoring the effects of protection provides a valuable insight into ecosystem health. Without reserves the true state of overfishing on Tasmania's reefs would not have been realized.

Reference: Edgar & Barrett 1999.

L. Sumilon Island Reserve, Philippines

Reserve benefits to fisheries are vulnerable to local politics

Sumilon Island is a small coralline island in the central Philippines. There is no local community on the island, but it is used by about 100 small-scale fishers from the neighbouring islands of Oslob, Santander and southern Cebu. In 1974, biologists from Silliman University on the island of Negros, persuaded the municipal council of Oslob to declare one of the world's first marine reserves on Sumilon. By local government decree, a quarter of the island's coral reef was totally protected from fishing. Whilst these official negotiations were taking place, local fishers were also being educated about how the proposed reserve would benefit them, although it later emerged that many people had been unclear about the purpose of the reserve. Nevertheless, enough people respected the closure to fishing for benefits from the reserve to start to filter through. By the late 1970s most fishers believed that their yields had improved as a result of the marine reserve.

Unfortunately, problems began in 1980 following the election of new mayors in Oslob and Santander islands. They opposed the reserve, and as a result several serious fishing violations were allowed to take place. In response, Silliman University appealed for help to the national government, who instigated protection under national law. The University was given powers to manage the reserve, and to do research there. However, resentment brewed amongst local officials at this interference in their area and fishing violations continued to escalate over the next five years. Between 1984 and1985 protection broke down completely and the reserve became heavily fished. As if this wasn't bad enough, destructive techniques such as "muro-ami" (drive net fishing) and dynamite fishing were instigated.

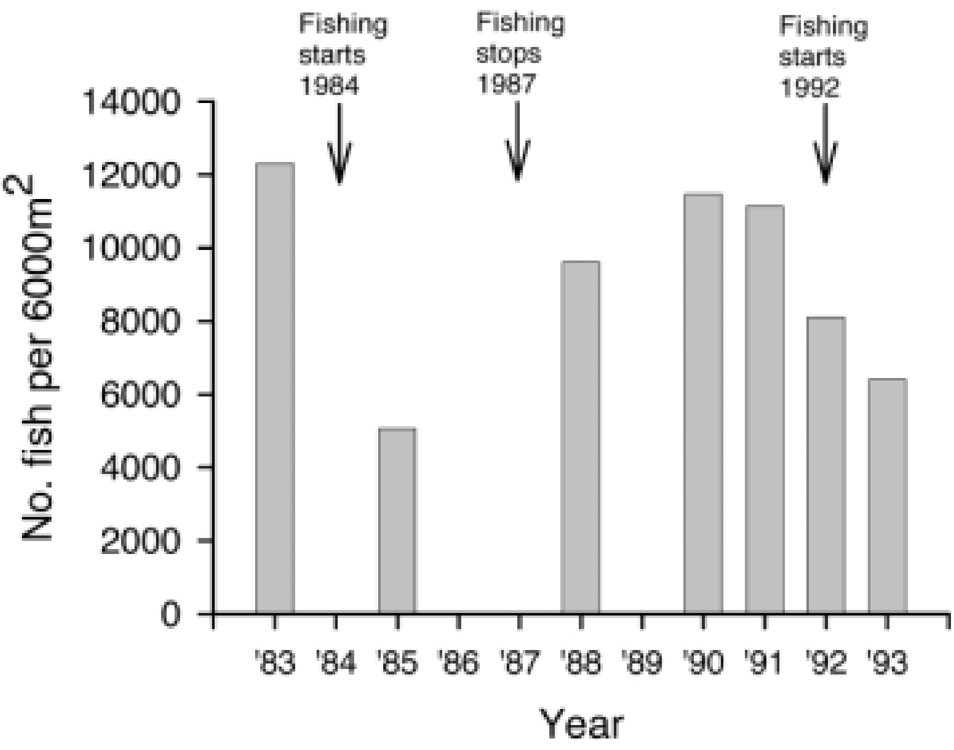

***Figure 26:** Patterns of decline and recovery for the most important family in the Sumilon fishery, the fusiliers (Caesionidae). The abundance of these short lived (2-5years), fast growing species, closely tracked patterns of illegal fishing in the marine reserve. Redrawn from Russ & Alcala (1994).*

By 1987 the situation began to improve. Santander and Oslob councils wanted to develop a tourist resort on Sumilon Island and as a result decided to issue a local ban on all fishing there. This was upheld for four years until the resort was completed. In 1992 all restrictions were lifted from the former fishing area, while hook and line fishing became legal in the old reserve. With the return of fishers to the area, and insufficient enforcement to protect the marine reserve, it was not long before illegal fishing resumed. Violations included establishment of a fish corral (where fish are driven into a large, fixed position trap), widespread use of small bamboo fish traps, and spear fishing, some possibly by scuba diving tourists.

Throughout this turbulent period, scientists visually estimated the biomass and density of fish species within the Sumilon reserve. In addition, they collected quantitative data on yields and catch per unit effort for seven years between 1976 and 1983. This latter information showed that when the reserve was functional, total catches and catch per unit effort were around 50% higher than when it broke down, despite the extra area which became available for fishing. This suggests that the reserve had been enhancing adjacent fisheries, although falls in catches may have

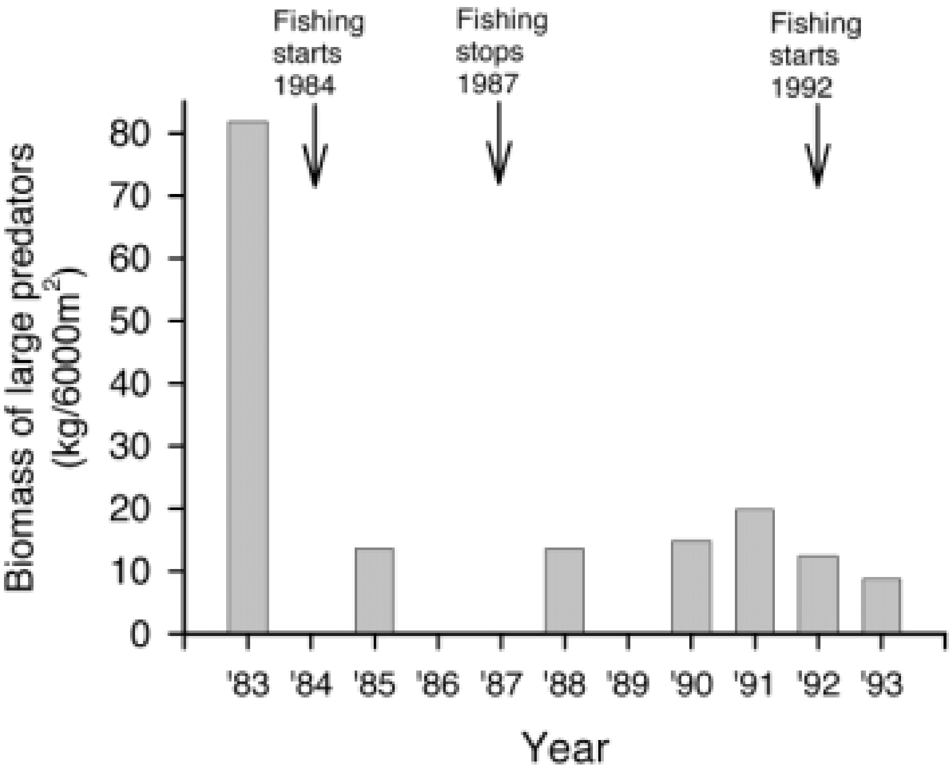

***Figure 27:* Patterns of decline and recovery for large predatory fishes at Sumilon, the snappers (Lutjanidae), groupers (Serranidae) and emperors (Lethrinidae). These species respond more slowly to protection and are very easily depleted by illegal fishing. Redrawn from Russ & Alcala (1994).**

resulted from destructive fishing methods undermining productivity of the reef.

Results from the underwater surveys made between 1976 and 1986 showed strong patterns of recovery and decline for the most important family in the fishery, the fusiliers. These are short lived (2-5years), fast growing species, and their abundance closely tracked patterns of illegal fishing in the marine reserve (Figure 26). When reserves were being respected fusiliers were abundant, but shortly after fishing resumed their populations crashed. Between 1983 and 1993, the same pattern was found for groupers, snappers and emperors, which are much less abundant, but highly prized by fishers. These are big, long-lived (5-20 years), slow growing species, and their rates of recovery were much slower than those of the fusiliers (Figure 27). This meant that even though populations were able to recover after the illegal fishing bout of 1984 -1987 stopped, their numbers and biomass were dramatically down over what they had been during the protected period. When the next bout of poaching started in 1992, populations of these fishes dropped to their lowest levels.

The Sumilon reserve was one of the first to show the great importance of protecting areas of the sea from fishing. The roller-coaster ride of protection implemented, taken away, implemented again and so on, has proved enormously frustrating for all the people who have worked so hard to protect the reserve. However, it has proved a bonus for understanding of how effective reserves are, how fast they provide benefits, and how fast these can be lost. The evidence is clear - reserves can offer rapid results but these are fragile gains that are easily eroded if protection lapses.

Key lessons:

- Benefits from protection are rapid.
- Illegal fishing erodes the long-term gains provided by marine reserves.
- Benefits to fishers from re-opening marine reserves are extremely short-lived.
- Large, slow-growing, long-lived species are more vulnerable to exploitation than small, fast-growing, short-lived species. Vulnerable species are the ones most at risk from poaching.
- Political upheaval poses a threat to marine reserves.
- Community support is more important than protection by local or national law.

References: Alcala 1988; Russ & Alcala 1994.

M. Dry Tortugas Ecological Reserve, Proposal B, Florida Keys National Marine Sanctuary, USA

Setting up a new fully-protected zone in the Florida Keys - making the right compromises

The management plan for the US Florida Keys National Marine Sanctuary is the size of a large telephone directory and just as dense. It provides what is probably one of the world's most detailed blueprints for managing a large marine ecosystem. Over the years this management plan has been responsible for much contention, drawn out battles, and even personal threats. However, people in the Keys are now working together to set up the Dry Tortugas Ecological Reserve.

The Sanctuary is managed by the National Oceanic and Atmospheric Administration (NOAA) and protects America's only barrier coral reef, plus vast seagrass meadows, and innumerable mangrove fringed islands. It was established in 1990 and covers 2,800 square nautical miles surrounding the Florida Keys, and extending to the southernmost tip of the United States.

Early zoning schemes proposed to set aside approximately 20% of the Sanctuary in five fully-protected marine reserves. However concerted political action reduced this proposal to three reserves and finally to one, leaving only half a percent of the Sanctuary fully-protected from fishing. The original proposal included a reserve in the Tortugas but the boundary, which encompassed around 100 square miles, was hotly contested. Consequently the reserve was dropped from the management plan, although marked out for reconsideration in the future. Billy Causey, the superintendent of the Sanctuary described this as leaving the sanctuary with "unfinished business."

Sport fishing is a major money spinner in the Florida Keys, but good catches depend on there being good replenishment of exploited populations. The Dry Tortugas are ideally placed, being upstream of most reefs in the Keys, to supply young fish to support these fisheries. Creation of a fully-protected, ecological reserve will ensure high levels of reproduction by fish within it and is expected to help sustain sport and commercial fisheries.

Second time around, NOAA developed a truly comprehensive approach towards setting up a Tortugas reserve. They carried out detailed scientific research and made a thorough socio-economic study of the area. In addition Billy Causey's team launched the project 'Tortugas 2000' which was designed to raise public interest and steer people towards creating a workable reserve. As a result, a participatory group was established containing commercial and recreational fishers, divers, conservationists and other interested stakeholders. They were responsible for presenting the Sanctuary's Advisory Council with revised recommendations for the reserve.

The shallow banks of the Tortugas provide an ideal spot for a fully-protected marine reserve. They are remote and relatively undisturbed, with high water quality and a rich diversity of marine life. Being upstream of all other reefs in the Keys, they are perfectly placed to benefit Florida's fisheries by exporting the eggs and larvae of commercially important animals that are resident in the reserve.

In April 1999, the Tortugas working group started making provisional proposals for the reserve's boundary. They took into consideration many different criteria. The reserve needed to provide fisheries benefits and protect important fish spawning aggregation sites. It needed to be easy to locate and straightforward to patrol. Commercial fishers wanted to retain access to key fishing grounds, and divers wanted to ensure that the best dive spots were included in the fully-protected area.

With all these different priorities, building consensus around a single proposal was not easy. A key element of success was that during initial meetings the group discussed people's interests without putting lines on a map. By getting to know each other well, and working through their differences together first, the group learnt to co-operate with goodwill and humour. By the time proposals started being drawn up, people had confidence that their views and interests would be properly considered.

Many different proposals emerged, but eventually one began to gain the support of both conservationists and fishers. Some people felt it left too much unprotected, while others thought it reached too far beyond existing Sanctuary boundaries, but this plan received the kind of consensus previously unknown in the Sanctuary. Voters that had seemed destined to object to any kind of reserve approved it, and the proposal was carried forward with unanimous support. Getting consensus depended on making the proposal realistic for everybody. For example, keeping access to king mackerel grounds over a relatively small area won the support of recreational fishers. At 186 square nautical miles, the newly proposed reserve was nearly twice the size of the one put forward in 1990.

There is still a long way to go before the Tortugas reserve is formally established. However with fishers and conservationists committed to backing the proposal it should just be a matter of passing through the legislative process. In the end neither conservationists nor commercial fishers got exactly what they might have liked. One member of the group noted that no-one was completely happy but everyone could live with the decision. People involved in formulating the proposal were clearly surprised but delighted at the level of consensus, and it was felt that NOAA had learnt a lot from their earlier attempts at setting up the reserve.

Key lessons:

- All stakeholders need to be involved in the planning process from the beginning.
- It is essential to gain the trust and support of local communities and all stakeholders. This takes time but the value of support is priceless.
- Establishing a protected area involves compromises - usually from everybody.

Further information: For further information on the Dry Tortugas Ecological Reserve, or to find out about other aspects of management in the Florida Keys National Marine Sanctuary, visit their website at www.nos.noaa.gov/nmsp/fknms or contact the Sanctuary's science co-ordinator directly: Ben Haskell, Science Co-ordinator, Florida Keys National Marine Sanctuary, Marathon, Florida 33050, USA. Tel: +1 305 743-2437, Fax: +1 305 743 2357, Email: bhaskell@noaa.gov.

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Glossary

Analysis of complementarity: a process by which sets of reserve locations are chosen that optimize the number of species or habitats protected, while minimizing some function such as the cost of protection (often expressed as the total area of reserves required). The analyses can be undertaken in many ways, but usually involves first selecting sites with the most species, or the greatest number of geographically restricted species. The next site selected is the one that adds the most new (i.e. unrepresented) species. The selection process continues until all species, or some target fraction of them, are represented.

Allee effect: a reduction in fitness at low population densities, often measured as the numbers of offspring that are produced or survive. For example, many marine species reproduce by releasing eggs and sperm into the water where they are fertilized externally. The rate of fertilization is greatly reduced as the distance between reproductive partners increases. For animals that have low mobility, such as clams that are attached to the sea bed, reductions in population density can prevent effective reproduction long before all the individuals have been removed. Strong Allee effects render populations vulnerable to extinction when their densities have been reduced to low levels, for example by fishing. They also hinder the recovery of populations from low densities.

Biodiversity: the variety of life. Biodiversity is manifested at many different levels, from genetic variation within populations, to different races of species, to the variety of different species present, the habitats they create and occupy, and the land and seascapes that they help shape.

By-catch: species caught unintentionally while fishers are in pursuit of other **target species.**

Connectivity: the movement of organisms from place to place (e.g. among reserves) through dispersal or migration.

Directional selection: the tendency for the genetic structure of a population to be channeled in a particular direction by a selective force such as fishing. Fishing tends to reduce the abundance of the largest and boldest fish in a population preferentially. This often leads to a shift towards shorter-lived, earlier reproducing fish that may be less able to persist in the face of long-term environmental fluctuations.

Economic yield: net economic benefit from an exploited resource, such as a fish population.

Ecosystem: the complete biological community in an area, together with its physical environment. Ecosystem boundaries are usually vaguely defined since virtually no ecosystem is completely isolated from others.

Ecosystem processes: processes that take place within ecosystems that are mediated by biological action, such as breakdown of organic matter, production of oxygen, or growth of coral reefs.

Ecosystem services: ecosystem processes or properties that are useful to humanity. For example filtration of water, production of fish, protection of coastal areas from storms or breakdown of pollutants.

Eutrophication: addition of excess nutrients can lead to changes in marine ecosystems that together are called eutrophication. They include excess growth of planktonic (drifting, open water) algae and seaweeds, reduced light penetration through seawater, low oxygen or anoxic conditions at the sea bed due to breakdown of dead organic matter, red tides (blooms of toxic planktonic organisms), mass mortalities of fish or shellfish, among other effects.

Fecundity: the level of reproductive output from an organism.

Fish: throughout this book we frequently use the term ‘fish’ in the sense used by fishery managers, meaning any organism that is exploited, whether it is a fish, mollusc, crustacean or whatever.

Fishing-the-line: the tendency of fishers to fish very close to the boundaries of successful marine reserves.

Fully-protected marine reserve: an area of the sea that is protected from all fishing, extractive or harmful human uses. Many people react negatively to the term **no-take reserve**, believing that it means 'no-people reserve'. Furthermore, no-take reserves may not limit other non-consumptive human activities to non-damaging levels. Hence, the broader term fully-protected reserve is used here. The term is not perfect, as to some people it may imply protected from all uses. However, it should be interpreted as meaning fully-protected from extractive uses (= no-take) and from harm by other uses. Thus, a fully-protected reserve is one where there is no fishing, and no extractive use (e.g. mining, dredging or curio collection). However, non-consumptive uses such as swimming, scuba diving, snorkelling, recreational boating, passage of shipping etc. are permitted up to levels which do not harm the environment.

Habitat: the place where organisms live. Ecologists usually use the word to describe distinct associations between species and their environment, such as hydro-thermal vents, upwelling areas, sandy beaches, kelp forests or rocky shores.

Harvest refugium: an area of the sea that is closed to fishing for one or more target species. Such an area may be permanent or temporary.

Infilling: the creation of new land by dumping of fill material into the sea. Areas that are infilled are generally shallow and are often highly productive marine habitats like mud-flats, coral reefs or seagrass beds.

Marine protected area (MPA): The World Conservation Union (IUCN) defines marine protected areas 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 of all of the enclosed environment". An MPA can be zoned to support multiple uses, including zones providing full-protection. Some authors have argued that the possession of at least one fully-protected zone should be a minimum standard for MPAs.

Maximum sustainable yield: There is a hump-backed relationship between the amount of fish caught and the amount of fishing effort. Low and high levels of fishing effort attract small catches, while maximum catches can be obtained from intermediate fishing intensities. The maximum sustainable yield point marks the highest level of catch that can be obtained and has been a traditional target for fishery managers. However, managing fisheries for this level of catch risks overexploiting them in the long run.

Metapopulation: a population that consists of a series of physically separate sub-populations that are linked by dispersal. Metapopulations persist as a result of a balance between extinctions of sub-populations and recolonization of habitat patches (and hence re-establishment of sub-populations).

Network: see **Reserve Network**.

No-take marine reserve: an area of the sea that is closed to all forms of fishing and other extractive uses. No-take reserves are distinguished from fully-protected reserves in that they may not have any other forms of management to limit non-consumptive human uses to non-damaging levels.

Non-target species: species that are not the intended targets of exploitation by fishers.

Open access: free-for-all fishing. Fisheries are open access where there are no legal constraints to prevent people from fishing. The decision of whether or not to fish, and for what, lies entirely with the individual.

Overcapacity: too much fishing power present to catch the available fish efficiently.

Participatory management: stakeholders and managers working together to develop, and often to implement, management.

Recruitment: For fishery scientists, the moment of recruitment to a fish stock is the time that fish first become vulnerable to capture by fishers. However, in this book we adopt a broader use of the term, taking it to mean the replenishment of populations by new reproduction.

Recruitment overfishing: the exploitation of a fish population to the point where there are too few reproductively active fish present to assure the population can replace itself.

Reserve network: a group of reserves which is designed to meet objectives that single reserves cannot achieve on their own. Networks of reserves are linked by dispersal of marine organisms and by ocean currents.

Reserve system: the totality of a series of reserve networks that in combination meet objectives of fully-representing all marine species and habitats, and replicating them in different reserves (wherever possible).

Sectoral management: the pursuit of management objectives by different agencies independently of one another, or with only limited interaction or coordination. Such management approaches often lead to competition, conflict, confusion among users and the perception of protection rather than the reality.

Services: see **Ecosystem Services.**

Spawning stock: the amount of reproductively active fish present in a population (often expressed in terms of biomass).

Spawning potential ratio: this is the ratio between the amount (usually measured as weight) of reproductively active fish in an exploited population, compared to an unexploited population. Lower values of spawning potential ratio (< 35-40%) indicate a heavily exploited stock whose reproductive output has been significantly reduced by fishing.

Spillover: export of organisms from a reserve into fishing grounds.

Stakeholders: anybody having an interest in the region where a reserve is being proposed. In the past, stakeholders were only considered to be users of an area. However, it is now recognized that all interested parties should be involved in discussion and planning for reserves, including those who do not necessarily use the area directly.

Stock-recruitment relationship: the relationship between the number of reproductively active fish in a population (the stock) and the number of offspring that they produce which eventually reach a size where they can be caught (recruitment). Such relationships are often highly variable and so difficult to estimate.

Target species: a species that is the intended target of fishing operations.

Yield per recruit model: a model which examines the weight of fish caught for every individual that is recruited to a fishery. A higher yield per recruit can often be obtained by allowing fish to live longer and grow larger before capturing them. Fully-protected reserves, by reducing the number of juvenile fish that are caught as by-catch in other fisheries, can increase yield per recruit, especially of migratory species.

Zoning: the spatial separation of different uses and mixes of uses within an MPA.

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