The Science of Marine Reserves

Second Edition: Europe

PISCO Partnership for Interdisciplinary Studies of Coastal Oceans

The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) produced the Science of Marine Reserves booklets in collaboration with the Communication Partnership for Science and the Sea (COMPASS, www.compassonline.org). PISCO is a consortium of academic scientists at Oregon State University; University of California, Santa Barbara; University of California, Santa Cruz; and Stanford University. PISCO advances the understanding of coastal marine ecosystems and communicates scientific knowledge to diverse audiences.

Visit www.piscoweb.org/outreach/pubs/reserves for a downloadable PDF version of this report; companion materials; and information about PISCO. To request printed copies of this report, contact one of the addresses listed on the back cover. Copying and distributing this report is permissible, provided copies are not sold and the material is properly credited to PISCO.

European Science Advisory Committee and Content Authors
Steven Gaines, Co-Chair (University of California, Santa Barbara, USA)
Peter Jones, Co-Chair (University College London, England)
Jennifer Caselle (University of California, Santa Barbara, USA)
Joachim Claudet (National Center for Scientific Research, France)
Michaela Clemence (University of California, Santa Barbara, USA)
Phillip Fenberg (Oregon State University, USA)
José Antonio García Charton (Universidad de Murcia, Spain)
Emanuel Gonçalves (ISPA – Instituto Universitário, Portugal)
Kirsten Grorud-Colvert (Oregon State University, USA)
Paolo Guidetti (Università del Salento, Italy)
Stuart Jenkins (Bangor University, Wales)
Sarah Lester (University of California, Santa Barbara, USA)
Rob McAllen (University College Cork, Ireland)
Even Moland (Institute of Marine Research, Norway)
Serge Planes (Université de Perpignan, France)
Enric Sala (National Geographic Society, Spain/USA)
Thomas Kirk Sørensen (Danmarks Tekniske Universitet, Denmark)

European Science of Marine Reserves Project Director
Phillip Fenberg

Science of Marine Reserves Project Director
Kirsten Grorud-Colvert

European Project Assistant Director
Michaela Clemence

European Project Advisor
Sarah Lester

Convening Lead Authors
Jane Lubchenco (2000–2008,Oregon State University), **Steven Gaines** (University of California, Santa Barbara), **Kirsten Grorud-Colvert** (Oregon State University), **Satie Airamé** (University of California, Santa Barbara), **Stephen Palumbi** (Stanford University), **Robert Warner** (University of California, Santa Barbara), **Brooke Simler Smith** (Oregon State University)

Creative Director: Monica Pessino
Science Writing Advisor: Peter H. Taylor

The authors gratefully acknowledge more than 150 experts on marine reserves from around the world who reviewed drafts of this report and earlier reports. The final content is the sole responsibility of PISCO.

Funding provided by:
The David and Lucile Packard Foundation, Oregon State University, University of California, Santa Barbara and Natural England

Cover photo: Paul Naylor, www.marinephoto.co.uk. Opposite page photos, top to bottom: Michael Maggs, James Marsden, Emanuel Gonçalves, Emanuel Gonçalves, Emanuel Gonçalves, Evan D'Alessandro.

Please cite this document as:
Partnership for Interdisciplinary Studies of Coastal Oceans. 2011.
The Science of Marine Reserves (2nd Edition, Europe).
www.piscoweb.org. 22 pages.

Page 1 References: 1, 8

Table of Contents

Overview:

O **ceans** around the world are heavily used. Evidence shows that human activities are altering ocean ecosystems beyond their natural range of variability. According to numerous scientific studies, habitats, fish, shellfish and other species are declining in many places. The changes are impairing the ocean's capacity to provide food, protect livelihoods, maintain water quality and recover from environmental stress. These and other benefits, collectively called **ecosystem services**, depend on healthy ecosystems.

Many people are inquiring about solutions to reduce impacts and foster ocean health and resilience. Increasingly, government agencies, commercial groups, non-government organisations, the public and scientists are discussing the idea of establishing marine reserves to complement other efforts to restore and sustain ocean ecosystems.

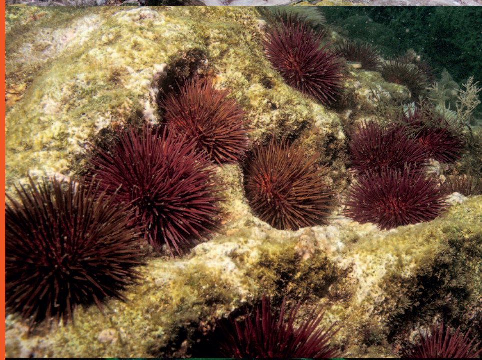
Marine reserves are defined as ocean or intertidal areas that are fully protected from activities that remove animals and seaweeds or alter habitats—such as fishing, aquaculture, dredging and mining—except as needed for scientific monitoring. Protection in reserves can range from completely restricted access to permissible activities such as swimming, boating and scuba-diving. Marine reserves are permanently protected, rather than seasonally or in the short-term. Because marine reserves protect habitats and the animals and seaweeds that live in those habitats, they are a form of ecosystem protection that produces different outcomes from other management tools. Benefits of reserves occur both inside and outside of their boundaries, but reserves are only effective if protection is enforced.

Marine reserves, or no-take areas, are specific types of marine protected areas (MPAs). Other kinds of MPAs can allow for multiple uses and exclude only some human activities. MPAs without marine reserves typically provide more limited benefits than fully protected areas.

Although marine reserves can be an effective tool, reserves alone cannot address problems such as pollution, climate change or widespread overfishing. Other management strategies are needed along with the creation of marine reserves, such as marine spatial planning.

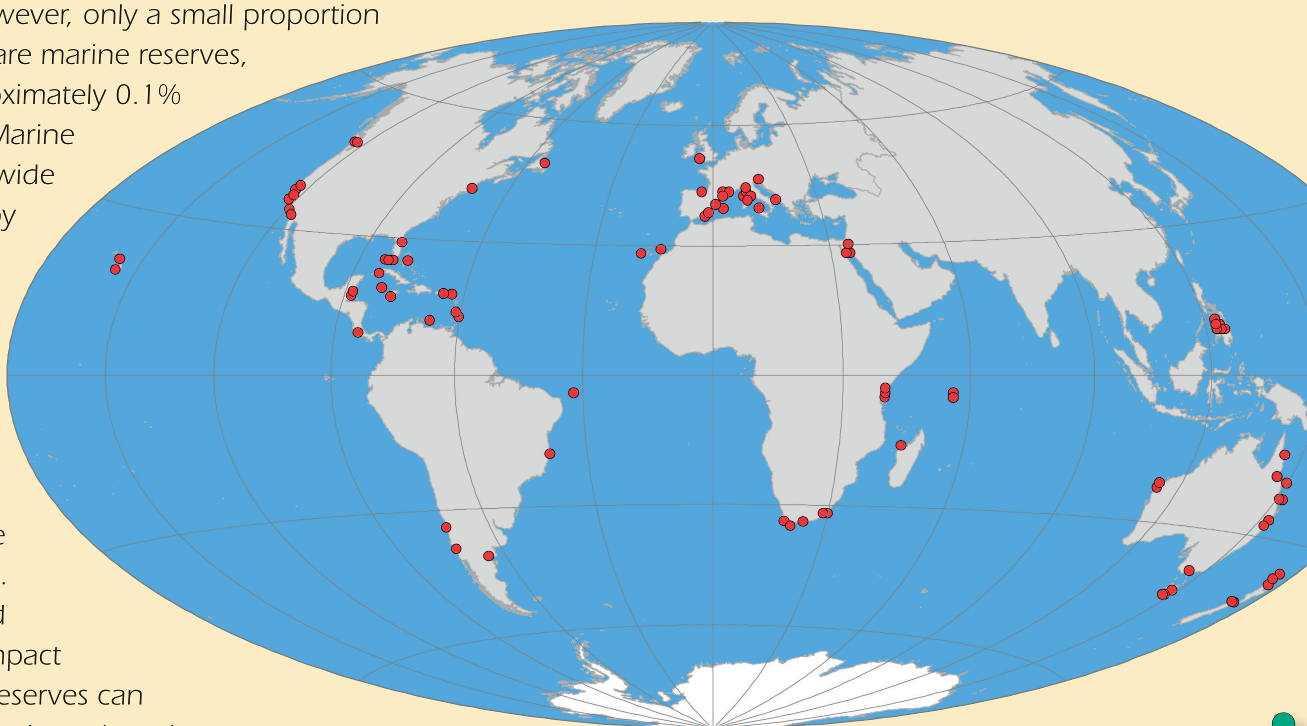
This booklet summarises the latest scientific information about marine reserves, including case studies from Europe. Evidence shows that marine reserves usually boost the abundance, diversity and size of species living within their borders and can provide benefits to areas outside. Science can explain how these changes occur and provide useful information for designing marine reserves.

what is a marine reserve?



Marine Reserves Are Different from Other Marine Protected Areas

As of 2010, scientists have identified at least 5,800 marine protected areas (MPAs) globally. They cover some 4.2 million square kilometres, or approximately 1.2% of the ocean. However, only a small proportion of these MPAs are marine reserves, covering approximately 0.1% of the ocean. Marine reserves worldwide can be called by many different names, including no-take zones, integral reserves, fully protected areas or marine nature reserves. Areas protected from human impact inside marine reserves can act as reference sites when they are compared to areas receiving less protection.



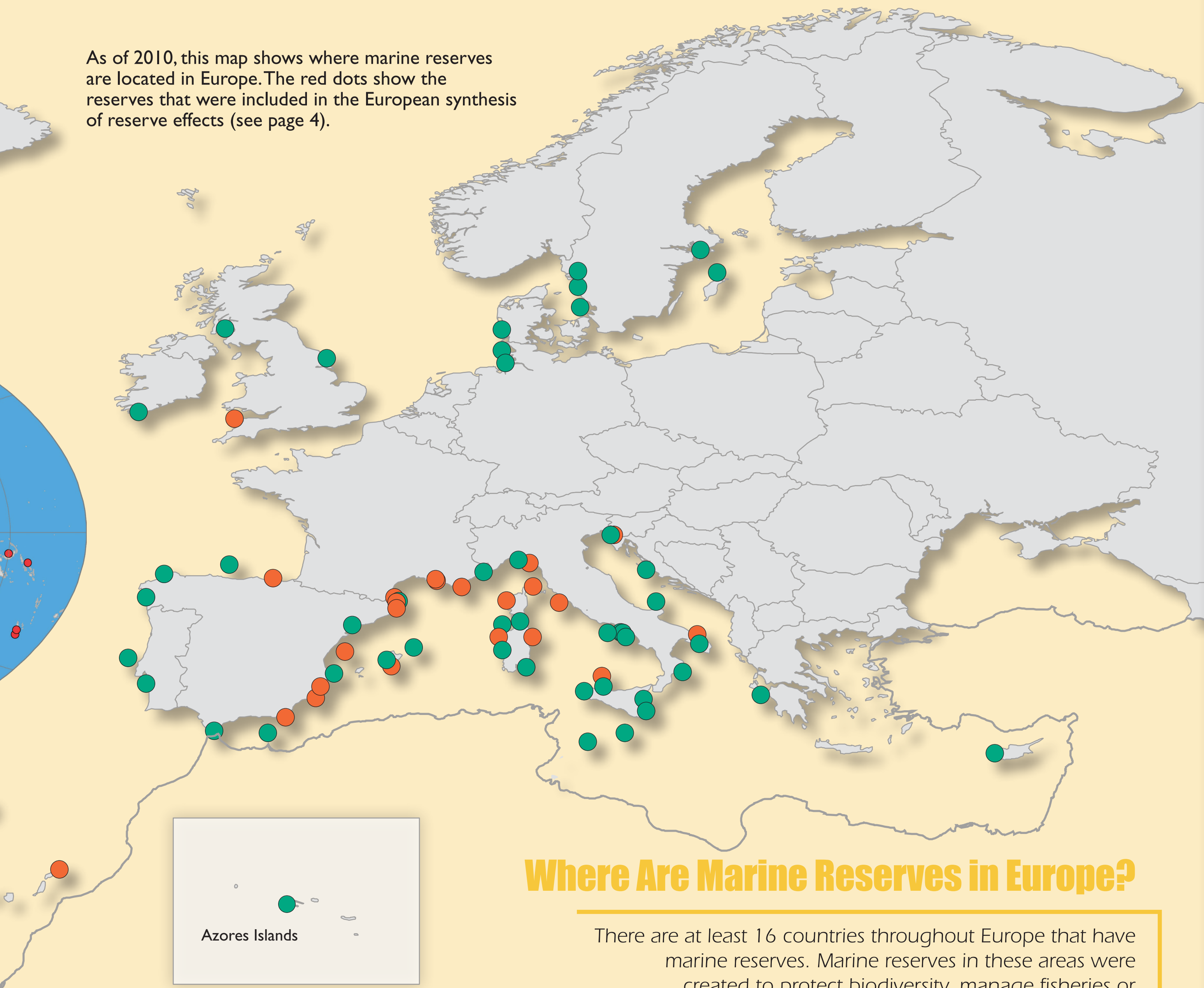
This map shows the locations of the marine reserves that have been included in the global and/or European syntheses of reserve effects on page 4.

The difference in area protected by marine reserves and area protected by other kinds of MPAs is significant because full protection provides more benefits than lower levels of protection. For example, scientific studies demonstrated that fish in Sardinia benefited when they were in marine reserves but not when they were in MPAs where recreational fishing was allowed. A global study of 21 MPAs across 11 countries found that marine reserves sustained higher densities of species than partially protected areas nearby.

Marine reserves are often integrated within MPAs to benefit species and ecosystems. Partially protected areas around marine reserves allow varying levels of local uses such as fishing and diving and can benefit fisheries. For example, scientific studies in Italy demonstrated that catch rates of octopus and commercial fish species within a well-managed partially protected area increased to twice the catch rates outside the MPA after 3 years.

marine reserves studied around the world

As of 2010, this map shows where marine reserves are located in Europe. The red dots show the reserves that were included in the European synthesis of reserve effects (see page 4).



Where Are Marine Reserves in Europe?

There are at least 16 countries throughout Europe that have marine reserves. Marine reserves in these areas were created to protect biodiversity, manage fisheries or restore marine species.

Croatia
Cyprus
Denmark
England
France
Germany
Greece
Ireland
Italy
Malta
Monaco
Portugal
Scotland
Slovenia
Spain
Sweden

Marine Reserve Facts

- **Of the 74 European marine reserves, only 18 occur outside of the Mediterranean Sea and the Azores and Canary Islands.**
- **Most European reserves are quite small. Half of the reserves in Europe cover less than 1.8 square kilometres.**
- **A survey of 15 Italian marine reserves found that only 3 had adequate enforcement.**

Legal Framework

The main legal obligations to designate MPAs in the EU are provided by the Marine Strategy Framework Directive (MSFD) and the Habitats and Birds Directives. Although these do not explicitly require marine reserves, they do require that *coherent networks* of designated sites help achieve *good environmental status* by 2020. These networks will protect habitats and species. Legal obligations such as EU policies, regional seas conventions and the Convention on Biological Diversity, in combination with the best available science, offer an opportunity to further marine conservation throughout Europe.

References: 2, 3, 4, 5, 6, 7, 8, 52

effects of marine reserves inside their borders

Typically when a marine reserve is established, the goal is to increase the abundance and diversity of marine life inside. Scientific research shows that marine reserves consistently accomplish this goal.

More Fishes, Shellfish, and Other Marine Life

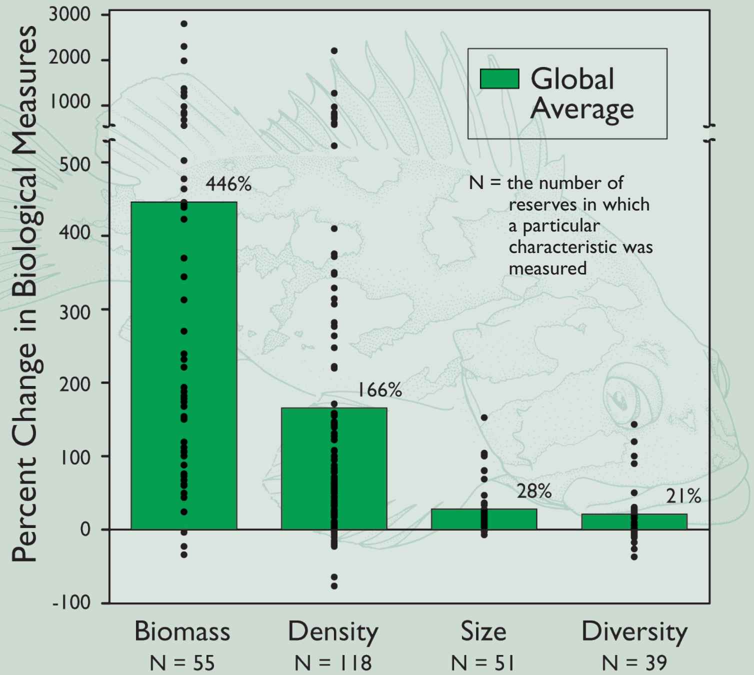
Considerable scientific documentation—published in peer-reviewed journals—provides a clear picture of what has happened after the establishment of marine reserves.

Scientists have studied more than 150 marine reserves around the world and monitored biological changes inside the reserves. In 2006, a global review of many of these studies (see top graph) revealed that fishes, invertebrates and seaweeds have shown average increases in biomass, density, size and diversity inside marine reserves.

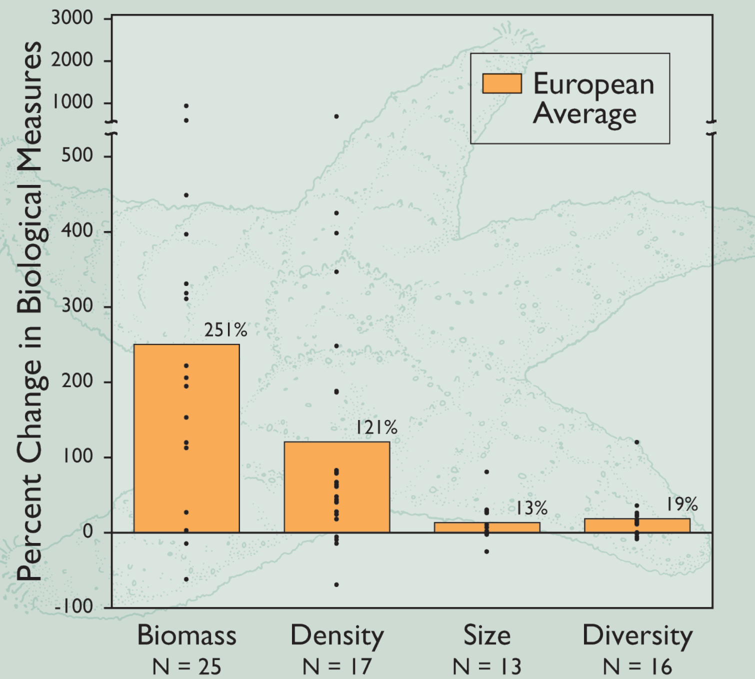
A new review of the studies about marine reserves inside European waters shows similar increases (see bottom graph). Fishes, invertebrates and seaweeds had the following average increases inside European marine reserves:

1. **Biomass,** or the total weight of animals and seaweeds, increased an average of 251%.
2. **Density,** or the number of seaweeds or animals in a given area, increased an average of 121%.
3. **Body size** of animals increased an average of 13%.
4. **Species diversity,** or the number of species, increased an average of 19% in the sample area.

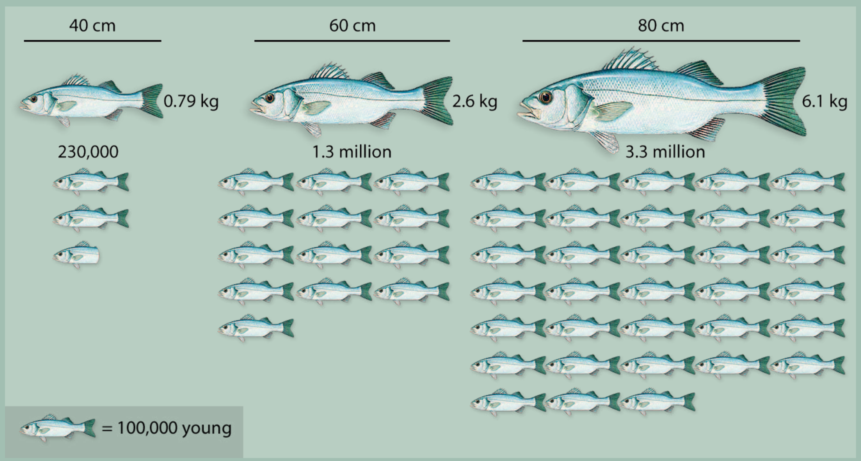
Heavily fished species often showed the most dramatic increases. Some fished species had more than 10 times higher biomass or density inside marine reserves. Species that are not fished can also increase if their habitat is protected. Species diversity and body size have less opportunity for change, but even small increases can be important.



Average changes (green bars) in fishes, invertebrates and seaweeds within marine reserves around the world. Although changes varied among reserves (black dots), most reserves had positive changes. *Data: Ref. 8*



Average changes (orange bars) in fishes, invertebrates and seaweeds within marine reserves in Europe. Although there are far fewer data for Europe, changes as a result of reserve protection look remarkably similar to the global results. *Data: Fenberg et al. in prep*



Average number of young produced by three different sizes of European seabass.

Bigger Animals Have More Young

Fishes and invertebrates grow bigger in marine reserves than in unprotected areas. This effect of marine reserves is extremely important because these large animals contribute much more to the next generation. They produce disproportionately more offspring than small fishes and invertebrates. For example, an 80 cm European sea bass produces 14 times more young than when it was 40 cm (see figure, left). Bigger and more abundant animals living in a marine reserve can produce far more young than their smaller neighbours in unprotected waters.

Reserves Are Effective in Temperate Waters

A global scientific review of biological responses to reserve protection conducted in 2006 (see top figure, opposite page) found that increases in biomass, density, body size and diversity were similar between tropical and temperate reserves. Biomass especially increased dramatically in both temperate and tropical reserves. These findings show that marine reserves can be effective regardless of latitude.

Small Reserves Can Be Effective

Marine reserves included in peer-reviewed scientific studies have ranged in size from 0.006 to 800 square kilometres. The global scientific review in 2006 showed that some species can benefit from small marine reserves. If managed well, even small reserves can produce benefits that are distributed to local people. However, small reserves by themselves cannot protect the numbers of individuals, species and habitat types typically protected by larger reserves.

Species May Increase, Decrease, or Not Change

Although there tend to be large overall increases in biomass, density, size and diversity inside marine reserves, some individual fish and invertebrate species may become more plentiful, while others decline or do not change. In general, species subject to fishing in unprotected waters tend to increase in marine reserves. A worldwide analysis found that 61% of fish species were more abundant inside reserves than outside, while 39% of species were more abundant outside reserves than inside.

Some fish and invertebrate species become less abundant in an area after it is designated as a marine reserve. Such declines generally reflect interactions among species, such as larger numbers of a predator eating more of its prey. For example, an increase in predatory fishes in a Spanish marine reserve led to a decrease in juvenile spiny lobster density inside the reserve.

Similar increases in predators and decreases in prey have been documented inside marine reserves in New Zealand, Australia, Chile and California, USA. These results suggest that natural biological interactions can be protected inside marine reserves.

Fast Facts

- The bigger fishes and invertebrates in marine reserves can produce more young than smaller animals outside reserves.
- In existing marine reserves, many species increased, particularly those that were fished, and some species decreased, such as those that are prey to fished species.
- Marine reserves help to restore the natural range of ages and sizes of many animals.


A diverse community of invertebrates in Italy.
Photo: Keith Hiscock

References: 8, 9, 10, 11, 12, 13, 14, 15, 16

How Long Does It Take to See a Response?

Although some changes happen rapidly, it may be decades before the full effects of a marine reserve are evident. Some fishes, shellfish and other species may not change noticeably in abundance, body size, biomass or diversity for some time. The following traits influence the response time after a reserve is established:

- The availability of breeding adults
- How fast individual seaweeds and animals grow
- The age at which animals and seaweeds can reproduce
- The number of young produced and timing of reproduction
- Characteristics during each life stage, such as young staying within the reserve versus dispersing outside
- Interactions among species, such as predators and prey
- Human impacts prior to reserve establishment, such as the intensity of fishing or amount of seabed damage from dredging
- Continuing impacts from outside, such as pollution and climate change
- The habitat's ability to recover after being damaged
- The level of enforcement used inside the reserve

A forkbeard in Arrábida marine reserve in Portugal. *Photo: Emanuel Gonçalves*

Species Grow and Mature at Different Rates

Fishes and invertebrates vary greatly in how fast they grow and in the age when they can first reproduce (see figure below). These traits influence the response of each species after a marine reserve is established.

Some species—such as plaice—grow quickly, mature at a young age and produce large numbers of young. These animals may multiply rapidly in a marine reserve and become much more abundant within 1 to 4 years.

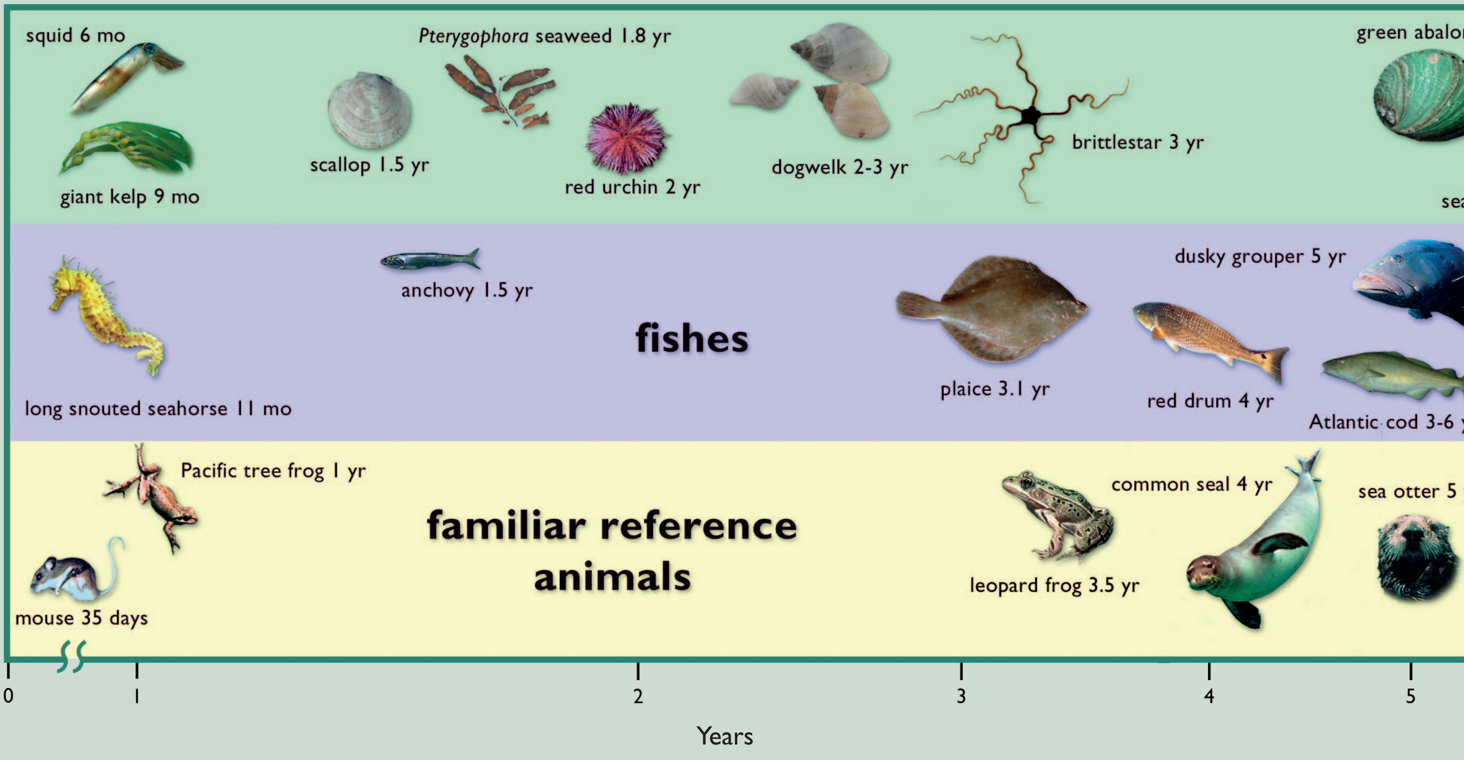
Other species—such as cod, grouper and orange roughy—grow slowly and mature at an older age. These slow-growing species are particularly vulnerable to overfishing. They may take many years to increase noticeably in a reserve.

Fast Facts

- Inside marine reserves, fast-growing fishes and invertebrates that mature quickly and produce many young are likely to increase most rapidly, sometimes within 1 to 4 years.
- Slow-growing fishes and invertebrates that mature at an older age and produce few young may increase slowly inside a reserve over years or decades.
- Some ecological changes may not be evident in a marine reserve for years or even decades after an area is protected.
- Long-term protection and monitoring are necessary to reveal the full effects of marine reserves.

6

Age of Maturity for Selected Species

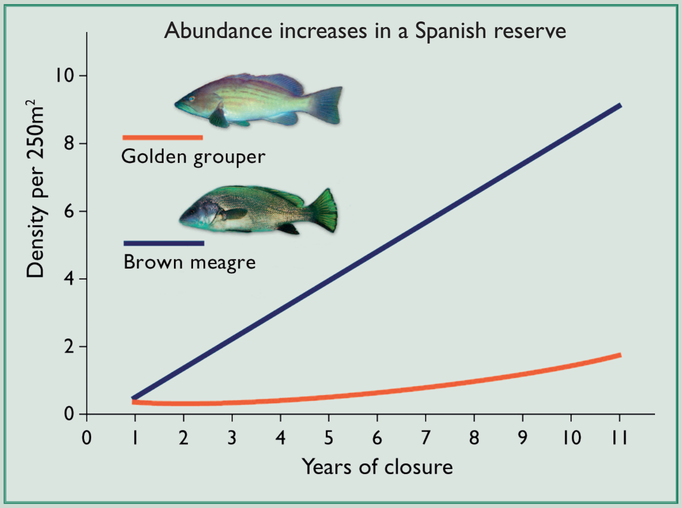


Changes Inside Marine Reserves Occur at Different Times

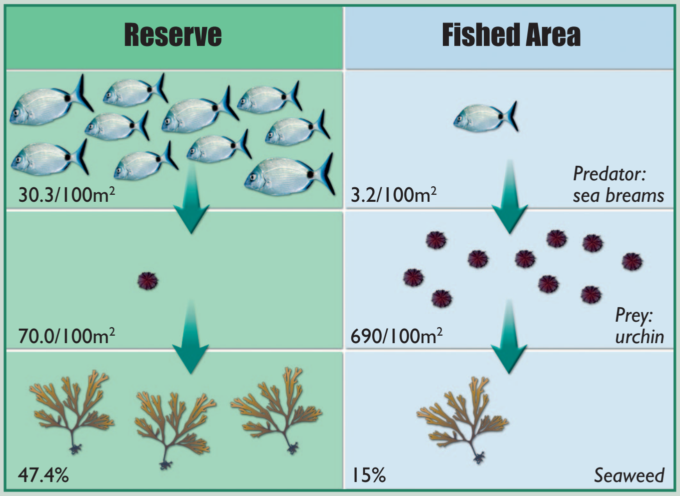
Among the factors affecting the response times of fishes, invertebrates and seaweeds are differences in their age at maturity, reproductive habits, how many young they produce, their interactions with other species, their mobility and the type of habitat in which they live.

Long-lived animals often take decades to fully recover after they are protected. In Spain, two commercially important fishes—the brown meagre and the golden grouper—have increased continually, without stabilising, for 11 years after protection at the Cabo de Palos reserve. This suggests that further increases in abundance will occur and that continued protection is needed for full ecosystem recovery.

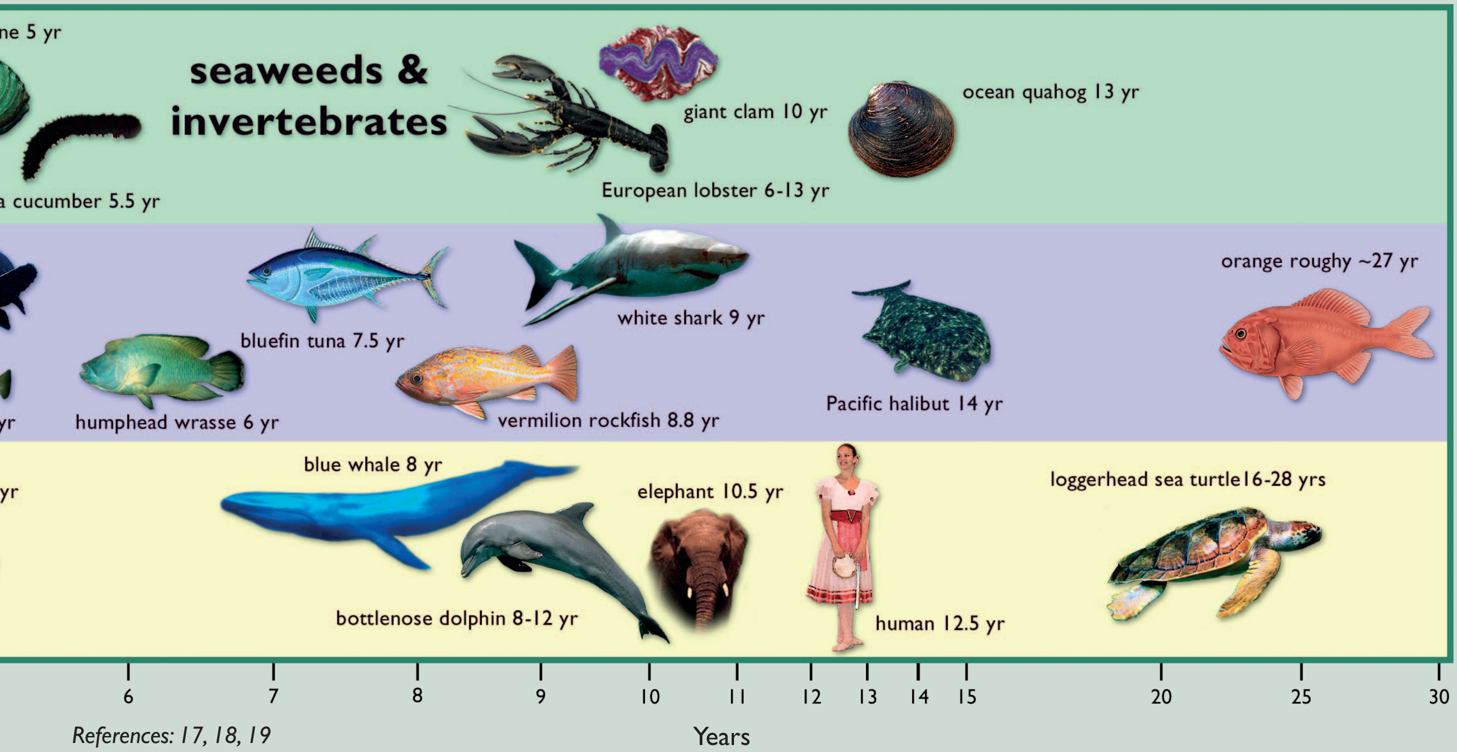
A synthesis of long-term monitoring studies in New Zealand, Australia, California, Kenya and the Philippines found that species targeted by fishing show noticeable responses within 5 years of protection in marine reserves. However, effects on unfished species took longer to appear, detected on average after 13 years of protection. This lag occurs because unfished species can be affected by reserve protection indirectly through interactions with other species. For example, commonly fished sea breams are 2 to 10 times more abundant, and far bigger in size, inside the no-take reserve within the Torre Guaceto MPA in Italy. Sea urchins, which are eaten by sea breams, were 10 times less abundant inside the reserve because of the higher numbers of their fish predators. This effect cascaded further down the food web, increasing the cover of large seaweed to 47 percent of the seabed inside the reserve. Meanwhile, surrounding fished areas where seaweed is grazed down by urchins had only 15 percent cover of seaweed.



Increases in abundance of brown meagre (blue line) and the golden grouper (red line) in the Cabo de Palos reserve. *Data: Ref. 17*



In the no-take reserve within the Torre Guaceto MPA in Italy, abundant sea breams keep their urchin prey in check, enabling seaweeds to flourish. Outside of the reserve, urchin barrens are common. *Data: Ref. 19*

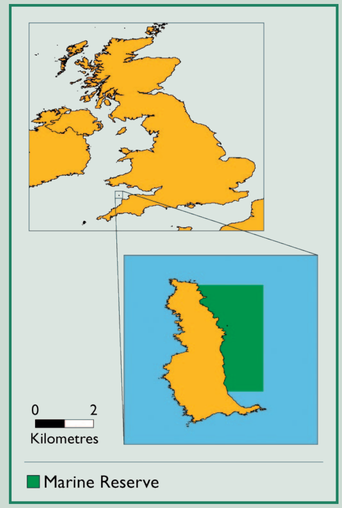


References: 17, 18, 19

Case Study: Lundy, United Kingdom

Coastline of Lundy. *Photo: James Wright*

The European lobster at Lundy. *Photo: Paul Naylor*



Lundy marine reserve, UK

A Marine Reserve Boosts Lobster Abundance and Size

Situated off the southwest coast of England, Lundy is home to species living in diverse habitats, including rocky reefs, sea caves, underwater canyons and sandy bottoms. To further protect habitat and species within a larger existing MPA, a 3.3 km^2 area along the coast of Lundy was designated in 2003 as the first marine reserve in the UK. Some local fishermen supported the Lundy marine reserve in the hopes that they would see higher catches of European lobster, an important commercial species, outside the reserve.

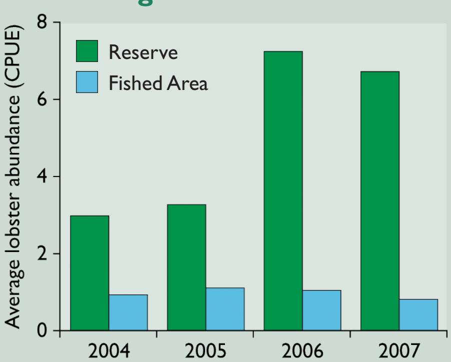
From 2003-2007, scientists monitored lobsters inside the Lundy marine reserve as well as in surrounding fished areas. They detected increases in sizes and numbers of lobster after only 18 months of full protection. By 2007, legal-sized lobsters were 5 times more abundant within the reserve than in fished areas. Scientists also found that lobsters were 9% larger inside the reserve than in the fished areas (see figures below). Legal-sized lobsters adjacent to the reserve had not increased in size or abundance within the 4 years of the study. However, there was an increase in abundance of sub-legal lobsters adjacent to the reserve during the study.

The Lundy marine reserve is small compared to others around the globe. The rapid increase in lobster size and abundance at Lundy, however, suggests that even a small reserve may benefit some species. Over time, further increases in size and biomass may lead to increases in the number of lobsters migrating to areas outside the reserve, which would benefit the lobster fishery. In Columbretes marine reserve in Spain, for example, lobsters increased in abundance and biomass for a decade before contributing to increased lobster catches in nearby fished areas.

Lessons Learned

- Lobsters are 5 times more abundant and 9% larger within Lundy marine reserve compared to fished areas.
- Increases in lobster numbers and sizes occurred at a rapid rate.
- Over time, more lobsters of larger sizes inside a reserve may lead to increased lobster catches in surrounding fished areas, as they did in a Spanish marine reserve.

Average Lobster Abundance



Average Lobster Size

Legal sized lobsters at Lundy marine reserve have become more numerous (left graph) and larger (right graph) since full protection started in 2003. CPUE = catch per unit effort. Lobster size = carapace length. *Data: Ref. 28*

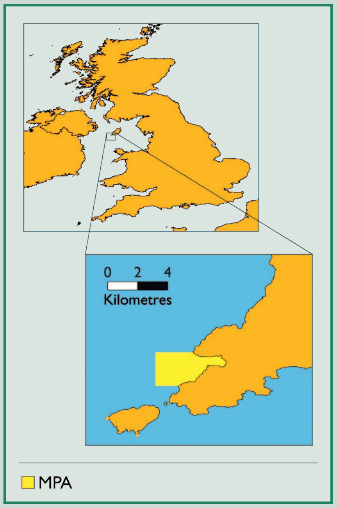
References: 28, 29

An example of a legal-sized lobster (left) and a large lobster (right) found at Lundy reserve. *Photo: Natural England/Chris Davis*

Case Study: Bradda Inshore Fishing Ground, Isle of Man

The great scallop in its natural habitat. *Photo: Port Erin Marine Laboratory, University of Liverpool*

Experimental scallop dredging off the coast of the Isle of Man. *Photo: Bryce Beukers-Stewart*



Bradda Inshore fishing exclusion zone, Isle of Man

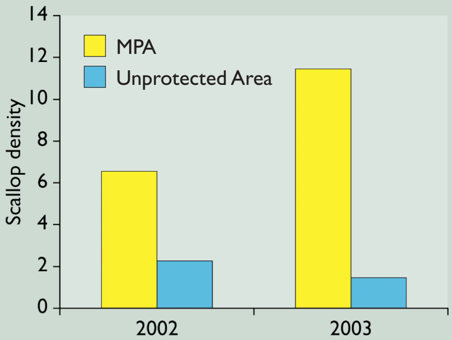
Long-Term Benefits of Seabed Protection

The Bradda Inshore fishing ground off the Isle of Man has supported a major scallop fishery since the 1930s. After 50 years of heavy dredging in the soft sediment habitat, the Bradda Inshore fishing exclusion zone was established in 1989 to protect declining scallop populations and other seabed species by banning trawling and dredging within 2 km^2 of the fishing ground. In 2003, fishermen supported an expansion of the MPA 700 m north of the original boundary.

This area is not a marine reserve because it allows some types of fishing for other species. However, because trawling and dredging—the fishing methods that most impact the seabed—have been banned for over 20 years, it offers an opportunity to study how long-term protection of the seabed benefits resident species and habitats.

Scientists monitored scallops and other seabed species from 1989-2003. Areas protected from dredging supported a more complex and diverse seabed community. Recovery following protection, however, was slow; it took over a decade to see significant increases in scallops within the closed area. After that, scallop numbers increased rapidly, and local fishermen became more supportive of the exclusion zone as scallops rebounded. By 2002, the density of legal-sized scallops had risen to 2.9 times higher and scallop biomass was 4.7 times higher than in nearby fished areas. A year later, density and biomass were 7.8 and 11 times higher, respectively. This pattern of increasing biomass and density over time illustrates the importance of long-term protection.

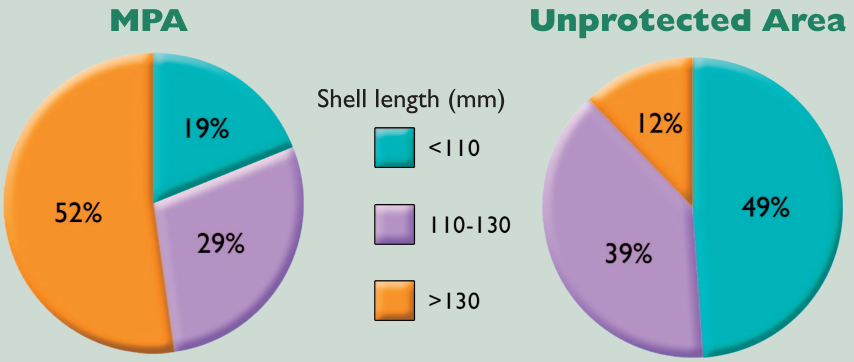
Scallops within the fishing closure are much larger than those outside, which is significant because larger scallops can produce more offspring, potentially helping to enhance surrounding scallop populations. In 2003, over 50% of scallops in the closed area exceeded 130 mm, compared to only about 12% of scallops in nearby fished areas.



Average densities of legal-sized scallops per 100m both inside the Bradda Inshore fishing exclusion zone and outside in adjacent fully fished areas during the years 2002 and 2003. *Data: Ref: 31*

Lessons Learned

- MPAs that prohibit trawling and dredging can have positive effects on target species and habitats.
- After 14 years of protection, scallop density was 8 times greater and biomass was 11 times higher inside a fishing closure than in nearby fished areas.



At left: Scallop sizes within the Bradda Inshore fishing exclusion zone (left) and in surrounding fully fished areas (right) in 2003. *Data: Ref. 31*

References: 30, 31

effects of marine reserves beyond their borders

A marine reserve's effects on fishes, invertebrates and other species are most apparent inside the reserve. However, these impacts may extend to less protected areas outside. Boosts in growth, reproduction and biodiversity in a marine reserve can replenish fished areas when young and adults move out of the reserve.

Fast Facts

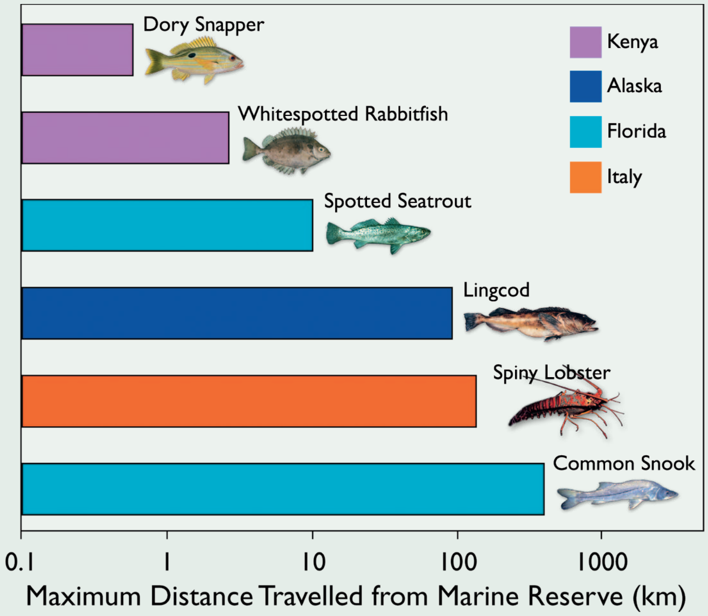
- Some adult and juvenile animals move outside marine reserves to less protected areas.
- Young animals may drift out from marine reserves into fished areas and help replenish local stocks.

Movement of Adults and Juveniles

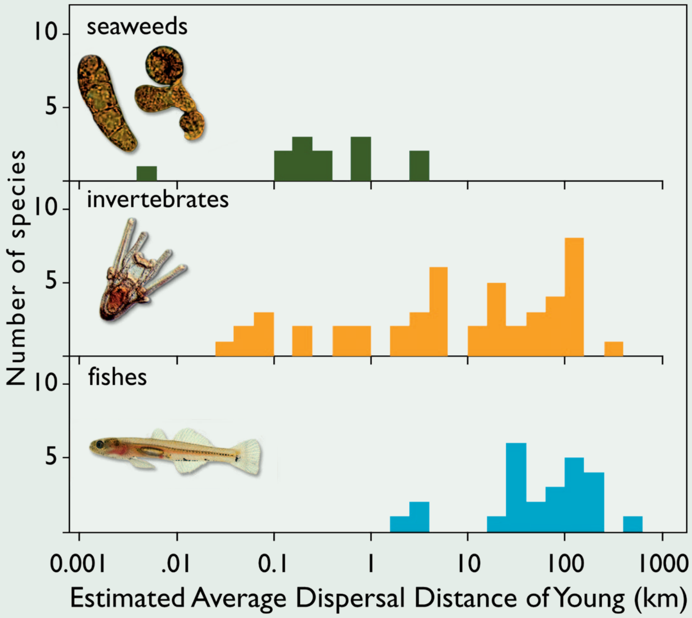
As fishes and invertebrates become more abundant inside a marine reserve, some adults and juveniles may leave the marine reserve to live elsewhere. They also may leave because they need a different habitat as they grow or because they reproduce in a specific place outside the reserve. The spillover of adult and juvenile fishes and invertebrates can contribute to populations living in fished waters outside reserves. Scientists have documented spillover from marine reserves in many locations around the world, including reserves in Spain, France and Italy.

Movement of Young

Fishes, invertebrates and seaweeds typically release huge numbers of tiny young into the open ocean. They can stay there for days or months, potentially travelling far from their origin. Some young produced in a marine reserve may remain inside, while others may settle far away from the reserve. Through this export of young, animals in marine reserves can help replenish populations in outside waters. Scientists are using genetic data, life-cycle information, computer models and advanced tagging techniques to learn how many young are exported from marine reserves and where they go.



The maximum distances that tagged fish and invertebrates travelled from marine reserves in Kenya (violet), Alaska (navy), Florida (turquoise), and Italy (orange). These studies provide direct evidence that fishes and invertebrates spill over from marine reserves into surrounding waters. *Data: Ref. 23, 24, 25, 26*

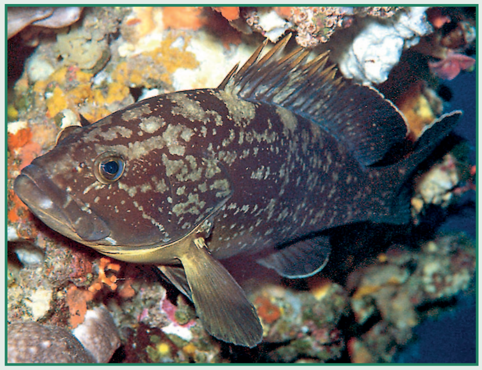


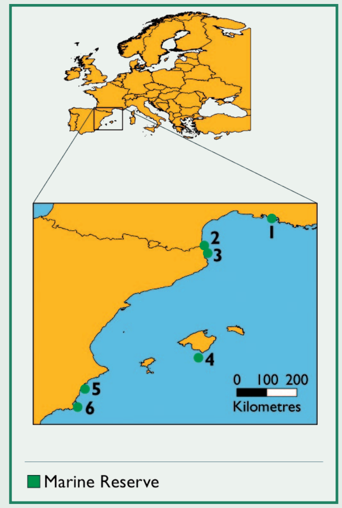
The estimated average distances travelled by young invertebrates (51 species), fishes (26 species), and seaweeds (13 species) prior to settling at their adult habitat. Distances are based on genetic analysis of species around the world. *Data: Ref. 27*

References: 20, 21, 22, 23, 24, 25, 26, 27

Case Study: Western Mediterranean


A Mediterranean fisherman hauls in his catch. *Photo: Paolo Guidetti*


An adult dusky grouper. *Photo: Robert Patzner*



Location of the six Mediterranean marine reserves studied: 1=Carry, 2=Banyuls, 3=Medes, 4=Cabrera, 5=Tabarca, and 6=Cabo de Palos

Fishes Move Outside Mediterranean Marine Reserves

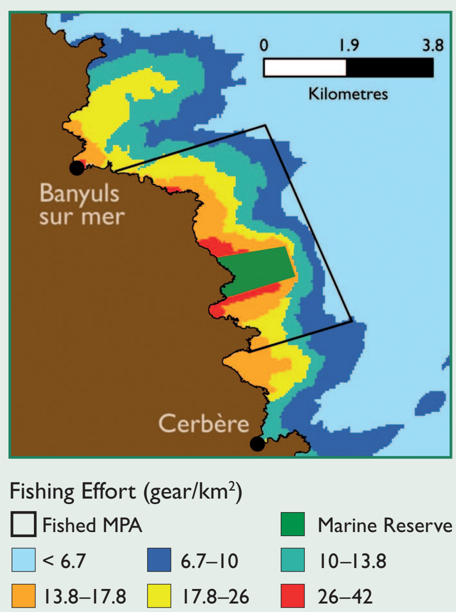
In 2003, scientists and fishermen began a collaborative study of 6 well-enforced marine reserves in the western Mediterranean. Their goal was to determine whether the young and the adults of dozens of commercial fish species move outside fully protected areas, potentially enhancing surrounding fisheries.

They found that across all 6 reserves, average fish biomass was 4.7 times higher and average fish weight was 3.4 times higher inside the reserves than in the surrounding fished areas. Through their video and SCUBA observations, scientists discovered that fish biomass decreased consistently across the reserve borders and into fished areas, indicating that adults were spilling over into fished waters. Data on fishing effort and catches confirmed that fishing boats concentrated near marine reserve boundaries (see example at right), where catch rates were higher.

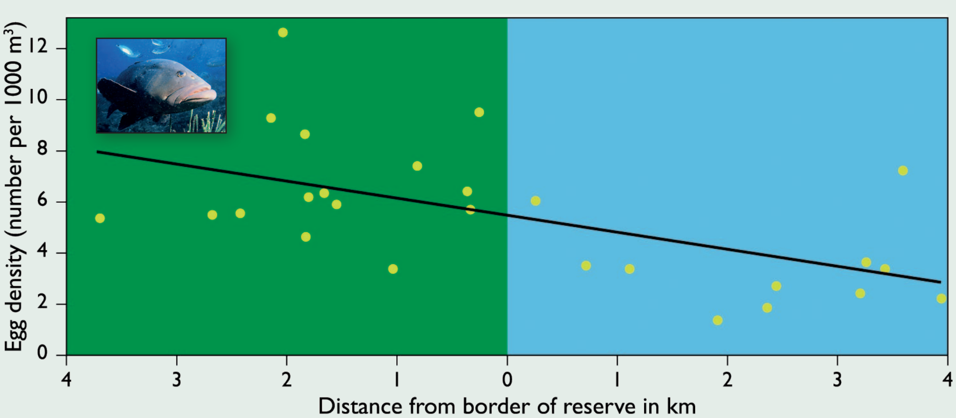
These marine reserves also appear to be a source of fish eggs that can drift outside and support populations beyond the reserve borders. Greater numbers and sizes of adult fish within reserves can produce eggs and young that are exported to fished areas. For example, at Spain's Cabrera reserve, grouper eggs decreased in density from inside the reserve to surrounding fished waters (see figure below) where groupers are rare. Such data provide mounting evidence that reserves can benefit local fisheries by protecting important spawning grounds for commercial fish species.

Lessons Learned

- Adult fishes moved from 6 western Mediterranean marine reserves, where they were most abundant and reached their largest sizes, into nearby fished waters.
- Grouper eggs drifted outside the Cabrera reserve in Spain to surrounding waters.



Map of estimated fishing effort density around the Banyuls marine reserve. Fishing effort concentrates around marine reserve edges. *Data: Ref. 34*



The density of grouper eggs as a function of distance from the Cabrera reserve in Spain. The area shaded in green indicates the location of the reserve. *Data: Ref. 32*

References: 32, 33, 34

scientific considerations for designing marine reserves

Marine reserves are intricately connected with human society and economics. As scientists learn more about marine ecosystems and human interactions with the ocean, analyses suggest that reserves work best when ecological, social and economic considerations are all factored into the design plans. In general, creating reserves involves balancing diverse interests to meet management goals. For example, a large reserve might be ecologically optimal but economically or institutionally impractical. Commonly asked questions about designing marine reserves include:

- **Where should a marine reserve be located?**
- **How big should a marine reserve be?**
- **What are the benefits of a network?**
- **How are marine reserves placed within a network?**


The marine reserve of La Graciosa in the Canary Islands. *Photo: Benutzer Khero*

Reserve Design Depends on the Goals

A successful design for a set of marine reserves depends on clearly stated goals. Clearly defined goals are important because they influence critical decisions about how to design marine reserves.

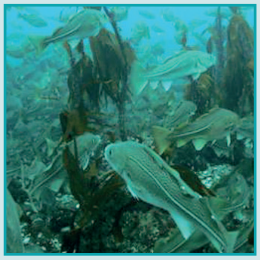
Although ecological goals are often viewed as being in conflict with some social and economic goals, recent research suggests that a properly designed network of marine reserves can lead to both conservation and fisheries benefits. This is because profitable fisheries depend directly on ecosystems that are healthy and resilient over the long term.

Consequently, one important goal for creating marine reserves is to protect or restore an ocean ecosystem, enabling it to provide ecosystem services now and long into the future. These ecosystem services include seafood supply, good water quality, coastal protection and climate regulation (see page 16). Other important goals for marine reserves and surrounding waters are to maintain fishing lifestyles and incomes, provide recreational and cultural opportunities, minimise disruption of human uses of the ocean and provide places for education and research.

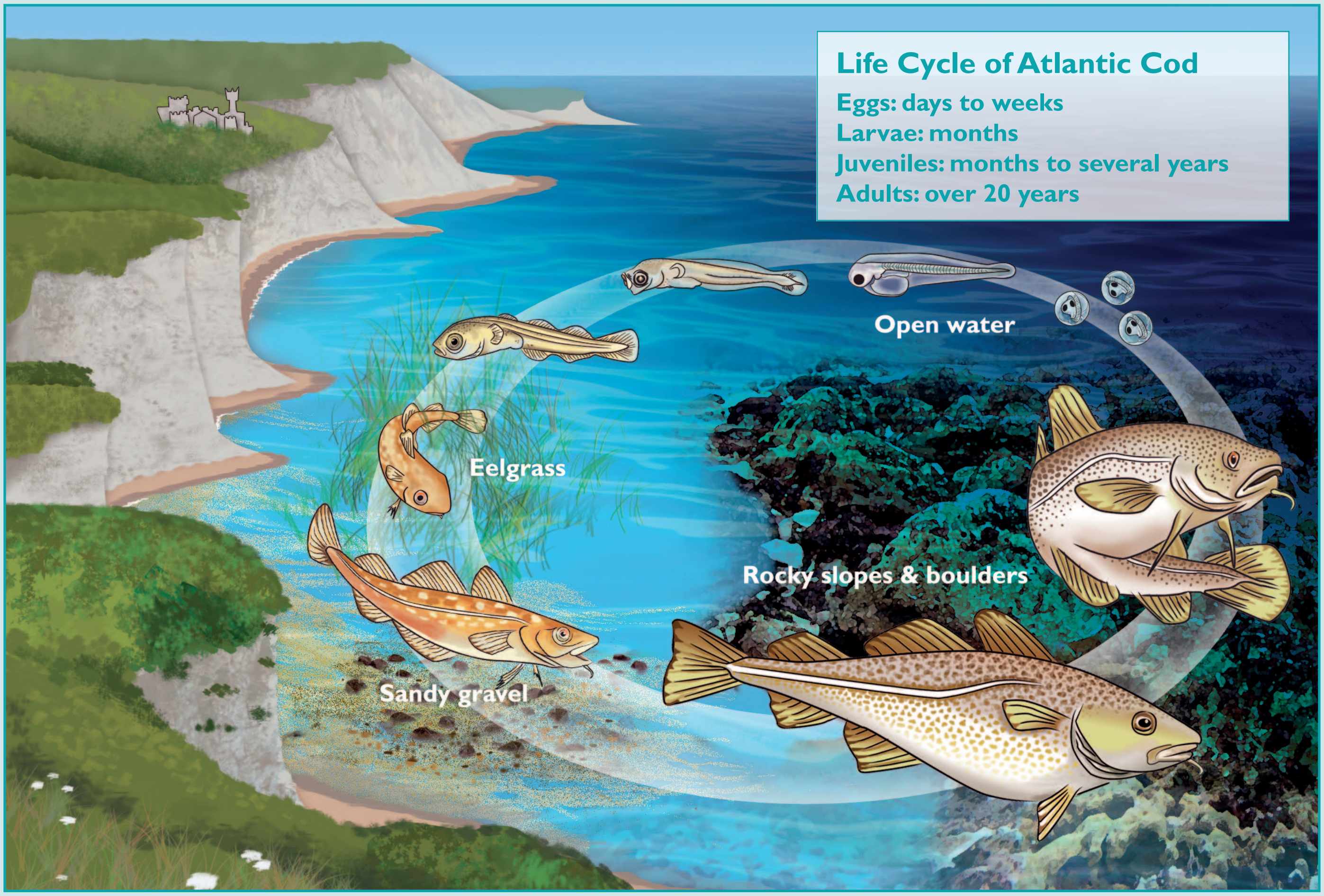
The Role of Reserve Networks

Sometimes it is more economically sustainable to establish several smaller marine reserves instead of one large reserve in a particular area. For example, in some regions it might not be feasible to include a portion of each habitat in a single marine reserve without disrupting human activities. In such cases, ecological benefits can be maximised by creating multiple reserves that are close enough together to act as a network. In a marine reserve network, young and adults travelling out of one reserve may end up being protected in another reserve. Marine reserve networks provide more protection than a set of individual, unconnected reserves.



Photos: Paul Kay, Paul Kay, Paul Naylor, Erlendur Bogason, Paul Kay



The Atlantic cod uses many habitats throughout its life. Open water, eelgrass beds, sandy and gravel areas, kelp, boulder fields and steep rocky ledges are important for growth and survival during different life stages of this fish. *Art by Molly Thomson*

Ocean Ecosystems Depend on Connected Habitats

In the ocean, habitats are connected by movement of animals and seaweeds and through the exchange of nutrients. Most marine animals use more than one habitat during their lives, making them vulnerable to many human impacts.

The Atlantic cod, a commercially important fish found throughout the North Atlantic Ocean, is an example of a species that uses multiple habitats. Adult cod gather and form schools at the same location year after year to release eggs and sperm into the water. In the water column, cod eggs hatch into young, called larvae, that may continue to drift in coastal currents for up to a few months before settling to the seafloor. By the age of three months, most young cod favour shallower areas, particularly rocky areas and eelgrass beds where they are able to hide from predators. As they age, juvenile cod move into slightly deeper water, living in kelp, sandy bottom and rocky habitats. Adult cod may remain stationary or migrate off into deeper habitat and typically live near the seafloor among boulder fields and steep rocky ledges.

Atlantic cod need a range of habitats to thrive from birth through old age. Cod living in different regions prefer distinct areas, increasing the number of habitats that need protection. If a diversity of habitats is not available, their life cycle cannot be completed. Other marine species have similar requirements for multiple habitats over their lifetime.

When species move through multiple habitats as they mature, marine reserves that include those habitats will provide greater benefits.

Fast Facts

- Most marine fishes and invertebrates use more than one habitat during their lives.
- Each habitat is home to a special group of animals and seaweeds.
- When the goal of a marine reserve is to protect many species, key habitats used by vulnerable life stages must be included.

Adult thornback ray winter in deep water and move in to shallow waters to breed in the late spring and summer. Juveniles use shallower, coastal waters as nursery grounds. *Photo: Jim Ellis*

References: 35, 36, 37, 38, 39

Considerations for Individual Marine Reserves

Where Should a Marine Reserve Be Located?

Once it is decided to establish a marine reserve—or more than one—in a region, the next decision is where to put it.

Considerations for locating marine reserves include the following:

- Different habitat types in the region
- Oceanographic features, such as linkages created by ocean currents
- Important places for species of interest, such as spawning grounds
- Locations inhabited by rare or geographically restricted species
- Prior habitat damage and potential for recovery
- Vulnerability to natural and human impacts, including those from which marine reserves do not offer protection, such as pollution
- Location of human activities such as fishing, tourism, transportation, scientific research and cultural or recreational uses
- Perceptions and preferences of local communities and policy makers
- Socio-economic impacts and opportunities provided by a reserve

The importance given to each of these factors varies with the reasons for establishing the marine reserve. For example, if a goal is to support the general health of the marine ecosystem in order to benefit local communities, marine reserves need to protect some of all habitats found in each oceanic region and accommodate human uses of the ocean in the surrounding area.

Some habitats such as maerl beds provide food and shelter for young scallops and cod. Maerl is a vulnerable and slow-growing seaweed that can benefit from reserve protection. *Photo: Paul Kay*

Fast Facts

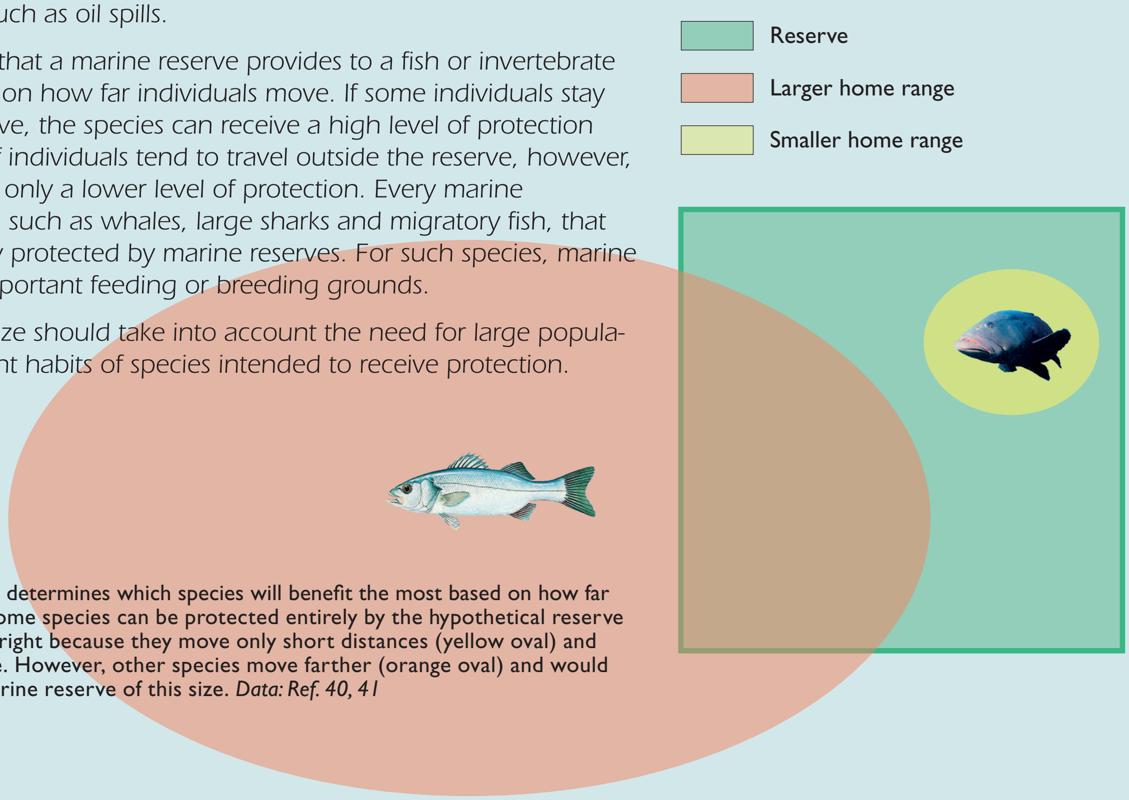
- A small marine reserve can provide some benefits, but by itself it will not be able to protect larger populations of many different species.
- A large marine reserve can have a greater effect because it includes more habitats and more wide-ranging species.
- Reserve size and patterns of animal movement determine the level of protection that a marine reserve provides to each species.

How Big Should a Marine Reserve Be?

Scientific studies show that even small marine reserves can have positive impacts on the abundance, biomass, body size and biodiversity of animals and seaweeds within their boundaries. However, a bigger marine reserve can protect more habitat types, more habitat area, bigger populations of animals and a larger fraction of the total number of species in an ecosystem. Bigger populations in areas with more species are especially important as insurance against catastrophes, such as oil spills.

The level of protection that a marine reserve provides to a fish or invertebrate species depends partly on how far individuals move. If some individuals stay entirely inside the reserve, the species can receive a high level of protection (see graphic at right). If individuals tend to travel outside the reserve, however, the species can receive only a lower level of protection. Every marine ecosystem has animals, such as whales, large sharks and migratory fish, that move too far to be fully protected by marine reserves. For such species, marine reserves can protect important feeding or breeding grounds.

The choice of reserve size should take into account the need for large populations and the movement habits of species intended to receive protection.



The size of a marine reserve determines which species will benefit the most based on how far the adults move. Adults of some species can be protected entirely by the hypothetical reserve (green box) in the figure at right because they move only short distances (yellow oval) and may never leave the reserve. However, other species move farther (orange oval) and would likely benefit less from a marine reserve of this size. *Data: Ref. 40, 41*

Considerations for Marine Reserves in Networks

What Are the Benefits of a Network?

In many cases, a well-designed network of several small- or medium-sized reserves in a region may accomplish the same goals as a single very large reserve. The most suitable type of network depends on the management goals. For example, a **conservation network** can meet the goal of conserving biodiversity by protecting threatened species or habitats in multiple reserves. A **fishery management network**, on the other hand, seeks to benefit fisheries, for example by protecting key sites such as spawning grounds. Healthy populations inside marine reserves can then seed fished populations outside. Both of these network types may include other types of MPAs in addition to reserves.

Conservation and management goals are enhanced if the reserves in a network are effectively connected to each other and to outside areas through the movement of adults and young. Young invertebrates and fishes generally are not vulnerable to fishing so a portion of the population may disperse safely among reserves, providing a source of young for both reserves and fished areas.

Fast Facts

- A network of several smaller marine reserves and MPAs can be a viable alternative to one large reserve or MPA.
- A network can function to protect multiple habitats and species and to meet both conservation and management goals.
- Reserves within a network should be spaced closely enough that young fishes and invertebrates can move among them.

How Are Reserves Placed Within an MPA Network?

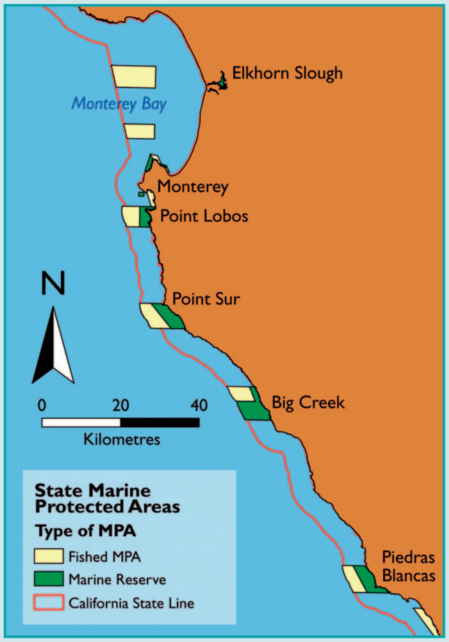
Marine reserves placed within a network of MPAs can allow some types of fishing and other activities to occur in areas of partial protection between the reserves. One way to determine where to place reserves in a network is by establishing them in multiple habitats, ensuring that multiple species are protected. Additionally, it can be helpful to place multiple reserves in the same habitat type to provide insurance, because a catastrophe affecting populations and habitats in one reserve may not affect other reserves.

For a group of marine reserves and other types of MPAs to function as an **ecologically coherent network**, or connectivity network, protected sites must be placed close enough to be connected through the movements of young. Ecosystems are better protected if the young fishes and invertebrates that leave one reserve are able to settle successfully into another.

For many coastal species, the young, called larvae, move farther than adults. As a result, individual reserves in a network may be designed so that they are large enough to accommodate the movement of adults within their borders, while spacing reserves at appropriate distances accommodates the longer-distance movement of larvae among reserves.

In California, USA, the Marine Life Protection Act required the creation of a network of reserves and other MPAs to protect marine ecosystems. Using the best available science on distances moved by larvae and adults, a series of guidelines were created for size and spacing of MPAs (see figure at right). By 2010, 51 MPAs, including 26 marine reserves, were implemented along the central and north central California coast. A similar approach is being adopted in parts of UK waters.

A Network of MPAs



Part of a network of marine reserves (green) and fished MPAs (yellow) established along the central coast of California in 2007.

Photos: Paul Naylor, Getxotarra, AnticheSere

References: 40, 41, 42, 43, 44

People and Marine Reserve Design

Human Dimensions

The socio-economic costs and benefits of marine reserves influence their planning, design and eventual outcomes. Broader policy issues, such as the relationship between marine reserves and other fisheries management practices, also play an important role. For example, reserves alone cannot protect ocean biodiversity or fisheries if unsustainable fishing occurs in waters outside marine reserves. Increased attention to the human dimensions of marine reserves and ocean governance will be necessary to ensure effective management over the long term.

Social scientists have begun to identify the social and economic factors that enhance the success of marine reserves:

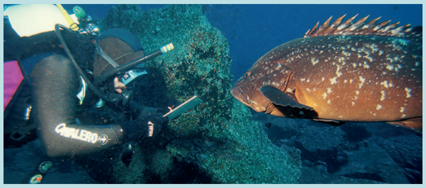
- ***Clear objectives***
- ***Supportive institutions and legislation***
- ***High community participation in decision-making***
- ***Involvement of people with different interests***
- ***Open communication about reserve goals, obligations and restrictions***
- ***Effective use of scientific information***
- ***Effective conflict-resolution mechanisms***
- ***Sustainable funds to support planning and monitoring***
- ***Initiatives to provide equitable sharing of economic benefits***
- ***Fair and effective enforcement***

Quick Summary

- Marine reserves can help sustain valuable services provided by ecosystems.
- People are important players in the ocean ecosystem. They have many different viewpoints that can be incorporated into the design of marine reserves.
- Community involvement, education, enforcement and long-term funding are crucial for the success of marine reserves.
- Marine reserves can generate economic benefits.

Photos clockwise from upper left: Emanuel Gonçalves, Jane Lubchenco, Natural England/Rachel Penny, Emanuel Gonçalves, Emanuel Gonçalves, Ernesto Weil

What Are Ecosystem Services?



People—even those who live far from the sea—depend on ocean and coastal ecosystems for their survival and well-being. Benefits produced by ecological systems are called ecosystem services. Examples of ecosystem services provided by the ocean and coast include: seafood supply; climate regulation; recycling of nutrients; protection of coasts from erosion; removal of excess nutrients coming from the land; and provision of recreation, inspiration and cultural heritage.

Coastal ecosystems provide essential services, but they suffer some of the most intense human impacts. People often take these ecosystem services for granted and do not recognize how the impairment or loss of these services can affect their communities.

For example, towns and cities can become more vulnerable to natural catastrophes such as intense storms and flooding when urbanization degrades rocky reefs, kelp forests, coastal wetlands, sand dunes and other natural features that normally offer protection from storms. By protecting marine habitats and species in one place, marine reserves can help to sustain the ecosystem services that humans want and need.

References: 45, 46, 47

People and Marine Reserve Design

How Do People Influence the Planning and Design of Marine Reserves?

As people are involved in marine reserve planning, many different viewpoints can be accommodated while still achieving conservation and management goals. Both scientific and socio-economic priorities are important in the design and planning of marine reserves. The following are important human factors to consider:

Existing Patterns of Human Activities

Maps showing where human activities—such as fishing, aquaculture, seabed mining and energy production—occur in the ocean can be used to reduce the potential negative effects of marine reserves on people's lives and the economy.

Cultural Values

Sometimes marine reserves can protect areas of historical, cultural or spiritual significance. Historians and cultural experts should be consulted to determine how marine reserves could help achieve this goal.

Compliance and Enforcement

If users have participated in the decisions that lead to restrictions they will be more aware of the objectives, boundaries and use restrictions. They are then more likely to cooperate and encourage other users to comply. This compliance is essential for successful conservation. Effective enforcement, for example by government wardens or members of the community, is also essential to ensure the compliance of all users. Compliance is likely to be most successful if policy mechanisms ensure integration across different levels of government and different user groups.

Monitoring

Monitoring ecological, social and economic changes associated with marine reserves is critical to determine if management goals are being achieved. Scientists, fishermen and reserve managers can collaborate to plan and implement monitoring programs.

Long-term Support

Ecological benefits that build up over decades can be wiped out in a year or two if a marine reserve is not maintained and enforced. Long-term arrangements for funding, training, management and other support are essential.

A fisherman looks out over the Irish Sea from his boat. *Photo: Natural England/Charlie Hedley*

SCUBA-diving in the Medes Island marine reserve adds an estimated value to the local economy of over €1.1 million annually. *Photo: Cristof deErisch. Data: Ref. 50*

Economic Impacts

The economic impacts of marine reserves are complex because they differ by site and business sector. Because marine reserves protect valuable ecosystem services that otherwise may be lost, a well-designed and enforced network of marine reserves could generate an overall long-term economic benefit.

After a marine reserve is established, fishing revenues may drop in the short term unless catches in another area can compensate. In a matter of years, the growth and reproduction of fishes and invertebrates in a marine reserve may boost fishing revenues.

For example, a survey of 12 southern European reserves found that 54 jobs were created per reserve and that commercial fishing around reserves generated €720,000 to local economies per year, on average. Alternative income opportunities can result from increases in local tourism. Some marine reserves draw sightseers, kayakers, scuba divers and other tourists, who add money to the local economy.

References: 45, 46, 47, 48, 49, 50, 51

the process of planning marine reserves

What Role Can Science Play?

Marine reserves are not designed by scientists alone. Establishing marine reserves usually involves people with diverse backgrounds in resource use, marine policy, natural and social sciences, business, conservation and ocean recreation. These people can use traditional knowledge and scientific information about habitats, species diversity, human uses and other factors to make informed decisions about marine reserves. In addition to this information, decision-makers usually consider people's short and long-term goals.

An analysis of marine reserve planning demonstrates that clear goals, effective use of scientific information and participation of multiple groups affect reserve success. The following 3 case studies are examples of different ways in which science has provided information for people engaged in creating marine reserves in diverse social and economic settings in Europe.

Lessons Learned

- Science should be used to make informed decisions about reserves.
- Involvement of stakeholders is vital for design, management and enforcement of marine reserves.
- Support from local, national and international government is critical for long-term effectiveness.
- Well-managed partially protected areas can complement marine reserves to allow a range of uses.

Case Study: Torre Guaceto Protected Area, Italy

The Torre Guaceto MPA covers over 22 km^2 of the Adriatic Sea in southeastern Italy and includes a 1.8 km^2 marine reserve, although initially the entire MPA was closed to fishing. Effective enforcement began in 2001, 10 years after the MPA was designated. By 2003, the MPA had 2 to 10 times as many sea breams, which are important commercial fishes, compared to a fully fished area.

The Torre Guaceto MPA is located adjacent to an artisanal fishing community. In 2005, scientists and fishermen who collaboratively studied the MPA designed an adaptive co-management plan to allow fishing in a partially protected area of the MPA. This plan was designed to sustain fishermen's income while also limiting fishing impacts. Scientists and fishermen worked together to select fishing gear that would minimise harm to the underwater habitats and protect functionally important fish predators and young fishes. Fishermen also agreed to fish only one day per week in the MPA.

Immediately after fishing was allowed in the partially protected area of the MPA, fishermen saw an increase in their income. Catch rates of commercially fished species including striped red mullet, octopus and peacock wrasse averaged 4 times higher than catch rates outside of the MPA. After a few years, catch rates within the partially protected area had stabilised to a level that was greater than double the catch rates outside the MPA.

Collaboration and co-management among fishermen, managers and scientists allowed for the maintenance of sustainable fisheries and the avoidance of overfishing in the partially protected area in Torre Guaceto. Many fishermen support the MPA, including the marine reserve portion, because of the long-term benefits they receive for their fishery. Increased trust and collaboration between scientists and fishermen is essential to designing marine reserves within MPAs that can benefit both conservation and fisheries.

Torre Guaceto Marine Reserve, Italy

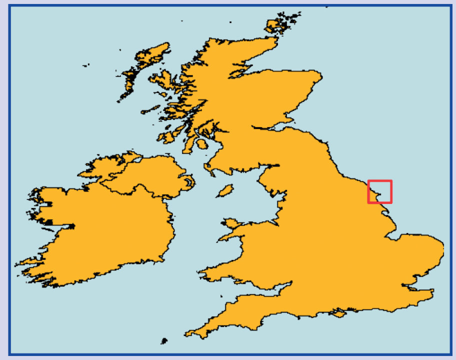
Scientists and fishermen study red striped mullet caught outside Torre Guaceto marine reserve. *Photo: Paolo Guidetti*

References: 52, 53, 54, 55, 56

Case Study: Flamborough Head, United Kingdom

In 2010, a portion of Flamborough Head marine protected area was designated as the first UK marine reserve in the North Sea. Collaborative efforts led by the local fishing community helped ensure that part of this MPA, originally established in 1993, is fully protected.

The Flamborough Head region was designated as a Special Area of Conservation under European legislation due to its extensive coastal chalk cliffs and its rich subtidal biodiversity. Flamborough Head is one of the northernmost extensions of chalk coast in Britain and harbours a diverse set of marine species. Given that this is an area of conservation concern and an important region for numerous economic activities—including commercial and recreational fisheries, tourism, research, wind energy and shipping—a zoning scheme that includes both no-take and multi-use zones is critical to management in Flamborough Head.



Flamborough Head, UK

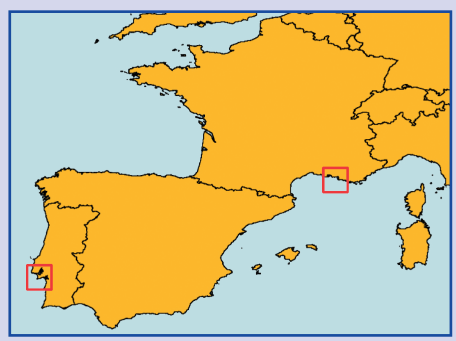
Designing the Flamborough Head marine reserve was complex due to the diversity of economic uses occurring in the MPA. Through a collaborative process, fishermen, scientists and policy makers determined the size and location of the no-take zone by balancing the closed area with the other uses in the MPA. With help from the local fishing industry, scientific research and monitoring are now underway to assess the effects of protection on the diverse species and habitats at Flamborough Head.

Flamborough Head. *Photo: Vicki Turner*

The zoning of the Flamborough Head MPA is an example of marine spatial planning, which can be an effective way to integrate the ecological benefits of reserves and the value of commercial and recreational activities. The management of multiple uses in the Flamborough Head region aims to protect a healthy ecosystem inside the reserve while also providing adjacent areas for sustainable fishing and recreation.

Case Study: Arrábida and Côte Bleue Marine Parks, Portugal and France

Baseline data collected before the implementation of marine reserves is essential to disentangle the effects of natural variation in ecosystems from the direct results of protection. The Arrábida Marine Park in Portugal, which includes a marine reserve, and the Côte Bleue Marine Park in France, which includes the Carry and Couronne marine reserves, are two of the few cases where 'before' data were collected. In both cases, ongoing monitoring involves scientists and fishermen working together to assess the ecological and fisheries benefits provided by the reserves. The Arrábida Marine Park was implemented in 2005 and fish data have been collected by visual census since 1992. In Côte Bleue Marine Park, managers, scientists and fishermen have been cooperatively monitoring the marine reserves since 1995 by collecting fisheries and ecological data such as experimental fishery data and visual census data of fish populations.



Arrábida and Côte Bleue Marine Parks, Portugal and France

In Arrábida Marine Park, a plan to adaptively manage the local fisheries required that the marine reserve rules be gradually implemented over a 4 year period. The management plan specifies that fisheries and conservation authorities should work with fishermen to co-manage the area surrounding the marine reserve. These collaborative monitoring approaches ensure community involvement in conservation and reserve management. Both Arrábida and Côte Bleue highlight the need to develop common and consistent monitoring plans throughout Europe. Similar monitoring data can provide ecological and socio-economic indicators to evaluate and compare the overall effects of marine reserves across locations.

Arrábida Marine Park in Portugal. *Photo: Emanuel Gonçalves*

summary: marine reserves contribute to ocean health

Scientific evidence clearly shows that people are causing a decline in the ocean's health. Marine reserves have proved to be an effective way to protect habitats and biodiversity in the ocean. While marine reserves are not a cure-all, they are important for sustaining ocean life and human well-being.

People Have Created Marine Reserves Around the World

At least 61 countries—ranging from small islands to large nations—have established marine reserves in temperate and tropical regions. Scientific studies on the effects of marine reserves in at least 150 reserves have been published in peer-reviewed journals as of 2010. Data from these studies support reliable conclusions about the effectiveness of marine reserves. Although numerous marine reserves have been established, they cover only approximately 0.1% of the world's oceans.

Marine Reserves Help to Sustain Ocean Life

Inside marine reserves, the abundance, diversity, biomass and size of fishes, invertebrates and seaweeds usually increase dramatically. Species that are commercially targeted show the biggest changes, sometimes increasing by 10 or 20 times in marine reserves. These outcomes are consistent across different habitats and may spillover to areas receiving less protection. Some species and habitats take many years—even decades—to respond, and the benefits can be removed in 1 to 2 years if the area is reopened to fishing.

Marine reserves support many ecosystem services, such as recycling of nutrients and protection of the coast from erosion, which are vital for the well-being of people living near marine reserves. The ecosystem in a marine reserve may withstand climate change and other environmental stresses better than altered ecosystems outside. Marine reserves provide a baseline for understanding how human activities affect other parts of the ocean, and they can protect places in the ocean with cultural and spiritual significance.

Marine Reserves Are Only Part of the Solution

Marine reserves and other types of MPAs lead to different outcomes than traditional management approaches because they can protect a wide range of animals, seaweeds and habitats within a specific area. However, other effectively implemented management practices, such as marine spatial planning, gear restrictions and biodiversity monitoring are necessary for sustainable management of the ocean. In practice, marine reserves require complementary management tools because marine reserves cannot protect against all types of human impacts affecting the ocean. Additional impacts, such as pollution and climate change, must be addressed in other ways. Marine reserves are best viewed as an important tool, but not the only tool, to protect the health of the ocean.





Photos, top to bottom: Karen Davies, Paul Kay, Paul Kay, Paul Naylor, Emanuel Gonçalves

selected references

These references contain information cited directly in *The Science of Marine Reserves*. There are many additional scientific references about marine reserves found in peer-reviewed publications and educational booklets for a range of audiences.

General

1. Millennium Ecosystem Assessment, www.maweb.org
2. IUCN (2010) Global Ocean Protection: Present Status and Future Possibilities
3. Spalding MD, et al. (2008) Conservation Letters 1: 217–226
4. Wood LJ, et al. (2008) Oryx 42: 340–351
5. Di Franco AD, et al. (2009) Marine Ecology Progress Series 387: 275–285
6. Lester SE, Halpern BS (2008) Marine Ecology Progress Series 367: 49–56
7. Guidetti P, et al. (2008) Biological Conservation 141: 699–709

Effects of Marine Reserves Inside Their Borders

8. Lester SE, et al. (2009) Marine Ecology Progress Series 384: 33–46
9. Mayer I, et al. (1990) Journal of Fish Biology 36: 141–148
10. Ergunden D, Turan C (2005) Pakistan Journal of Biological Sciences 8: 1584–1587
11. Micheli F, et al. (2004) Ecological Applications 14: 1709–1723
12. Diaz D, et al. (2005) New Zealand Journal of Marine and Freshwater Research 39: 447–453
13. Shears NT, Babcock RC (2003) Marine Ecology Progress Series 246: 1–16
14. Graham NAJ, et al. (2003) Environmental Conservation 30: 200–208
15. Duran LR, Castilla JC (1989) Marine Biology 103: 555–562
16. Behrens MD, Lafferty KD (2004) Marine Ecology Progress Series 279: 129–139
17. García-Charton J, et al. (2008) Journal for Nature Conservation 16: 193–221
18. Babcock RC, et al. (2010) Proceedings of the National Academy of Sciences 107: 18256–18261
19. Guidetti P (2006) Ecological Applications 16: 963–976

Effects of Marine Reserves Beyond Their Borders

20. Roberts CM, et al. (2001) Science 294:1920–1923
21. Goñi R, et al. (2008) Marine Ecology Progress Series 366: 159–174
22. Guidetti P (2007) Conservation Biology 21: 540–545
23. Kaunda-Arara B, Rose GA (2004) Environmental Biology of Fishes 70: 363–372
24. Johnson DR, et al. (1999) North American Journal of Fisheries Management 19: 436–453
25. Starr RM, et al. (2004) Canadian Journal of Fisheries and Aquatic Sciences 61: 1083–1094
26. Follesa MC, et al. (2009) Scientia Marina 73: 499–506
27. Kinlan BP, Gaines SD (2003) Ecology 84: 2007–2020

Case Studies: Impacts Inside and Outside

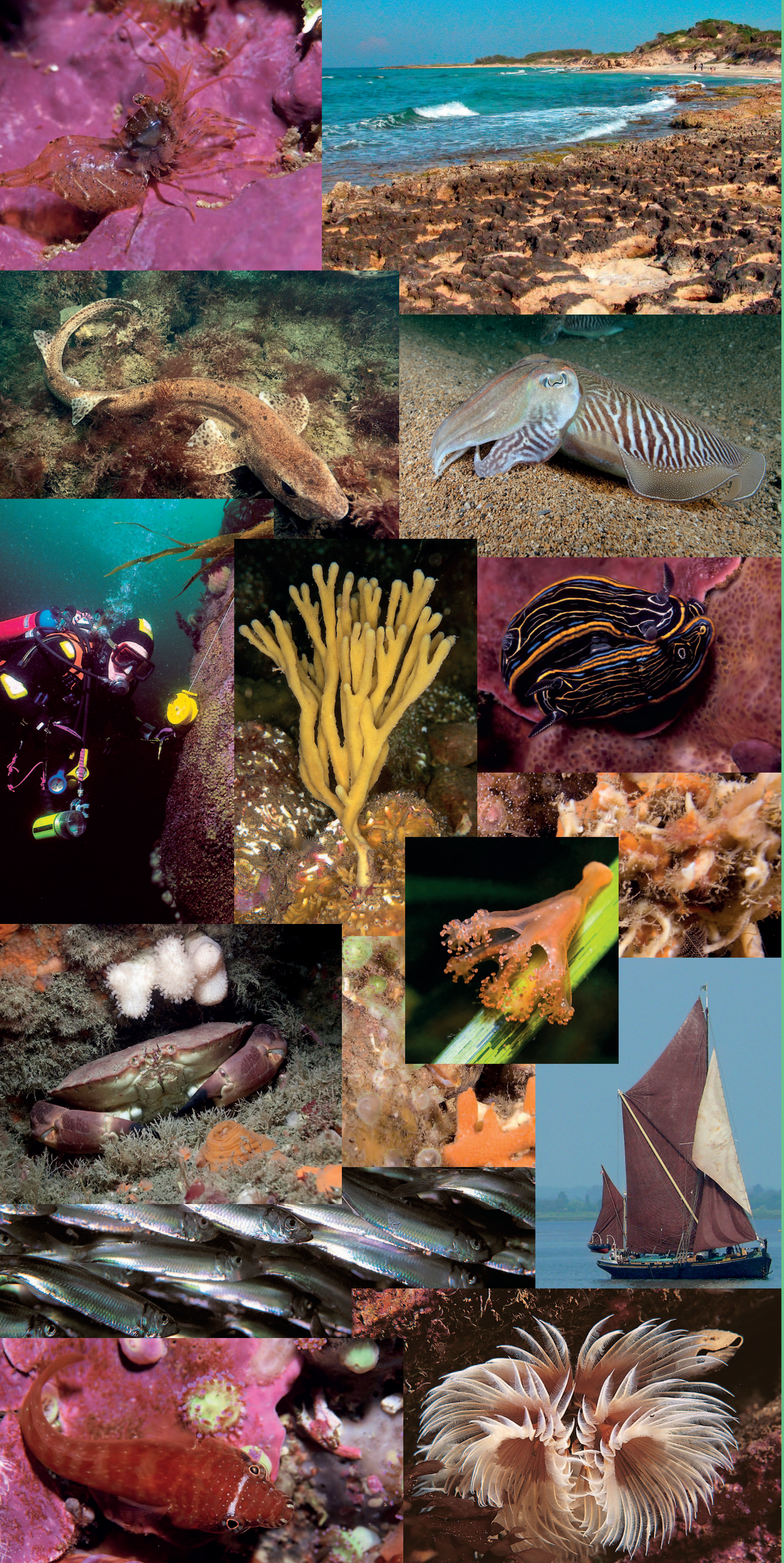
28. Hoskin M, et al. (2011) Canadian Journal of Fisheries and Aquatic Sciences
29. Goñi R, et al. (2010) Marine Ecology Progress Series 400: 233–243
30. Bradshaw C, et al. (2001) Hydrobiologia 465: 129–138
31. Beukers-Stewart BD, et al. (2005) Marine Ecology Progress Series 298: 189–204
32. Crec'hriou R, et al. (2010) Fisheries Oceanography 19: 132–150
33. Harmelin-Vivien ML, et al. (2008) Biological Conservation 141: 1829–1839
34. Stelzenmüller V, et al. (2008) Marine Pollution Bulletin 56: 2018–2026

Considerations for Designing Marine Reserves

35. Palumbi SR (2004) Annual Review of Environment and Resources 29: 31–68
36. Robichaud D, Rose GA (2004) Fish and Fisheries 5: 185–214
37. Vytenis G, et al. (1997) Canadian Journal of Fisheries and Aquatic Sciences 54: 1306–1319
38. Cote D, et al. (2004) Journal of Fish Biology 64: 665–679
39. Berg E, Albert OT (2003) ICES Journal of Marine Science 60: 787–797
40. Pastor J, et al. (2009) Comptes Rendus Biologies 332: 732-740
41. Pawson MG, et al. (2007) ICES Journal of Marine Science 64: 332–345
42. Grorud-Colvert K, et al. (in press) *Marine Protected Areas—A Multidisciplinary Approach*, ed. J Claudet
43. California Marine Life Protection Act Initiative. Master Plan Framework, California Fish and Game. January 2008. http://www.dfg.ca.gov/mlpa/pdfs/revisedmp0108.pdf
44. Gleason MS, et al. (2010) Ocean & Coastal Management 53: 52–68
45. White AT, et al. (2002) Coastal Management 30: 1–26
46. Jones PJS (2001) Reviews in Fish Biology and Fisheries 11: 197–216
47. Jones PJS (2009) Marine Policy 33: 759–765
48. Sanchirico JN, et al. (2006) Ecological Applications 16: 1643–1659
49. Mangi SC, Austen MC (2008) Journal for Nature Conservation 16: 271–280
50. Roncin N, et al. (2008) Journal for Nature Conservation 16: 256–270
51. Angulo-Valdés, Hatcher BG (2010) Marine Policy 43: 635-644

Case Studies: Science and Marine Reserve Planning

52. Guidetti P, Claudet J (2009) Conservation Biology 24: 312–318
53. Guidetti P (2007) Conservation Biology 21: 540–545
54. Joint Nature Conservation Committee, http://www.jncc.gov.uk/protectedsites/sacselection/sac.asp?eucode=uk0013036
55. Gonçalves EJ, et al. (2003) *Proceedings of the World Congress on Aquatic Protected Areas*, eds. JP Beumer, A Grant, DC Smith
56. Claudet J, et al. (2006) Biological Conservation 130: 349–369



Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)

For more information:
www.piscoweb.org/outreach/pubs/reserves
www.piscoweb.org
pisco@piscoweb.org

PISCO
University of California, Santa Barbara
Marine Science Institute
Santa Barbara, CA 93106-6150

PISCO
University of California, Santa Cruz
Long Marine Laboratory
100 Shaffer Road
Santa Cruz, CA 95060

PISCO
Stanford University
Hopkins Marine Station
Oceanview Boulevard
Pacific Grove, CA 93950

PISCO
Oregon State University
Department of Zoology
3029 Cordley Hall
Corvallis, OR 97331

__Photos:__ Emanuel Gonçalves, Stefano Trezzi, Paul Kay, Paul Naylor, Paul Naylor, Paul Naylor, Emanuel Gonçalves, Paul Naylor, Paul Kay, Paul Kay, Karen Davies, Paul Naylor, Emanuel Gonçalves, Paul Naylor

Printed on recycled, FSC certified paper.