Los Angeles
New Times
March 28, 2002

Fish Story

Is overfishing ruining the waters around the Channel Islands, known as North America's Galapagos? Scientists say yes, but local fishermen don't seem to care.

By Tony Ortega

A photograph taken nearly 20 years ago shows Jim Donlon's mitts buried in the gills of a yellowtail tuna that looks so heavy it threatens to topple Donlon over as he lifts it for the camera. He's standing on the deck of his boat, shirtless, with a crooked grin on his face. Blood is streaming from the yellowtail's gills after its battle with Donlon's rod and reel. But he has no intention of throwing his trophy back. Donlon was known for cooking everything he caught, and never catching more than he needed.

Donlon's lifelong love of fishing in any form was so well known -- whether it was trout fishing in the Sierras, freshwater angling in Lake Casitas, but mostly ocean fishing off of Ventura -- that when he died two years ago, the local newspaper felt compelled to explain that the man had other pursuits. "Fish not only interest of James Donlon III," was the headline on his lengthy obituary in the Ventura County Star. Besides casting a line every chance he got, Donlon had also built fishing boats (the first in 1937) as well as the first 500 slips in the Channel Islands Harbor marina, and had designed pens for raising juvenile white sea bass and salmon for release into the ocean.

It seemed nearly everything the man accomplished in his 87 years had some connection to taking fish from the sea.

"He was the best fish-killer I ever knew," says Web Palmquist, who went on excursions with Donlon in his final years.

But the legacy Donlon yearned for was very different. And it caused him plenty of hostility from his fellow fishers.

In 1998, after watching the ocean's yield deteriorate year after year for most of his life, the nearly legendary local figure shocked his cohorts by approaching the State of California and making a bold request. Donlon, leading a group of likeminded Ventura locals, asked that certain areas around the Channel Islands be closed off more or less permanently to fishing. Only that way, Donlon argued, would native species reproduce adequately and help stave off potential devastation.

In April 1998, Donlon and his group proposed to the state Fish and Game Commission that closing off at least 20 percent of the waters up to one mile from shore around the islands would prevent further decline and even improve fishing in the area.

Environmentalists say the idea of setting aside such no-fishing zones -- called marine reserves -- has been growing in popularity around the world. There's already a reserve protecting a small area off the coast of Anacapa Island in the Channel Islands chain, and for nearly a decade there had been some debate about expanding those reserves to other islands. But no one -- not even environmentalists -- had formally proposed that so much of the ocean should be made off limits. And most importantly, ecologists point out, the proposal was coming from *fishermen.*

"When Donlon came forward, that's when the process really got going," says Sean Hastings, who works for the Channel Islands National Marine Sanctuary, a federal agency that protects island waters from oil drilling. The Marine Sanctuary and other conservation-minded agencies -- including the Channel Islands National Park, half of which is under water -- quickly joined in supporting Donlon's proposal.

"Donlon was proud that he was a recreational fisherman and knew the species in those waters. But he wasn't afraid to say that things had changed. He wanted to do something about it," Hastings says. "He knew his time was limited. He often reminded me that he wouldn't be around much longer."

Donlon didn't live to see what happened to his idea. Supporters of marine reserves say his proposal was handled properly by the Fish and Game Commission, which empanelled a group of local interests and charged them with seeking the best, most scientifically sound method for determining the size and placement of any future reserves. But nearly from the start, they say, fishing industry lobbyists on the panel -- some of whom represent thousands of Los Angeles-area fishermen and boat operators -- sought to sabotage a science-based approach in favor of a more political one.

Both sides agree that the battle for the Channel Islands is one with massive importance to the rest of California's coast, and even to the rest of the world. A 1999 law, the California Marine Life Protection Act, has state officials considering similar reserves up and down the coast; many believe that the extent of no-take zones established around the Channel Islands will set a precedent for statewide planning.

With only months left before the state commission decides the future of reserves around the Channel Islands, recreational fishing representatives are pulling out all the political stops, drawing on their enormous clout with various state and federal officials to prevent what they claim will be a disastrous result for the business of fish-killing in Southern California waters.

Scientists and environmentalists counter with evidence that suggests the reserves will actually improve fishing in the region. Other, smaller reserves in places such as Florida and the

Caribbean show that fish allowed to reproduce and grow without the threat of being caught will eventually swim to areas where fishing is legal. And that, Jim Donlon's friends say, is exactly why he supported such closures.

"Jim Donlon didn't want to end fishing," says Palmquist. "He wanted to improve it."

Two years after he succumbed to cancer, Donlon's role in the battle over marine reserves at the Channel Islands seems to have been largely forgotten. Lobbyists for the fishing industry have pushed hard to cast the issue as a classic fight between (overreaching) environmentalists and (mostly put-upon) local businessmen, and to a large extent the daily newspapers have gone along with that portrayal.

The truth, say people intimately acquainted with the four-year struggle, is very different.

The northern Channel Islands chain is a favorite destination for Los Angeles anglers. Sportfishing industry lobbyist Bob Fletcher says that most of the men and women angling recreationally near the islands are from L.A., even if they actually go out on boats from Ventura or Santa Barbara. Overnight excursions from Marina del Rey and Long Beach are common, and most of those trips target Santa Barbara Island, the nearest of the northern islands to the city, lying about 46 miles away.

In summer, migratory species like salmon, yellowtail and albacore are the quarry. In winter, anglers go after the local residents: California sheephead, halibut and other flatfishes, lingcod and various types of rockfish like cow cod and boccacio (which, by the time they end up in a store or restaurant, have been renamed "red snapper").

But the fishing isn't what it used to be. Rockfish -- the cow cod in particular -- have been so overfished that the state announced emergency closures in all of Southern California's shallow waters this winter. Bobby Yoshihiro, who takes dozens of fishermen out on his overnighter, the *Thunderbird*, says his boat never left its Marina del Rey berth in November and December. More closures took place in January and February, and Yoshihiro wonders how he's going to make a living if the state keeps him off the water for four months out of 12.

"What are we supposed to do? Take people out and not let them fish? How many people will want to do that?" he asks, sounding frustrated. Yoshihiro, 42, bought the *Thunderbird* in 2000 after 22 years as a General Motors mechanic. He'd been fishing all his life, and when the boat came up for sale he jumped at the chance to make a living on the ocean. But he quickly learned that taking anglers out to a promising spot also meant paying attention to a myriad of government rules and regulations about where he could fish, which fish he could take, how many and of what size, and with what gear.

And Yoshihiro and his fellow boat operators know they're probably going to face even further restrictions and outright bans as regulators struggle to protect one species after another. Even if the badly depleted cow cod is able to make a comeback, another population of local creatures may take a sudden nosedive. And that means more gear restrictions, lower bag limits, even more outright closures.

The number of rules is enough to make Yoshihiro's head spin. "When I was a kid, you used to be able to fish anywhere you wanted, year-round. You can't do that now," he complains.

But things are very different than when Yoshihiro was a kid. In the 1950s and '60s, the Channel Islands were known as an anglers' paradise. The four principal islands of the northern group -- Anacapa, Santa Cruz, Santa Rosa and San Miguel -- extend east to west in a line about 64 miles long. Anacapa is the closest and most visited; it lies about 14 miles from Channel Islands Harbor in Oxnard. Scientists say there's a good reason that the islands gained such a reputation for abundant sea life: The Channel Islands is actually one of the most distinctive bioregions on earth.

The westernmost island, San Miguel, lies in cold waters that ride down in currents from the north; the island closest to shore, Anacapa, is surrounded by warmer waters coming up from the south. Between them, in the waters swirling around the two middle islands, is a transition zone that has its own unique character. That mix of different ecological zones creates a diversity of life so rich -- on land, sea and in the air -- that scientists often refer to the Channel Islands as the North American Galapagos.

But the region has been hit hard by several factors: environmental disasters such as El Niño, man-made pollution, and by both commercial and recreational fishing. Kelp forests, a key habitat for many other species, have lost two-thirds of their biomass since 1957. Some seabird species are down as much as 90 percent just since 1987. Rockfish have been severely overfished. Several species are below 10 percent of their historic levels and are considered critically endangered by environmental groups. Abalone came so close to extinction that all taking of its various kinds was stopped indefinitely in Southern California waters in 1996. Even the most commercially profitable species -- squid, urchin and California spiny lobster -- have had some bad years.

There's increasing agreement in the scientific community that traditional methods of protecting fish and ocean invertebrate species aren't working. Bag limits, gear restrictions and seasonal closures ignore a basic truth: A fish like the cow cod is part of a larger ecosystem it interacts with in very complex ways.

It's time, the argument goes, for governments to treat ocean resources as ecosystems, and not simply as individual species with particular bag limits. In other words, it's time to set aside portions of the ocean so those ecosystems can interact without being disturbed.

And that's the concept behind marine reserves.

There's already a line drawn around the northern Channel Islands that is supposed to protect them from environmental disaster. It's called the National Marine Sanctuary, and it includes the waters out to six miles from all four main islands, as well as Santa Barbara Island, which is farther south and closer to Los Angeles. That boundary encloses a total of 1,252 square nautical miles of protected waters, but some folks joke that it's really mislabeled: If it's a sanctuary, the fish haven't been told about it.

Created in 1980, the National Marine Sanctuary was designed to keep out offshore oil drillers. It has no special restrictions on fishing, even though the law behind it specifically mandated that species be protected. But commercial boats alone pull more than $100 million in fish and invertebrates from the waters every year.

After Jim Donlon proposed the creation of reserves near the islands, sanctuary officials seized on his plan as the best way to protect local waters from further deterioration. Sean Hastings, a policy coordinator at the marine sanctuary, says the easiest way to understand the concept of reserves is to compare it to how we protect wildlife on land.

If the sanctuary is like an oceanic national park, he says, then reserves inside it would be like wilderness areas -- places where people could sail, dive and snorkel but not take anything.

Within those reserves, the complex interaction of fish, invertebrates, plankton, kelp and other species would be left undisturbed. In theory, fish would reproduce more easily, grow larger in size and numbers, and then swim out to areas where anglers could catch them.

Everyone would win.

At least, that was the tune various participants were singing in 1999 when it came time for the hard work of turning Donlon's plan into reality. But it didn't take long for that initial optimism to turn sour.

Acting at the behest of the Fish and Game Commission, the National Marine Sanctuary empanelled a group representing local interests in March 1999 to discuss marine reserves for the Channel Islands. Called the "marine reserves working group," the body included scientists, environmentalists, divers, commercial and sport fishermen and even a surfer representative.

The state commission gave the working group a definite goal: Come up with a plan that everyone could agree on. Consensus was mandatory.

Two years and more than $1 million later, the group failed in that basic mission. Most blame two members of the panel: Tom Raftican and Bob Fletcher, lobbyists who respectively represent recreational anglers and the boat owners and marinas that serve them.

Although it was a sportfisherman who had proposed the reserves at the Channel Islands, it is sportfishing lobbies that are fighting against it harder than any other group.

Dale Glanz, a kelp harvester, was a member of the working group, and he remembers how optimistic everyone was as they sat down to hammer out a "win-win" plan and forward it to the commission. Soon, it became apparent that it would be a tall order.

"It was going to be a tremendous challenge. We had extreme environmentalists on one side, diehard recreational fishermen on the other and everything else in between," he says. But Glanz was struck by how much his perceptions of the participants changed over time, particularly of the environmentalists. "They came in wanting to protect everything. But after hearing from us, they changed their minds," he says.

At first, Glanz and others say, there was general agreement on the basic goals of reserves and on which scientists would advise the group. Everyone in the working group -- including Fletcher and Raftican, the sportfishing lobbyists -- approved the selection of marine and biological experts. The scientists were chosen from a large field of candidates, and were not allowed to have already expressed an opinion about reserves in their writings. That rule was so strict that the world's leading rockfish expert was banned from the panel because he had endorsed reserves in the past.

Working group members also reached consensus over what marching orders to give the scientists. They were told to collect reams of information about the Channel Islands and then make recommendations with two goals in mind: conservation of all native species as well as keeping commercial and recreational fishing healthy.

After gathering 50 years of research and hundreds of studies and papers, the science panel returned with its recommendation: To best meet both goals, between 30 and 50 percent of the sanctuary's waters should be sealed off to fishing.

If more than 50 percent were closed, the panel said, the impact on fishermen would be too great. If less than 30 percent were set aside, however, the conservation benefit would be too low.

Those numbers were shockingly high to the fishing interests in the working group, but its members still gamely attempted to find consensus and draw up a single set of maps to forward to the Fish and Game Commission.

Glanz says he had his own goals. As a kelp harvester, he knew that he would get little benefit from reserves. Fish might grow large in no-take zones and swim out to be caught, but kelp doesn't go anywhere. On the other hand, he knew there were kelp forests that couldn't be harvested because they were in rocky, inaccessible areas. Since reserves offered him no direct benefits, Glanz could only hope that they'd be sited in such a way as to encompass kelp forests that he couldn't reach anyway.

"We knew kelp habitat was important and we knew there would need to be reserves with kelp. But we hoped they'd be put in areas that didn't affect us," he says. "We figured we'd lose some of our harvesting grounds, but not enough to put us out of business."

Adopting that attitude -- to protect his interests while giving up some ground -- Glanz participated in the real progress of the working group, the behind-the-scenes meetings that took place between environmentalists, bureaucrats and commercial fishermen.

Among the supporters of reserves, there is universal praise for the commercial representatives such as Glanz. Although the commercial folks weren't happy about reserves or the recommendation of the science panel (most commercial members advocated reserve sizes in the

10 to 14 percent range), there was strong cooperation when it came time to specify the placement and size of reserves.

But the sportfishing attitude was very different. Fletcher, president of the Sportfishing Association of California, and Raftican, president of the United Anglers of Southern California, refused to entertain the thought of any reserves near the easternmost islands, the ones favored by recreational fishermen.

"They wouldn't even return our phone calls," says Mike McGinnis, a UC Santa Barbara professor who left the working group in disgust, primarily, he says, because of the behavior of Fletcher and Raftican. "The Santa Barbara commercial guys were very cooperative, but Fletcher and Raftican were not involved in any cooperative meetings behind the scenes. And that's how those things really work."

"They just sat there and said no to everything," says Greg Helms of the Ocean Conservancy, an environmental group in favor of no-take zones. That attitude irked him because, Helms says, everyone else in the working group knew they would have to make concessions to reach consensus. "They did that knowing that they have a much bigger impact on the Fish and Game Commission than some of the [other working group members]," Helms says.

Even Glanz admits that Fletcher and Raftican wouldn't play ball. "They had such a huge constituency, they couldn't budge," he says.

Fletcher and Raftican don't apologize for their opposition.

"Traditional fisheries management is working. It's not necessary to take away large portions of the ocean from commercial and sportfishermen," Fletcher says from his San Diego office.

"Before you take away vast areas from recreational fishermen who have a constitutional right to fish in state waters, let's make sure you do things right," Raftican says.

Both men say they believe in marine reserves in principle, but each claims that the scientists on the panel -- whom they personally approved -- had overstepped their bounds in recommending closure of at least 30 percent of the waters. Fletcher even believes that the scientists -- although from many different fields and institutions -- had actually conspired secretly, both in getting themselves selected and then in going beyond what the working group had asked them to do.

He insists the scientists were closet environmentalists who had duped the National Marine Sanctuary into letting them in on the process, and were bent on ruining the livelihood of Southern California fishermen. Raftican, while less conspiracy-minded, also claims that the science panel made grievous errors. "You're going to put people in the fishing business out of business," Raftican warns.

As maps and more maps were drafted and the working group fell far short of consensus, it became obvious that it never would be able to forward a single plan to the Fish and Game Commission.

Eventually, the Marine Sanctuary and the state Department of Fish and Game snatched the whole process away, settling on their own "preferred alternative" map -- with reserves taking up 24.6 percent of the sanctuary waters, well short of the minimum recommended by the working group scientists -- and submitted it to the commission.

Fishing advocates immediately forwarded their own plans for much smaller reserves, and the environmentalists tried to get the commission to entertain a map with 34 percent of the sanctuary set aside. (The commission accepted the plans with smaller reserves as possible choices, as well as Fletcher's recommendation that no action on reserves be taken, but few expect the commission to seriously consider the environmentalists' 34 percent solution.)

Although the preferred alternative, with its 24.6 percent set-asides, is well short of what they wanted, environmentalists have thrown their support behind it. So has Jim Donlon's original organization of fishermen who support the reserves.

Fletcher and Raftican, meanwhile, have gone on an all-out attack.

One in 20 Southern Californians have fishing licenses, and ocean sportfishing is a $500 million-a-year industry in California. And those numbers give Fletcher and Raftican plenty of influence on state and federal agencies that regulate fishing.

Fletcher, for example, hopes his clout with a federal agency, the Pacific Fishery Management Council, will have some effect on the state's decision. The PFMC regulates fishing in federal waters, which extend from 3 to 200 miles offshore, and is traditionally very responsive to fishing industry wishes. The PFMC had no input during the working group deliberations but now, as the state Fish and Game Commission nears a decision, the feds suddenly want to weigh in on the issue, delaying the state's timetable by several months. Some believe the timing was largely due to Fletcher's influence -- for 15 years he was a PFMC member and twice chaired the agency.

Hastings, of the marine sanctuary, says that a PFMC thumbs-down on the preferred reserves proposal could have a big impact on the Fish and Game Commission. Fletcher and Raftican, meanwhile, loudly advertise that the PFMC's scientists -- who they claim are much better judges of how fisheries would be affected -- had harsh things to say about the 30 to 50 percent recommendation by the working group's science panel.

But a closer look reveals that although the PFMC scientists were somewhat critical in their peer-review of the 30 to 50 percent report, in the end they endorsed the science behind it.

Hastings says that despite Fletcher's attempts to get the PFMC to put a damper on the state's decision on reserves, he doesn't think even a fishing industry-friendly body like the PFMC could overcome that scientific endorsement.

An even more obvious example of Fletcher and Raftican's clout occurred in January, when the two lobbyists convinced the California legislature to hold a special joint committee hearing at their request.

Fletcher says that the joint committee on Fisheries and Aquaculture normally holds a regular meeting in March, but that at his insistence, the senators and assemblymen convened in January to hear what Fletcher and Raftican had to say about the marine reserve plans.

The legislators also asked state Department of Fish and Game director Robert Hight to make an appearance and explain his department's position.

And, under the pressure of a public accounting, as Fletcher puts it, "the director flinched."

Hight announced that Fish and Game was scrapping the plans the department had drawn up under the Marine Life Protection Act for reserves at other points on the California coast and starting over. Fletcher and Raftican and the fishermen they represent had raised such a ruckus that Fish and Game decided to jettison two years of work that had already been done. It was a remarkable knuckling under, but not a word of it made the *L.A. Times*.

That decision doesn't directly effect the Channel Islands reserves process, which was already much further along than the department's plans for the rest of the state. But at the same time, Fletcher and Raftican have pushed hard for the Channel Islands process to be delayed and even rolled into the statewide process. Again, Fletcher is counting on his personal clout to help him convince Fish and Game to accede to his wishes: He was once the department's chief deputy director.

Nonetheless, time may soon run out on Fletcher and Raftican's delaying tactics.

On April 4, Fletcher will stand before the Fish and Game Commission in a crucial public meeting in Long Beach. Behind him, a large group of fishermen, all wearing red T-shirts, will be in attendance to show their solidarity with what Fletcher is going to say. The meeting will be the final opportunity for Fletcher and the boat owners, marina operators and anglers he represents to make their case to the commission. And, just as he has in times past, Fletcher will try to convince his listeners that California's fishermen were betrayed in the marine reserves process by a panel of scientists with hidden agendas.

That's been his message at a series of public meetings held by the commission, including one in Long Beach in December. Backed by his red-shirted brigade, Fletcher told the commission then that the working group had failed to come up with a single, agreed-upon plan because the scientists chosen for the job had exceeded their bounds. Their recommendation, Fletcher warned, would put the people he represents out of business. All of them.

The red shirts burst into applause and shouts.

But it took another fisherman, the man who replaced Jim Donlon after his death as the chief representative of anglers supporting the reserves, to point out what Fletcher didn't include in his speech. In a strong, challenging voice, Steve Roberson looked at Fletcher and reminded him that Fletcher was one of the people who *chose* the scientists and asked them to make recommendations on reserve size.

"Every member of that science panel was approved by every member of the working group. I hate to see those scientists get blasted by people taking cheap shots," Roberson said.

Roberson is also a lawyer, and Donlon picked his replacement for his speaking skills as well as his experience on the water. Since the 1970s, Roberson has been fishing around the Channel Islands, most recently on his 27-foot Boston Whaler, which he used to take out 70 to 80 times a year on long trips to some of the more distant islands. Nearly all the time, his son Jason was with him, but since Jason has entered law school, the two go out less frequently.

"Believe me, we've killed our share of fish," Roberson says as the two of them pull weatherproofing covers off the boat on a recent afternoon. They have hundreds of photographs to prove their acumen on the water, neatly arranged in huge portfolios. Each photo comes with a story -- usually about how far they had to pilot the boat to find good fishing grounds. Over the years, that journey has taken them farther and farther from shore as stocks near the islands have dwindled.

Roberson says he understands the frustration of the fishermen who dress in red shirts and follow Fletcher and Raftican from meeting to meeting. But he also says they suffer from a terminal case of small-mindedness and a lack of understanding of their own culpability in the ocean's deterioration.

"The establishment of no-take zones will probably hit the recreational guys harder than the commercial guys," Roberson explains. "So the recreational fishermen feel that they are bearing the brunt of it, even though they believe the commercial fishing is more to blame. And also, the recreational guys have supported conservation efforts in the past, like the white sea bass hatcheries, so they feel like they're being unfairly targeted.

"But the problem with their argument," he continues, "is that the resource is now so hammered, and so depleted, in my opinion and in the opinion of most scientists, that recreational fishing is having a major impact. Also, the technical developments in the last 20 years have totally changed recreational fishing. You give a guy a Global Positioning System receiver, fish sonar, scanners and other sophisticated equipment, and you get fishermen with better technology chasing fewer and fewer fish. There's no place for the fish to hide. The recreational guys have to realize that they're now having a significant impact. But these no-take reserves in five years or less will actually increase fishing opportunities. Yes, for four or five years, they'll have to keep out of places where they like to fish, but ultimately they will create better fishing for everyone."

On April 4, Roberson will be in Long Beach, hoping his message is also heard by the Fish and Game Commission. He says that although he isn't backed by a $500 million-a-year industry, he thinks the commissioners know that science is on his side.

The best proof that marine reserves work may come from an unlikely source: rocket launching pads.

In the late 1950s, as the U.S. space program tried desperately to catch up to the Soviets, Cape Canaveral in Florida was chosen as the place to build platforms for sending American rockets into space. It was only prudent to seal off much of the area to the public, for both safety and security reasons.

One of the areas permanently closed to the public in 1962 was a portion of the Banana River, an estuary that was home to manatees and various species of fish, including several species prized by local anglers: black drum, red drum and spotted sea trout.

The estuary wasn't sealed off for conservation reasons. The animals in it just happened to be living too close to rocket blasts for boats to approach safely.

In the 40 years since, the fish of Banana River have been allowed to live, grow and reproduce without predation by humans. And recently, a marine biologist named Callum Roberts made an interesting discovery there.

It had already been shown that the fish inside the closed area were bigger and more numerous than in areas outside it. Red drum were more than six times more abundant, and black drum were nearly 13 times more numerous than areas open to anglers. This was consistent with what scientists had found in reserves around the world: Ban fishing in an area, and the species there get more numerous and bigger.

Roberts was the first to measure another beneficial effect of reserves. He found that the majority of world-record-size black drum, red drum and spotted sea trout taken in Florida's waters have been landed within 100 kilometers of the Banana River reserve.

"If the Merritt Island Refuge [which includes the Banana River] were supplying fish to the adjacent recreational fishery, we would expect frequencies of world record catches to increase over time," Roberts wrote in his report, published recently in the prestigious journal *Science.* By charting the accumulation of record-size fish both near the reserve and in the rest of the state, Roberts was able to show a consistent and compelling trend.

In each case, the waters near the Banana River reserve began producing world-record fish at the time one would expect, given the different longevity of each species. The black drum, for example, is a fish that lives 70 years. Only after they had been protected for 31 years did the Banana River-adjacent black drums begin snagging world records.

And Roberts found that marine reserves produced benefits in shorter times as well. In 1995, a series of small reserves was established off the coast of the Caribbean island of St. Lucia. Within only a year, fish counts were dramatically up not only within the reserves themselves but also in adjacent areas. And that trend continued over the next five years.

Overall, Roberts found, the catch in local waters had increased, even though about 35 percent of the waters had been closed off.

(Roberts also found a curious by-product of the St. Lucia closures. Although scientific data showed that fishing had improved in the area, the perceptions of local fishermen varied. Younger fishermen, he found, were much more likely to agree that the fishing had gotten better after the reserves were established -- which the data proved to be true. Older fishermen, however, were more likely to complain that things had gotten even worse. The implication seemed to be that older fishermen are so resistant to change that they condemn reserves even after they prove to benefit them.)

In both the Florida and St. Lucia cases, Roberts showed, the benefits of reserves were felt well outside their borders. Prohibiting fishing in one area had actually improved fishing in other areas.

Environmentalists say Roberts' report couldn't have come at a better time.

"If there were enough fish, none of this furor would happen," says Steve Benavides, an Orange County resident who represents recreational divers and has observed the reserves issue for years. He was one of the key advocates of halting all abalone harvesting in Southern California in 1996. He said divers learned a valuable lesson from that experience that fishermen still don't grasp.

"The fishermen just don't get it. Reserves are there to protect habitat. They're there to protect species in case fishery management makes more mistakes. Because if you look at the past, we haven't done a good job. With reserves, if we make another mistake, we won't drive a species into extinction," he says.

But Benavides says Fletcher and Raftican are nervous that large Channel Islands reserves will affect how maps are drawn for the rest of the state under the Marine Life Protection Act. In both cases, Benavides says, politics was not supposed to be part of the process; it was science that would guide the drawing of maps.

"Sometimes you just can't compromise. You need to do what's right. And that's why you need to follow the law and let the scientists decide," he says.

THE ROYAL SOCIETY

Received 10 October 2002
Accepted 19 March 2003
Published online 17 July 2003

Review Paper

Matching marine reserve design to reserve objectives

Benjamin S. Halpern* and Robert R. Warner

Department of Ecology, Evolution and Marine Biology, University of California, Santa Barbara, CA 93106, USA

Recent interest in using marine reserves for marine resource management and conservation has largely been driven by the hope that reserves might counteract declines in fish populations and protect the biodiversity of the seas. However, the creation of reserves has led to dissension from some interested groups, such as fishermen, who fear that reserves will do more harm than good. These perceived differences in the effect of marine reserves on various stakeholder interests has led to a contentious debate over their merit. We argue here that recent findings in marine ecology suggest that this debate is largely unnecessary, and that a single general design of a network of reserves of moderate size and variable spacing can meet the needs and goals of most stakeholders interested in marine resources.

Given the high fecundity of most marine organisms and recent evidence for limited distance of larval dispersal, it is likely that reserves can both maintain their own biodiversity and service nearby non-reserve areas. In particular, spillover of larger organisms and dispersal of larvae to areas outside reserves can lead to reserves sustaining or even increasing local fisheries. Ultimately, the success of any reserve network requires attention to the uncertainty and variability in dispersal patterns of marine organisms, clear statements of goals by all stakeholder groups and proper evaluation of reserve performance.

Keywords: marine reserve design; fisheries; resource management; biodiversity conservation; marine protected areas

1. INTRODUCTION

The past few years have seen a tremendous increase in public interest in using marine protected areas to manage marine resources, and many countries are moving towards regional and national programmes of reserve establishment. Much of this interest has arisen as a result of the dramatic success of existing reserves in increasing population sizes within reserve boundaries. However, current reserve systems were established rather haphazardly. Some areas were set aside because they happened to be located adjacent to military installations, sub-tidal anthropogenic structures (oil rigs, communication cables, etc.) or dramatic natural features (e.g. Didier 1998; Johnson *et al.* 1999). Still other reserves were established because local fisheries began to collapse (e.g. Russ & Alcala 1996; Murawski *et al.* 2000) or because scientists wanted a small patch of 'natural' area to study (e.g. Ballantine & Gordon 1979; Castilla & Durán 1985). Briefly, most reserve locations and boundaries were chosen by a political process that focused on economics, logistics or public acceptance, while largely overlooking or ignoring how the complex ecology and biology of an area might be affected by reserve protection (McArdle 1997; Roberts 2000).

Recent planning efforts indicate a dramatic shift in the way reserves are being designed, with a focus on community and scientific involvement in creating ecologically sound networks of protected areas (National Oceanic and Atmospheric Administration 1996; Airame *et al.* 2003; CAFGC 1999). However, even these efforts show that it is difficult to develop reserve designs that satisfy all stakeholder groups involved in the planning process (Suman *et al.* 1999; Nuttall *et al.* 2000). For example, the process to develop no-take reserves in the Florida Keys National Marine Sanctuary led to 'overwhelming opposition' from the commercial fishermen in the area (Suman *et al.* 1999).

Although there exist a growing number of cases where fishermen have spoken out in support of reserves as a management tool (Roberts & Hawkins 2000; Roberts *et al.* 2001), many fishermen remain strongly opposed to including anything but the smallest amount of no-take reserves in management plans (Suman *et al.* 1999; Haskell 1999; Nuttall *et al.* 2000; Bustamante *et al.* 2001). We believe these difficulties in gaining full stakeholder support for reserve design efforts stem from: (i) a general lack of understanding of how existing marine reserves have performed; (ii) ignorance of what the questions are that remain to be addressed and answered; and (iii) a poorly articulated explanation of how stakeholder goals can be met using marine reserves. Reasonable goals, appropriate design criteria and the success of marine reserves can only be achieved if all stakeholders are armed with information about reserve performance *relative to their needs*.

To help address these information needs, it is useful to assess what is known about how reserves actually function relative to how current theory suggests they might function. More importantly, can this empirical evidence and existing theory then be put into practice to provide practical guidelines for marine reserve design?

The answers to these questions depend critically on the intended function of marine protected areas, and as often happens the perceived function depends on who is asked (Dayton *et al.* 2000). Groups interested in marine conservation or ecotourism view reserves as wilderness areas where all species and whole ecosystems can persist without extractive or destructive human activity. For these

*Author for correspondence (halpern@lifesci.ucsb.edu).

groups, reserves need to support and protect, within their boundaries, genetically diverse populations of the full suite of local and regional species. By contrast, other groups view reserves as a resource management tool, intended to export a dependable supply of some resource to other areas where it can be taken for human consumption. Economically viable increases, or at a minimum no decreases, in the total catch of organisms after the creation of a reserve is therefore the goal of these groups of people. These two sets of goals require reserves to provide fundamentally different functions. As we will show, however, the different goals of conservation and exploitation are not necessarily incompatible with one another.

2. STAKEHOLDER CRITERIA: CAN A SINGLE RESERVE NETWORK DESIGN MEET THEM ALL?

All stakeholder groups have the common goal of sustainability at the lowest cost (or maximum benefit), although exactly what they want to sustain differs dramatically between the groups.

(a) *Conservation and ecotourism: within-reserve responses to protection*

Some of the primary stakeholder groups espousing marine reserves are conservation/biodiversity preservation organizations and the people they represent, and those who profit from non-extractive human activity in the area (e.g. diving, ecotourism organizations). For these groups, marine reserves need to preserve and enhance biological resources inside reserves, and ensure them against future degradation. An even larger community may benefit from the 'ecosystem services' provided by intact marine communities, such as wave buffering and biological filtering of contaminants (Snelgrove 1999).

There is abundant evidence that marine species within reserve boundaries respond strongly and quickly to reserve establishment. Most of this evidence has been evaluated in a recent comprehensive review of empirical studies of more than 100 studies of reserves around the world (Halpern 2003). This review showed substantially higher values of organism density, biomass, average size and diversity inside reserves relative to appropriate reference areas. These results were independent of reserve size or age, and the higher values inside reserves accrued rapidly, reaching mean values within 1–3 years after protection (Halpern & Warner 2002; Halpern 2003). Thus, the overall pattern of response to marine reserve protection is one of rapid, dramatic and persistent increases of within-reserve biological measures. From a conservation perspective, therefore, no-take reserves successfully achieve the goal of increasing and maintaining abundance and diversity within reserves.

Conservationists also want systems of reserves that encompass a representative sample of the local and regional biodiversity. An extensive literature has developed on how such a goal can be achieved in terrestrial systems (see review by Margules & Pressey (2000)), and much of this work is now being modified for and applied to marine conservation efforts (Zacharias & Roff 2000; Carr *et al.* 2003). Although these ideas have recently been applied to the design of marine reserves (Zacharias & Roff 2001; Airame *et al.* 2003), few existing reserves were created with biological representation in mind. Since future systems will certainly include existing reserves, designers should make efforts to account for biodiversity not yet represented within marine reserves.

Furthermore, for reserves to fully achieve conservation goals, they should also enclose genetically diverse populations (Botsford *et al.* 2001). To provide this function, reserves should be connected to one another through dispersal to allow genetic mixing of populations. Therefore, dispersal distance is a critical input parameter for designing reserves that successfully provide within-reserve functions. We discuss below the implications for stakeholders of various species-dispersal patterns on marine reserve design.

To meet the criteria of biodiversity representation and sustainable populations within reserves, network designs will probably require that marine reserves be larger than those currently in existence. In most of the world, reserves make up less than 1% of the coastal ocean (Roberts & Hawkins 2000). While small reserves can be effective in increasing the diversity and abundance of many species (Halpern 2003), species–area models and existing evidence indicate that larger reserves will provide protection to more species than smaller reserves (MacArthur & Wilson 1967; McClanahan & Mangi 2000; McClanahan & Arthur 2001; Neigel 2003). Furthermore, reserves would need to be very extensive to maintain large, self-sustaining populations of all species. Such a reserve design, with large single reserves in each biogeographic region, is likely to be contentious with fishermen because it could force them to travel greater distances to reach fishable waters, although this design would serve conservation interests. Fortunately, reviews of existing research on risk minimization suggest that conservation goals for most species can be met with reserves covering 30–50% of the total stock area (Turpie *et al.* 2000; National Research Council 2001; Airame *et al.* 2003), and evidence suggests that networks of reserves of moderate size (10–100 km^2) and variable spacing should adequately protect and maintain the density and biodiversity of a large proportion of benthically associated organisms (Murray *et al.* 1999; National Research Council 2001; Roberts *et al.* 2001, 2003; Allison *et al.* 2003). The exact placement of individual reserves would need to account for: (i) biodiversity representation within the reserve network; and (ii) dispersal patterns (location of retention eddies, etc.) that would affect the self-sustainability of individual reserves and the connectivity within the network of reserves (Roberts *et al.* 2003).

While the overall results of biological responses inside reserves are encouraging, some important points of caution emerge. First, responses to reserve establishment can be highly variable, depending on the intensity of exploitation of the species before protection (e.g. the cessation of fishing in an area not being fished will obviously have little if any impact on that area), or the particular life history or trophic level of a species (Polacheck 1990; Carr & Reed 1993; Rowley 1994; Russ & Alcala 1998*b*; Jennings *et al.* 1999*a*,*b*). For example, large, long-lived species that require many years to reach maturity are likely to respond much less quickly than small, fast-growing species, and perceived impacts of reserve protection will depend on which species are measured (Russ 2002).

Second, the increases in abundance and diversity after reserve establishment do not necessarily represent a return to 'pristine' conditions (Dayton *et al.* 1998; Jackson *et al.* 2001). For example, there are many large species that have been effectively extirpated from coastal ecosystems over the past few hundred years (Jackson *et al.* 2001). Because of the rarity and large home range size of these large species, reserves may be ineffective in restoring these species to their former abundance in any local area.

Finally, reserves are effective in reducing habitat destruction and direct human-induced mortality on some species within reserves, but these are not the only sources of disruption in coastal ecosystems. Pollution, excess nutrients and alteration of pelagic communities outside reserves can have profound effects on species and community structure within protected areas (Allison *et al.* 1998), and any policy establishing reserves must take these distant factors into account. These three cautionary comments are important for setting appropriate goals for marine reserves and in the last case may modify decisions of where individual reserves are placed.

(b) *Sport fishers and artisanal fishermen: export of large fishes*

Small-scale fishermen also represent some of the major stakeholders, in terms of revenue generated and numbers of participants, affected by reserve establishment. If marine reserves are to benefit these fishermen, enough fishes must leave the reserve, where they can be caught, to compensate for the amount of fishes 'lost' to reserve closures. Research is just now beginning to show strong evidence for spillover rates high enough to sustain (and even increase) catches from local artisanal and small-scale fisheries (Attwood & Bennett 1994; Russ & Alcala 1998*a*; McClanahan & Mangi 2000; Roberts *et al.* 2001; Gell & Roberts 2002). A recent review of the evidence for spillover, in fact, suggests that spillover of fishes from reserves can be significant (Gell & Roberts 2002). Further evidence for spillover comes from studies showing how recreational fishermen often 'fish the edge' of a reserve for both greater catches and trophy-sized specimens (Johnson *et al.* 1999; Roberts *et al.* 2001). For example, between 1986 and 1990, eight world-record fishes were taken in the vicinity of the Merritt Island National Wildlife Refuge in Florida, where tagging studies have documented the movement of large adult fishes out of the reserve (Johnson *et al.* 1999; Roberts *et al.* 2001).

Theoretical modelling of reserve design has shown how body size, behaviour and movement patterns of particular species will affect their potential rate of spillover (e.g. Polacheck 1990; DeMartini 1993; Kramer & Chapman 1999). Optimal levels of spillover require that many organisms leave the reserve but that a sustainable number also remain within the reserve; excessive spillover negates the value of a reserve. Kramer & Chapman (1999) point out that spillover can be reduced by creating larger reserves that encompass the potential home ranges of species. Consequently, the degree to which spillover can compensate local fishermen for area (or stock) lost to reserve closures depends, mainly, on the mobility and home range of a given species, with mobile species having higher rates of spillover (Kramer & Chapman 1999; Cole *et al.* 2000; Gell & Roberts 2002). Local fishermen are more likely to benefit from spillover than regional fishermen since the export of large individuals tends to be concentrated near the edges of reserves (Chapman & Kramer 1999; McClanahan & Mangi 2000; Murawski *et al.* 2000).

Given that reserves must supply large organisms through spillover to meet the criteria of sport and artisanal fishermen, these stakeholders will benefit most with ready access to as much reserve edge as possible. The ideal reserve design for these stakeholders, then, may be one that includes many small reserves. However, if fishing pressure outside small reserves is particularly intense, highly mobile species may cross the boundaries often enough to be depleted despite reserve establishment (Kramer & Chapman 1999; Bohnsack 2000). Large reserves also have extensive boundaries, of course, and have the added benefit that continued protection in the centre of such reserves buffers the loss at the edges. Furthermore, the shape of these larger reserves can be modified to increase the edge-to-area ratio. Again, a network of reserves of moderate size and variable spacing should serve the needs of these stakeholder groups while allowing some protection from depletion.

(c) *Commercial fishermen: larval export*

Some of the most important stakeholders in ocean resources, and often the most vocally opposed to the creation of marine reserves, are commercial fishermen and those regulating the fishing fleets. Many from this group feel that the removal of any fishing area simply means fewer fishes to catch. To meet the needs of these stakeholders, marine reserves must supply enough larvae and adults to non-reserve areas to compensate for the area lost to fishing.

Models of successful networks of fisheries reserves require that sufficient numbers of larvae be exported outside the protected areas (Hastings & Botsford 1999; Mangel 2000), and suggest that marine reserves can provide this function as long as they constitute a significant portion (model estimates generally range between 20% and 50% set asides) of the total stock area (Roberts & Hawkins 2000; National Research Council 2001). Reserves larger than these levels will be less effective because of the extensive loss of area where extraction is allowed. We have performed quantitative analyses of the potential effects of marine reserves on larval export and have shown that reserves can export a sufficient amount of larvae to compensate for reserve closures of up to at least 50% of the total area used by a population (B. S. Halpern, S. D. Gaines and R. R. Warner, unpublished data). Of course, the larval replenishment function of reserves is most effective for those fisheries that are most depleted, and so the implementation of reserves may have little effect on fisheries that are not overfished and could have no effect, or even a detrimental effect, on well-regulated fisheries (Hastings & Botsford 1999; National Research Council 2001).

Unfortunately, empirical support for the ability of reserves to replenish fished areas through larval dispersal is limited. There exist very few marine reserves of sufficient size relative to the management unit that would allow for a proper evaluation of model predictions. One exception is the large area (*ca.* 17 000 km^2) set aside in 1994 for groundfish protection on Georges Bank and southern New England; this represents between 17% and

29% of the area occupied by the stocks (Murawski *et al.* 2000). Although groundfish densities are increasing in the reserves, it is the faster-growing sea scallops (also protected by the closure) that have shown the most rapid response; biomass increased 14-fold over 4 years. Significantly, scallop recruitment to areas outside the reserve has increased and become more dependable, sustaining an active fishery. Scallop landings from the Georges Bank in 1998 were over twice the level in 1994, whereas landings in the Middle Atlantic Bight (without reserves) declined by *ca*. 50% over the same period (Murawski *et al.* 2000). Therefore, the evidence suggests that a network of reserves covering a significant portion of the management area could ensure adequate larval export of species for fisheries, as well as the conservation and sustainability of those species within the reserve network.

(d) *All stakeholders: lowest cost for maximum benefit*

The establishment of marine reserves will displace some fishermen. To be successful from the perspective of sport, artisanal and commercial fishermen, then, reserves must not only increase the value of the catch outside the reserves (through either larger or more numerous fishes), but also increase catch value enough to compensate for the lost fishing grounds. As mentioned above, many fishery models of reserves suggest that this compensation can occur with a moderate proportion of the total area set aside in a network of reserves. Impacts can also be lessened by placing reserves away from fishing ports, and to leave space between individual reserves so that no group of local fishermen is disproportionately affected by reserve implementation. By contrast, the easiest way to minimize enforcement costs (therefore meeting conservationists' goals) would be to create fewer larger reserves, although reserve designs composed of smaller reserves with clearly defined and easy-to-identify boundaries should help minimize these costs.

Several cases illustrate that all groups can benefit from a single reserve design, such that fish populations within reserve boundaries increase in size and biomass while at the same time local sport and commercial fishermen actually have higher net value of catch as a result of reserve implementation (Russ & Alcala 1998*a*; Murawski *et al.* 2000; Leeworthy 2001; Roberts *et al.* 2001; Gell & Roberts 2002). For example, in the Florida Keys National Marine Sanctuary all fishermen saw a net increase in catch value after the creation of the Sambos reserve, but the net increase in catch value was 44% higher for fishermen who fished near the reserve relative to fishermen who fished elsewhere in the Sanctuary (Leeworthy 2001). Everyone appeared to benefit from the reserve; those people fishing closest to the reserve benefited the most.

3. ASSESSING WHAT WE DO NOT KNOW

Given that some reserve functions appear to 'work' on a small scale, the fundamental remaining questions for reserve design are how big to make reserves—how big should individual reserves be and how much of a total management area should be set aside in reserves—and how far apart from each other should reserves be placed. Answers to these questions depend largely on issues of dispersal and so are difficult to address, but there is a growing body of evidence that can inform the process of designing reserve networks.

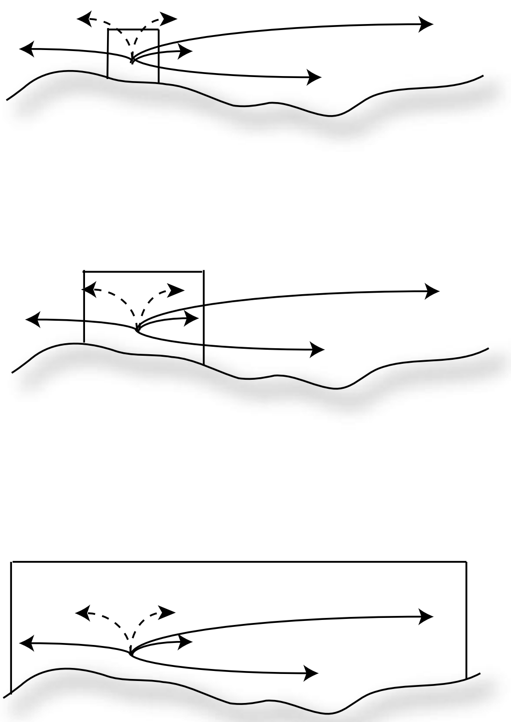
(a) *Reserve size*

(i) *Individual reserve size*

Reserves of all sizes can have positive impacts on biological measures within the reserve (see above), but this may not be sufficient to sustain an entire population. The primary factor determining optimal reserve size is dispersal, both adult and larval (figure 1). If reserves are too small, most if not all of the adults and larvae will leave the reserve, making within-reserve populations unable to sustain themselves. On the other hand, if reserves are too large, too few adults leave the reserves to make the reserve design palatable to fishermen, although such a design would be ideal for conservationists. Unfortunately, dispersal distance is notoriously difficult to measure and is therefore not known for most marine species. However, some estimates of adult movement have been made (see above), and Shanks *et al.* (2003) review dispersal patterns for 32 taxa and suggest that reserves should be able to capture most short-dispersing species if they are *ca*. 4–6 km across, and that appropriate spacing of these reserves (see below) can help capture the long-dispersing species.

Designing an optimal network of reserves for a particular species with known dispersal distances would be a relatively simple task. However, reserves are intended to serve community and ecosystem functions, and these functions involve species with many different dispersal patterns, most of which are not currently known. Such variation makes it difficult to prescribe an exact network design of given reserve size and spacing. However, given the uncertainty in sources and destination of recruits for most marine species, a consensus is emerging that networks of intermediate-sized reserves (10–100 km^2) will be more effective than fewer large reserves, particularly if the networks include a variety of representative habitats (National Research Council 2001).

The question of the efficacy of a single large or several small (SLOSS) reserves has been fully addressed for terrestrial reserve design (see Shafer 1990 for review). Although it is tempting to turn to this literature for guidance on how to design networks of marine reserves, many fundamental differences exist between terrestrial and marine systems, making it difficult to transfer lessons learned from one ecosystem to the other (Carr *et al.* 2003). These differences include: (i) the enormous potential role of dispersal in marine systems in transferring production between locations and 'blurring' boundaries; (ii) the ability for organisms to live between the reserves (unless those areas are being completely exploited); and (iii) the dramatic role of fishing in controlling population sizes (the SLOSS debate for terrestrial systems focuses more on habitat loss than direct take of target species). Because fishermen are likely to be strong advocates for smaller reserves and because dispersal of larvae will help connect and support reserves separated from one another, it is likely that a design of several smaller reserves (instead of one large reserve) will function well while also garnering the most stakeholder support.



	conservation	small fishery	commercial fishery	overall
(a)	reserve not self-sustaining; most species lost	high periph-to-area ratio but unsustainable	small effect on recruitment	too much loss out of reserve; minimal effect on fisheries
(b)	reserve moderately self-sustaining; some species lost	adequate periph-to-area ratio, with some individuals retained	significant source of recruits to fished areas; moderate reduction of fishing grounds	good balance of benefits for all stake-holders
(c)	reserve completely self-sustaining; all species retained	low periph-to-area ratio; relatively small amounts of spillover	little recruitment outside reserve; severe reduction of fishing grounds	little export function

Figure 1. Possible individual reserve sizes assuming adult and larval dispersal distances for a relatively sedentary species with an extended larval phase. Three possible reserve sizes (boxes) are drawn along a hypothetical coastline over dispersal distances for larvae (solid arrows) and large fishes (dashed arrows) for the stock area of a species. The ability of each reserve size to meet stakeholder goals is indicated next to each design. Small reserves export all fishes (larvae and/or large fishes), and are unable to sustain themselves (*a*). This option is unable to meet any stakeholder goals. Large reserves (*c*) capture all fishes, making the reserves suitable for conservation goals but useless for fishing interests. Reserves that are of moderate size (Shanks *et al.* 2003) suggest 4–6 km across; (*b*) retain many large fishes and some dispersing larvae but export all others. This design allows the reserve to be self-sustaining for some species while exporting enough larvae and large fishes into non-reserve areas to sustain fisheries. However, this reserve size (*b*) may not capture enough dispersing larvae and retain larger fishes for other species, and needs to be replicated in a network to preserve the entire biodiversity of an area (see figure 2).

(ii) *Total area set aside*

As outlined above, most recommendations for minimizing risk (for conservation of biodiversity) or maximizing yield (for fishery management) suggest that a minimum of 20% and an optimum of 30–50% of the total management area be set aside in reserves (National Research Council 2001; Roberts *et al.* 2002; Airame *et al.* 2003). This aggregate reserve size allows populations to remain large enough to produce sufficient offspring for maintaining themselves and to supply fisheries, while simultaneously leaving enough area open for fishermen to have sustainable catches. Unfortunately, actual reserve planning areas are often much smaller than that encompassing a stock management unit, and this can compromise the ability to detect a reserve effect. Ideally, many independent reserve networks that cover 30–50% of different management areas should be established to test their effectiveness empirically. Short of this, currently available models can only effectively guide reserve establishment if dispersal out of the reserve is confined mainly to the remaining planning area. If dispersal is much greater than this, then the reserve will represent a relatively small proportion of the area to be serviced, and models suggest that enhanced recruitment will be slight and difficult to detect in a monitoring programme. This is an important point to remember when evaluating the success of reserve networks.

(b) *Reserve spacing*

Determining the optimal spacing of reserves within a network requires knowledge of how far larvae regularly disperse and how close reserves can be to each other and still be acceptable to fishermen. Shanks *et al.* (2003) estimate that reserves spaced *ca.* 20 km apart should allow long-dispersing species to encounter reserves frequently enough to ensure sustainability of populations and stocks. However, even these distances are not likely to encompass the dispersal distances of all species, and so a reserve network that incorporates a wide range of between-reserve distances is more likely to be successful than one that has uniform spacing (Carr *et al.* 2003; Kinlan & Gaines 2003; Palumbi 2003; Shanks *et al.* 2003; figure 2). Such a design should be acceptable to fishermen because it maintains accessibility to large areas of local fishing grounds.

4. NEEDS AND CAVEATS FOR FUTURE PLANNING

Clearly, the estimated dispersal distance of target species is an important parameter in planning effective marine

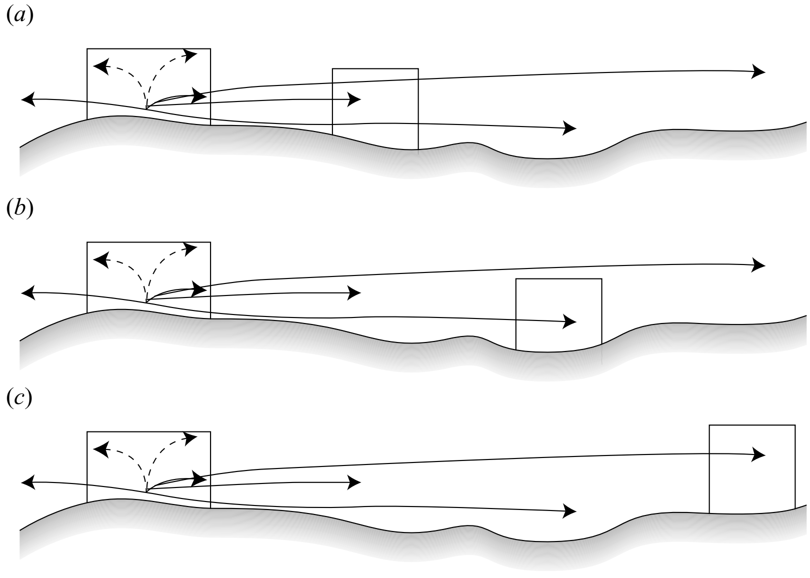


Figure 2. Possible reserve spacing within a network given a relatively sedentary species with an extended larval phase. Three possible reserve spacing options (boxes) along a hypothetical coastline are presented using option (*b*) from figure 1 for individual reserve size and assuming that large fishes (dashed arrows) disperse relatively short distances and larvae (solid arrows) can disperse varying distances for the stock area of a species. Individual reserve size can vary as long as the reserve is sufficiently large to capture enough short-dispersing individuals to make it self-sustaining (see figure 1). Reserve spacing should vary (to include options (*a*–*c*)) within the entire network (many reserves) to ensure that dispersers of all distances (short, medium and long dispersers for options (*a*), (*b*) and (*c*), respectively) are captured within the network of reserves. This compensates for the inability of a single reserve to capture the entire biodiversity of an area (as outlined in figure 1). This reserve network design would be self-sustaining and capture most of the biodiversity of the region (conservation goals) while exporting large fishes across reserve boundaries (artisanal/sport fishing goals) and larvae to fished areas (commercial fishing goals).

reserves. Such estimates provide an idea of how well local populations can sustain themselves as well as offering guidance for how to construct networks of reserves. Unfortunately, the spatial recruitment patterns resulting from local production are unknown for any marine species with a pelagic stage lasting longer than a few hours, although recent evidence suggests a surprising amount of local retention of production at small scales (tens of kilometres) for species with relatively long (20–50 days) pelagic larval durations (Jones *et al.* 1999; Swearer *et al.* 1999, 2002; Cowen *et al.* 2000; Warner & Cowen 2002). Given the very high fecundity of many marine organisms, it is entirely possible that a local population within a reserve could both sustain itself and provide substantial export to non-reserve areas. Estimating dispersal distances remains one of the great challenges in marine ecology.

It is important to keep in mind that our evaluations of trade-offs between reserve benefits and stakeholder requirements have focused on longer-term outcomes. Reserve effects will take at least a year or two to accrue, and decades for some species. The impacts of spatial closures on fishermen, however, will be felt immediately. To offset some of these short-term costs to fishermen from the creation of reserves, other forms of management (e.g. fleet buy-back programmes) may be necessary. In fact, many have argued that the use of marine reserves must be embedded in a larger scheme of marine management that includes a range of tools and techniques (Agardy *et al.* 2003). However, the goals of both conservation and resource exploitation focus on long-term stability of marine species, which should be achievable through the reserve design described here.

Reserve planning will be most effective if performed at the proper scale. Planning that involves only a small portion of the coastal environment (perhaps owing to limited jurisdiction) is complicated by the potential transport of organisms from outside the planning area. Of course, reserves cannot be equally effective for all the species contained within their borders, but larger planning areas allow reserve network designs that target a wider variety of species. This suggests that coordinated, large-scale programmes will have the best chance of translating marine reserve design theory into practice.

Given the relatively sparse amount of empirical data on the effectiveness of reserves for recruitment enhancement (and subsequent harvest) outside of protected areas, it is tempting to suggest that no action be taken until better information becomes available. However, the continued decline of many fisheries suggests a need to supplement traditional effort-based resource management as quickly as possible (Murray *et al.* 1999). As such, the establishment of reserves should be linked with programmes designed to gauge their effectiveness as a fishery management tool. Such an experimental approach would begin with a design based on the best scientific information available, continue with a dedicated programme to monitor reserve performance, and include a scheme to alter reserve design as performance information becomes available. To be fair and appropriate assessments of the performance of marine reserves, such pilot reserve networks should cover a significant proportion of the management area and be designed according to ecological principles (Airame *et al.* 2003; CAFGC 1999).

5. CONCLUSION

As described above, it is entirely possible that most stakeholders could be served, and served well, by a common design for a system of marine reserves. A network of marine reserves should cover a substantial portion (estimates converge on 20–50%) of the total area being managed. Individual reserves should be large enough to supply recruits to areas outside the reserve and to sustain populations inside, but small enough to allow a sufficient number of adults to 'spill' across reserve boundaries to supply opportunities to 'fish the edge'. The exact size and spacing of individual reserves within the network remain difficult to specify, but a precautionary approach of including a variety of sizes and spacing should allow for a higher likelihood of reserve success. If this design is followed, stakeholders should be able to benefit from the use of marine reserves. However, for the success of reserves to be judged fairly by all stakeholders, it remains essential that: (i) educating stakeholders about the benefits and limitations of marine reserves as a management tool be an integral part of designing reserve networks; (ii) the goals for a reserve be clearly outlined at establishment; and (iii) monitoring programmes be used to assess how well these goals are attained and to help guide modifications to the reserve system as needed. There can never be any guarantees in this process, but greater acceptance can be attained through clear expectations and continued attention to the needs of all stakeholders.

This work was conducted as part of the working group on the Science of Marine Reserves, supported by the National Center for Ecological Analysis and Synthesis, a centre funded by the US NSF (grant DEB-94-21535), the University of California—Santa Barbara, the California Resources Agency and the California Environmental Protection Agency. Support was also provided by the Partnership for the Interdisciplinary Study of Coastal Oceans (PISCO), funded by the David and Lucille Packard Foundation. S. Andelman, S. Gaines, C. Roberts and two anonymous reviewers provided valuable comments on the manuscript.

REFERENCES

Agardy, T., Bridgewater, P., Crosby, M. P., Day J., Dayton, P. K., Kenchington, R., Laffoley, D., McConney, P., Murray, P. A., Parks, J. E. & Peau, L. 2003 Dangerous targets? Unresolved issues and ideological clashes around marine protected areas. *Aquat. Conserv.* (In the press.)

Airame, S., Dugan, J. E., Lafferty, K. D., Leslie, H. M., McArdle, D. A. & Warner, R. R. 2003 Applying ecological criteria to marine reserve design: a case study from the California Channel Islands. *Ecol. Appl.* **13**, S170–S184.

Allison, G. W., Lubchenco, J. & Carr, M. H. 1998 Marine reserves are necessary but not sufficient for marine conservation. *Ecol. Appl.* **8**, S79–S92.

Allison, G. W., Gaines, S. D., Lubchenco, J. & Possingham, H. P. 2003 Ensuring persistence of marine reserves: catastrophes require adopting an insurance factor. *Ecol. Appl.* **13**, S8–S24.

Attwood, C. G. & Bennett, B. A. 1994 Variation in dispersal of galjoen (*Coracinus capensis*) (Teleostei: Coracinidae) from a marine reserve. *Can. J. Fish. Aquat. Sci.* **51**, 1247–1257.

Ballantine, W. J. & Gordon, D. P. 1979 New Zealand's first marine reserve, Cape Rodney to Okakari Point, Leigh. *Biol. Conserv.* **15**, 273–280.

Bohnsack, J. A. 2000 A comparison of the short-term impacts of no-take marine reserves and minimum size limits. *Bull. Mar. Sci.* **66**, 635–650.

Botsford, L. W., Hastings, A. & Gaines, S. D. 2001 Dependence of sustainability on the configuration of marine reserves and larval dispersal distance. *Ecol. Lett.* **4**, 144–150.

Bustamante, R., Wellington, J. & Troya, R. 2001 In Galápagos, clashes between fishers and managers jeopardize conservation efforts. *MPA News* **2**, 1–3.

CAFGC (California Fish and Game Code) Marine Life Protection Act 1999 Division 3, chapter 10.5, sections 2850–2863.

Carr, M. H. & Reed, D. C. 1993 Conceptual issues relevant to marine harvest refuges: examples from temperate reef fishes. *Can. J. Fish. Aquat. Sci.* **50**, 2019–2028.

Carr, M. H., Neigel, J. E., Estes, J. A., Andelman, S. J., Warner, R. R., Largier, J. L. & Lubchenco, J. 2003 Comparing marine and terrestrial ecosystems: implications for principles of reserve design in coastal marine ecosystems. *Ecol. Appl.* **13**, S90–S107.

Castilla, J. C. & Durán, L. R. 1985 Human exclusion from the rocky intertidal zone of central Chile: the effects on *Concholepas concholepas* (Gastropoda). *Oikos* **45**, 391–399.

Chapman, M. R. & Kramer, D. L. 1999 Gradients in coral reef fish density and size across the Barbados Marine Reserve boundary: effects of reserve protection and habitat characteristics. *Mar. Ecol. Progr. Ser.* **181**, 81–96.

Cole, R. G., Villouta, E. & Davidson, R. J. 2000 Direct evidence of limited dispersal of the reef fish *Parapercis colias* (Pinguipeidae) within a marine reserve and adjacent fished areas. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* **10**, 421–436.

Cowen, R. K., Lwiza, K. M. M., Sponaugle, S., Paris, C. B. & Olson, D. B. 2000 Connectivity of marine populations: open or closed? *Science* **287**, 857–859.

Dayton, P. K., Tegner, M. J., Edwards, P. B. & Riser, K. L. 1998 Sliding baselines, ghosts, and reduced expectations in kelp forest communities. *Ecol. Appl.* **8**, 309–322.

Dayton, P. K., Sala, E., Tegner, M. J. & Thrush, S. 2000 Marine reserves: parks, baselines, and fishery enhancement. *Bull. Mar. Sci.* **66**, 617–634.

DeMartini, E. E. 1993 Modeling the potential of fishery reserves for managing Pacific coral reef fishes. *Fish. Bull.* **91**, 414–427.

Didier Jr, A. J. 1998 Marine protected areas of Washington, Oregon, and California. Report to the Pacific Fishery Management Council, Gladston, OR.

Gell, F. R. & Roberts, C. M. 2002 *The fishery effects of marine reserves and fishery closures*. Washington: WWF-US.

Halpern, B. S. 2003 The impact of marine reserves: have reserves worked and does reserve size matter? *Ecol. Appl.* **13**, S117–S137.

Halpern, B. S. & Warner, R. R. 2002 Marine reserves have rapid and lasting effects. *Ecol. Lett.* **5**, 361–366.

Haskell, B. 1999 Tortugas working group gets consensus on reserve, is challenged by anglers. *MPA News* **1**, 1–2.

Hastings, A. & Botsford, L. W. 1999 Equivalence in yield from marine reserves and traditional fisheries management. *Science* **284**, 1537–1538.

Jackson, J. B. C. (and 18 others) 2001 Historical overfishing and the recent collapse of coastal ecosystems. *Science* **293**, 629–637.

Jennings, S., Greenstreet, S. P. R. & Reynolds, J. D. 1999*a* Structural change in an exploited fish community: a consequence of differential fishing effects on species with contrasting life histories. *J. Anim. Ecol.* **68**, 617–627.

Jennings, S., Reynolds, J. D. & Polunin, N. V. C. 1999*b* Predicting the vulnerability of tropical reef fishes to exploitation with phylogenies and life histories. *Conserv. Biol.* **13**, 1466–1475.

Johnson, D. R., Funicelli, N. A. & Bohnsack, J. A. 1999 Effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Center, Florida. *N. Am. J. Fish. Mngmt* **19**, 436–453.

Jones, G. P., Milicich, M. J., Emslie, M. J. & Lunow, C. 1999 Self-recruitment in a coral reef fish population. *Nature* **402**, 802–804.

Kinlan, B. P. & Gaines, S. D. 2003 Propagule dispersal in marine and terrestrial environments: a community perspective. *Ecology* **84** (In the press.)

Kramer, D. L. & Chapman, M. R. 1999 Implications of fish home range size and relocation for marine reserve function. *Environ. Biol. Fish.* **55**, 65–79.

Leeworthy, V. R. 2001 Preliminary findings from two years of monitoring the commercial fisheries: impact of no take areas. Report to NOAA, US Dept. Comm., Silver Spring, Maryland.

McArdle, D. A. 1997 *California marine protected areas*. La Jolla, CA: California Sea Grant College System.

MacArthur, R. H. & Wilson, E. O. 1967 *The theory of island biogeography*. Princeton University Press.

McClanahan, T. R. & Arthur, R. 2001 The effect of marine reserves and habitat on populations of east African coral reef fishes. *Ecol. Appl.* **11**, 559–569.

McClanahan, T. R. & Mangi, S. 2000 Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecol. Appl.* **10**, 1792–1805.

Mangel, M. 2000 On the fraction of habitat allocated to marine reserves. *Ecol. Lett.* **3**, 15–22.

Margules, C. R. & Pressey, R. L. 2000 Systematic conservation planning. *Nature* **405**, 243–253.

Murawski, S. A., Brown, R., Lai, H.-L., Rago, P. J. & Hendrickson, L. 2000 Large-scale closed areas as a fishery-management tool in temperate marine systems: the Georges Bank experience. *Bull. Mar. Sci.* **66**, 775–798.

Murray, S. N. (and 18 others) 1999 No-take reserve networks: sustaining fishery populations and marine ecosystems. *Fisheries* **24**, 11–25.

National Oceanic and Atmospheric Administration (NOAA) 1996 Florida Keys National Marine Sanctuary final management plan/environmental impact statement, vol. 1. Silver Spring, MD: NOAA, US Dept. Comm.

National Research Council (NRC) 2001 Report of the committee on the evaluation, design and monitoring of marine reserves and protected areas in the United States. Washington, DC: National Academy Press.

Neigel, J. E. 2003 Species–area relationships and marine conservation. *Ecol. Applications* **13**, S138–S145.

Nuttall, N., Braynen, M., Hixon, M. & Sealey, K. S. 2000 Bahamas to create no-take reserve network to protect fisheries, fishermen. *MPA News* **1**, 1–3.

Palumbi, S. R. 2003 *Marine reserves: a tool for ecosystem management and conservation*. Arlington, VA: Pews Ocean Commission.

Polacheck, T. 1990 Year around closed areas as a management tool. *Nat. Resource Model.* **4**, 327–353.

Roberts, C. M. 2000 Selecting marine reserve locations: optimality versus opportunism. *Bull. Mar. Sci.* **66**, 581–592.

Roberts, C. M. & Hawkins, J. P. 2000 *Fully-protected marine reserves: a guide*. Washington, DC: WWF Endangered Seas Campaign and York: Environment Department, University of York.

Roberts, C. M., Bohnsack, J. A., Gell, F., Hawkins, J. P. & Goodridge, R. 2001 Effects of marine reserves on adjacent fisheries. *Science* **294**, 1920–1923.

Roberts, C. M., Halpern, B. S., Warner, R. R. & Palumbi, S. 2002 Designing marine reserve networks: why small, isolated protected areas are not enough. *Conserv. Biol. Practice* **2**, 9–17.

Roberts, C. M. (and 11 others) 2003 Application of ecological criteria in selecting marine reserves and developing reserve networks. *Ecol. Appl.* **13**, S215–S228.

Rowley, R. J. 1994 Marine reserves in fisheries management. *Aquat. Conserv. Mar. Freshwat. Ecosyst.* **4**, 233–254.

Russ, G. R. 2002 Yet another review of marine reserves as reef fisheries management tools. In *Coral reef fishes: dynamics and diversity in a complex ecosystem* (ed. P. F. Sale), pp. 421–443. San Diego, CA: Academic Press.

Russ, G. R. & Alcala, A. C. 1996 Marine reserves: rates and patterns of recovery and decline of large predatory fish. *Ecol. Appl.* **6**, 947–961.

Russ, G. R. & Alcala, A. C. 1998*a* Natural fishing experiments in marine reserves 1983–1993: community and trophic responses. *Coral Reefs* **17**, 383–397.

Russ, G. R. & Alcala, A. C. 1998*b* Natural fishing experiments in marine reserves 1983–1993: roles of life history and fishing intensity in family responses. *Coral Reefs* **17**, 399–416.

Shafer, C. L. 1990 *Nature reserves: island theory and conservation practice*. Washington, DC: Smithsonian Institution Press.

Shanks, A. L., Grantham, B. & Carr, M. H. 2003 Propagule dispersal distance and the size and spacing of marine reserves. *Ecol. Appl.* **13**, S159–S169.

Snelgrove, P. V. R. 1999 Getting to the bottom of marine biodiversity: sedimentary habitats—ocean bottoms are the most widespread habitat on Earth and support high biodiversity and key ecosystem services. *Bioscience* **49**, 129–138.

Suman, D., Shivlani, M. & Milon, J. W. 1999 Perceptions and attitudes regarding marine reserves: a comparison of stakeholder groups in the Florida Keys National Marine Sanctuary. *Ocean Coast. Mngmt* **42**, 1019–1040.

Swearer, S. E., Caselle, J. E., Lea, D. W. & Warner, R. R. 1999 Larval retention and recruitment in an island population of a coral-reef fish. *Nature* **402**, 799–802.

Swearer, S. E., Shima, J. S., Hellberg, M. E., Thorrold, S. R., Jones, G. P., Robertson, D. R., Morgan, S. G., Selkoe, K. A., Ruiz, G. M. & Warner, R. R. 2002 Evidence of self-recruitment in demersal marine populations. *Bull. Mar. Sci.* **70**, 251–271.

Turpie, J. K., Beckley, L. E. & Katua, S. M. 2000 Biogeography and the selection of priority areas for conservation of South African coastal fishes. *Biol. Conserv.* **92**, 59–72.

Warner, R. R. & Cowen, R. K. 2002 Local retention of production in marine populations: evidence, mechanisms, and consequences. *Bull. Mar. Sci.* **70**, 245–249.

Zacharias, M. A. & Roff, J. C. 2000 A hierarchical ecological approach to conserving marine biodiversity. *Conserv. Biol.* **14**, 1327–1334.

Zacharias, M. A. & Roff, J. C. 2001 Zacharias and Roff vs. Salomon *et al.*: who adds more value to marine conservation efforts? *Conserv. Biol.* **15**, 1456–1458.

No Take Marine Protected Areas (nMPAs) as a fishery management tool, a pragmatic perspective

A Report to the FishAmerica Foundation

By Robert L. Shipp, Ph.D.

Executive Summary

Marine Protected Areas (MPAs) are portions of the marine environment which are protected from some or all human activity. Often these are proposed as a safeguard against collapse of fish stocks, although there are numerous other suggested purposes for their establishment. “No take” MPAs (hereafter referenced as nMPAs) are those from which no harvest is allowed. Other types include those where certain types of harvest are prohibited, which are reserved for certain user groups, or which are protected from other human activities such as drilling or dredging.

Establishment of nMPAs may have numerous beneficial purposes. However, as a tool for fisheries management, where optimal and/or maximum sustainable yield is the objective, nMPAs are generally not as effective as traditional management measures, and are not appropriate for the vast majority of marine species. This is because most marine species are far too mobile to remain within an nMPA and/or are not overfished. For those few species that could receive benefit, creation of nMPAs would have an adverse effect on optimal management of sympatric forms.

Eight percent of US fish stocks of the Exclusive Economic Zone (EEZ) are reported to be experiencing overfishing. The finfish stocks included in this number are primarily pelagic or highly mobile species, movement patterns that don’t lend themselves to benefit from nMPAs. Thus a very small percentage, something less than 2 %, depending on mobility potentials, is likely to benefit from creation of these no-take zones. However, many of these species have come under management within the last decade, employing more traditional fishery management measures, and are experiencing recovery.

MPAs (both “no take” and other types) can serve a positive function as a management tool in protecting breeding aggregations, in helping recovery of severely overfished and unmanaged insular fish populations with little connectivity to adjacent stocks, and in protecting critical habitat which can be damaged by certain fishing methods.

Introduction

Concept of MPAs

In recent years, a great deal of interest has been expressed in the establishment of Marine Protected Areas (MPAs), marine "no take" areas, or marine sanctuaries (e.g. National Research Council: "Marine Protected Areas: Tools for Sustaining Ocean Ecosystems, 2001; National Resource Defense Council: "Keeping Oceans Wild: How marine reserves protect our living seas, 2001") This interest has been spurred by the frequent references to depleted fish stocks, and continued decline in marine fishery resources.

Proponents of so called "no take" Marine Protected Areas (nMPAs) have described the benefits to include potential as a fishery management tool as well as several other related advantages, specifically, conserving biodiversity, protecting (coastal) ecosystem integrity, preserving cultural heritage, providing educational and recreational opportunities, and establishing sites for scientific research (Houde et al., 2001). In addition, other benefits suggested include enhancing ecotourism, and reducing user group conflict (e.g. divers and harvesters).

The concept of nMPAs is initially attractive, and will no doubt elicit a great deal of support and discussion among various groups interested in protecting marine habitats. However, the many offered benefits described above often overlap, and become intertwined in the discussions that ensue. <u>A fishery management tool is one that sustains and/or increases through time the yield of a fish stock, or several sympatric stocks of an ecosystem.</u> If nMPAs are to be considered as a management tool, then that goal or objective, sustained and/or increased yield, needs to be clearly stated, and distinguished from other, more theoretical goals.

Traditional Management Tools

Traditional management tools generally focus on reducing effort, enhancing stocks from hatchery operations, and protecting critical habitat. Effort reduction includes bag and size limits (including sometimes slot limits), quotas, seasonal and/or areal closures, gear restrictions, and by-catch reduction. These have been successful for more than a century in freshwater environments. Their use in marine habitats has only become widespread in the United States in recent decades, especially since passage of the Fishery Conservation and Management Act in 1976. Hatchery operations and stocking have also been primarily a freshwater endeavor, although recent efforts to stock some marine species have been attempted and yet to be evaluated over the long term. Protection of critical marine habitats has become an issue of extreme concern and is the focus of current efforts on the part of all Fishery Management Councils, as required in the most recent reauthorization of the Sustainable Fisheries Act. Use of MPAs for this purpose is discussed later in this paper.

Purposes of MPAs

In order for nMPAs to function as a management tool for marine fisheries, there needs to be an examination in specific instances and with specific stocks to determine the potential benefits. This is especially true when stakeholders are currently so involved in management decisions that impact their livelihood. In their work on no-take reserves (Murray et al., 1999), the authors list guidelines for these reserves, including first:

1. Reserves should have clearly identified goals, objectives, and expectations.

a) Clearly identify and describe the purposes of each reserve.
b) Clearly identify the species, communities, and habitats to be protected.
c) Clearly identify the projected role and contribution of each reserve to the network.

I am in total agreement with these guidelines. For this reason, a systematic approach, detailing the potential benefits or lack thereof of nMPAs on managed stocks is justified, and is the intent of this paper. It is not the intent of this paper to pass judgment on the benefits of MPAs ("no take" or MPAs of other design) on any of the other stated objectives (e.g. conserving biodiversity, study sites for ecosystem research, ecotourism sites, protection of habitat from destructive fishing methods, protection of habitats from other harmful anthropogenic activities such as drilling, coastal development etc.). These are socioeconomic or scientific questions that may have socioeconomic and/or scientific consequences, but are distinct from evaluating scientifically nMPAs as a fishery management tool.

Methodology

The procedure followed here is to develop a comprehensive list of economically (commercial and recreational) important finfish from the mid to south Atlantic, the Gulf of Mexico, and Pacific US coasts (shellfish are excluded here because of the radical differences in their life history, harvest methods, etc.). For each species in the list, determine the status of the stocks (underutilized, fully utilized, over utilized, unknown). Then review their life histories, especially movement and/or migratory patterns, and make a judgment as to the possible benefits that may be conferred by establishment of an nMPA.

Determination of nMPA impacts

NMPAs are predicated on two fundamental components: keeping harvesters out and keeping the species in. The first of these is primarily an enforcement, compliance, and education issue and not to be discussed herein. The second is wholly a scientific issue, that is, whether the biology of the species is such that they will remain within an nMPA for a period of their life long enough to accrue the protection desired.

Studies assessing the management potentials of nMPAs recognize this, and the "keeping species in" component is critical in modeling efforts. For example, Nowlis and Roberts (1998) state that their models "**included the key assumptions that adults did not cross reserve boundaries and that larvae mixed thoroughly across the boundary but were retained sufficiently to produce a stock-recruitment relationship for the management area."**

In addition, for an nMPA to be an effective management tool, the clear implication is that management is needed. Thus, the stocks must be overfished, or overfishing is occurring or likely to occur, and the stocks may be approaching an overfished condition. There are formal and legal definitions for these terms, but briefly, an "overfished stock" is one whose current biomass is below that needed to maintain current harvest rates, and "overfishing" refers to a **<u>rate</u>** of fishing pressure that will lead to the overfished condition, even though current biomass of that stock is adequate to sustain maximum sustainable yield (MSY) if properly managed.

If the stocks are healthy, and projected to remain so, that is they are neither overfished nor is overfishing occurring, the need for nMPAs as a management tool is nil. This is also true if the preferred but complex ecosystem management strategy is employed, and no species within the complex is overfished or experiencing overfishing. In fact the literature is clear on this point, that if the stocks are healthy, nMPAs at best are yield neutral or will reduce harvest in some ratio to the size of the nMPAs (e.g. Polachek, 1990; DeMartini, 1993; Holland and Brazee, 1996; Sladik and Roberts, 1997; Botsford et al., 1999; Hastings and Botsford, 1999; R. Hilborn, U. of Wash. pers. com.).

Current status of fisheries

So it is first important to gain some perspective on the extent of overfishing in U.S. waters before we can assess the possible benefits of nMPAs. In the latest Report to Congress (NMFS 2001), 905 fish stocks in the EEZ were addressed, including both finfish and shellfish. Ninety-two stocks (10%) were determined to be overfished; seventy-two stocks (8%) were found to have overfishing occurring. Of these, 57 stocks (6.3%) were found to be both overfished and are experiencing overfishing. These percentages are somewhat misleading in that there were a large number of stocks for which the stock status was undetermined. However most of these were economically less important and less targeted species.

Determination of Potential Benefits

In determining possible benefits for each species, while movement patterns and stock condition are primary considerations, additional parameters include any that may impact the management of the species. Examples include utility and effectiveness of alternative management measures, presence of critical habitat, by-catch mortality, release mortality, and recruitment (i.e. larval dispersal) characteristics.

The species movement patterns of course relate to the proposed dimensions of an nMPA, but in most discussions, vast area nMPAs, covering extents within which a migratory species or all life history stages of sedentary species would be contained, are not proposed. Exceptions exist in dire cases, such as the major areas established off the upper western North Atlantic shelf, where an attempt is being made to recover the depleted ground fish stocks (NOAA, 1999). In fact, these can also be interpreted as a proxy for effort reduction on a collapsed fishery.

There have been suggestions that certain areas which serve as major migratory pathways or important spawning areas for pelagic species be considered as nMPAs (e.g. NOAA, 1999). These in fact will be discussed as critical habitat parameters, but are not what are generally considered as an nMPA, as these may be seasonal, or even variable in locale, depending on certain physical conditions.

The basic document employed for this list determination is the aforementioned “Report on the Status of US Living Resources” published by the US Dept of Commerce for the year 1999 (NOAA, 1999) and “The Report to Congress. Status of Fisheries of the United States” (NMFS, 2001). These reports provide species lists for each of the coasts, and their current stock status. This is supplemented by including additional species that may fall under individual state management, or have some economic importance external to the parameters of the federal documents. Where these species have been added, a brief commentary on the rationale to do so is included.

Thus the concern often expressed is for troubled species, and the purpose of this report is to determine if those species are potential beneficiaries of nMPAs.

Mid to south Atlantic species

Anadromous Species

NOAA (1999) lists five managed anadromous species of the Atlantic Coast: Striped bass, American shad, alewife/blueback, sturgeons, and Atlantic salmon. All these stocks are considered overfished except striped bass.

Striped bass *(Morone saxatili*s) suffered severe recruitment failures in the 1970s, but restrictive management measures implemented in the 1980s and some good recruitment levels have restored the stocks. For the other species, agricultural and industrial development and damming of rivers are cited as the major impediments to rebuilding. And while improvements of these riverine habitats may be necessary for recovery of these stocks, none of these species can be considered as potential beneficiaries of an nMPA.

Atlantic Highly Migratory Species.

NOAA (1999) lists 10 categories of highly migratory fish stocks: yellowfin tuna, bigeye tuna, albacore, skipjack tuna, bluefin tuna, “other” tunas, swordfish, blue marlin, white marlin and sailfish. Of these, all are considered over exploited, except yellowfin (fully exploited), skipjack (possibly fully exploited) and other tunas (unknown). While there is grave concern for the future of these severely overfished stocks, their highly migratory nature and requirements for international quota regulations preclude them from receiving significant benefit from an nMPA. However, identification of critical spawning areas may justify seasonal/areal closures in the future.

Atlantic Shark Fishery.

There are thirty-four species of sharks listed in the Atlantic shark fishery by NOAA (1999), however these are grouped into only three categories: large coastal, small coastal, and pelagic. The large coastal species as a group are considered overfished, although lack of knowledge of the individual species status is a concern. Small coastal sharks are thought to be fully utilized, and their stock levels above that necessary to maintain a long-term potential maximum yield. The exploitation status of the highly pelagic grouping is unknown. But practically all shark species for which tagging studies have been implemented show extensive movement patterns, and as a result, are unlikely to benefit from nMPAs. However, recent information on critical nursery areas for some species may warrant seasonal/areal closures or other measures to protect critical habitat of juveniles.

Summer Flounder.

Along the New England and mid Atlantic coast, summer flounder (*Paralichthys dentatus*) of the mid Atlantic states is a heavily exploited species, both commercially and recreationally. The species undergoes an offshore spawning migration from late summer to mid-winter, and the larvae and post-larvae drift inshore, where metamorphosis is completed, and the juveniles utilize eelgrass beds or similar habitats. The extensive migratory patterns minimize potential benefit to the species by nMPAs, however, consideration should be given to protection and even expansion of the required juvenile habitat.

Other south Atlantic and Gulf of Mexico stocks

Atlantic and Gulf of Mexico Migratory Pelagic Fisheries.

Because of their migratory patterns which ingress between both the Gulf and south Atlantic, Gulf and Atlantic migratory species are included together. The species listed include dolphinfish, king mackerel, Spanish mackerel, cobia, and cero mackerel. To this list is added wahoo, because both Management Councils (the South Atlantic Fishery Management Council [SAFMC] and the Gulf of Mexico Fishery Management Council [GOMFMC]) have recently begun an assessment and management plan for this species.

Of these seven species, only the Gulf stock king mackerel have been considered overfished, although the most recent stock assessment has concluded that this stock has now recovered to the fully utilized level (Dr. Will Patterson, chair GOMFMC Coastal Migratory Stock Assessment Panel, pers. com). Dolphinfish, cobia, cero, and wahoo fishery utilization levels are unknown. But in any case, these species are so migratory that none could be considered to benefit by an nMPA.

Atlantic and Gulf of Mexico Reef Fisheries.

About 60 species of reef fishes are managed in the South Atlantic and Gulf EEZ. For the vast majority of these, stock assessments have not been performed and life history data, including movement patterns, are also unknown. Thus any consideration of nMPA benefits for these species is pre mature. However, in recent decades, great concern has been expressed for several of the more valuable species, and more is known of their stocks and life history than the lesser known forms. These will form the analytical basis for the potential benefits of nMPAs, and for the present, can be considered as reasonable proxies for the other less studied species.

The species included in this discussion are: jewfish (= goliath grouper), Nassau grouper, gag grouper, red grouper, red snapper, vermilion snapper, mutton snapper, greater amberjack, red porgy, and gray triggerfish. Each of these is treated individually in regard to their stock status and current trends, life history parameters, and potential benefits of nMPAs.

Goliath grouper (*Epinephelus itajara*) has been a species of great concern for more than a decade. In fact, a total harvest prohibition was placed on this species in the late 1980s. Since then, the population has experienced significant recovery (A. E. Eklund, NMFS, pers.comm.), and has led many commercial and recreational fishermen to express concern that its predatory behavior may negatively impact populations of sympatric reef species, especially spiny lobsters. At the recent (January 2002) meeting of the Reef Fish Advisory Panel (RFAP) of the GOMFMC, several members noted that these stocks have rebounded so strongly and are impacting their prey species so heavily that the Panel voted unanimously to request that the Council consider a controlled harvest to determine the status of the stocks.

Nassau groupers (*Epinephelus striatus*) are found only in the most extreme southern US, primarily the Florida Keys (Sadovy and Eklund, 1999). The status of their stocks has also been of great concern, especially because of their well-documented spawning aggregations (Colin, 1992) that make them vulnerable to intense harvest at that time. For this reason, protection of these sites during spawning is certainly a positive function of an nMPA. Whether these sites should be so designated permanently would require additional studies to determine if habitat requirements were threatened by harvest activities during other times. In addition, designation of areas other than the spawning sites as nMPAs for protection of Nassau would not be beneficial, since they would leave those areas during spawning, and thus become vulnerable to capture (Bolden, 2000).

Gag grouper (*Mycteroperca microlepis*) is an extremely important commercial and recreational species, occurring along the entire mid- Atlantic and Gulf coasts. There has been a great deal of study on this species (see Turner et al., 2001) because of its economic importance, fears for the condition of the stock, the formation of spawning aggregations, its protogynous life cycle, and the possibility of a major shift in sex ratios (fewer males) due to overfishing and the extremely aggressive habits of the males during this period (Coleman et al., 1996). Several regions off the big bend area of Florida were proposed as nMPAs by the GOMFMC for this species during the spawning period (late winter-early spring), but prevented from implementation by subsequent litigation. However, the occurrence of spawning aggregations and concern over sex ratios does argue for protection in those areas well documented as spawning sites. Although the current stock assessment indicates that the stocks are not overfished (GOMFMC, Stock Assessment Panel [SAP], 2001), gag is definitely a potential candidate for protection at aggregate spawning sites and during spawning periods.

Red grouper (*Epinephelus morio*) range from Massachusetts to Brazil, and are most abundant on the west Florida and Yucatan shelves. They're found from coastal estuaries to the outer continental shelf (Robins et al., 1986; Shipp, 2000) and will likely be declared overfished during the year 2002 (Dr. Jim Cowan, chair, GOMFMC, SAP), although there continues to be a great deal of uncertainty regarding the status of the stocks, due in large part to historical catch by the Cuban fleet through the 1960s. In addition, little is known about the migratory patterns of this species. But there is no indication that they are any more sedentary than other groupers, and the juveniles occur in nearshore waters, moving offshore as they approach maturity. It is possible that adults form small breeding aggregations (Coleman et al., 1996), but whether these occur in well-defined areas is not known. If such areas are located, they could possibly be designated as an nMPA during spawning periods.

Red snapper (*Lutjanus campechanus*) has doubtlessly become the most controversial finfish species in the Gulf of Mexico, less so in the south Atlantic. It's high market value, favor by recreational fisherman, and the vulnerability of juveniles to shrimp trawls, has resulted in stakeholder conflicts on many fronts. The species was declared as severely overfished in the late 1980s and early 1990s (Goodyear, 1995; Schirripa and Legault, 1999). This resulted in numerous harvest restrictions, including minimum size limits, seasonal closures, trip limits for commercial fishermen, bag limits for recreational fishermen, and mandates for by-catch reduction devices by the shrimp fleet.

Because of these factors, and the fact that it's a reef species thought to have relatively sedentary habits, several recent papers on red snapper have cited the species as one that might be benefited by nMPAs (Bohnsack, 1996; Fogarty et al. 2000, Houde, 2001). However, on closer examination, red snapper would likely not benefit. Recent papers describing results of tagging studies (Watterson et al., 1998; Patterson et al. 2001) demonstrate that while strongly reef associated, red snappers exhibit slow movement away from tagging sites under normal conditions, and extensive movement as a result of tropical cyclones, a very frequent occurrence throughout the entire range of the species Figure 1). Thus, a "permanent" red snapper stock in an nMPA would be largely relocated to other areas with each of these events.

In addition, recent model projections of snapper recovery (Goodyear, 1995; Schirripa and Legault, 1999) cite the need for very substantial (40%-80%) shrimp trawl by-catch reduction of age 0 and 1 juveniles. Red snapper larvae remain in the plankton for two weeks or more. Thus any potential contribution of larvae to the overall population from and nMPA stock would be subjected to the same mortality over most of its range. But despite the stresses experienced by the stock, red snapper appear to have begun to recover. With the implementation of the traditional management measures described above, quotas and CPUE have increased consistently during the last decade.

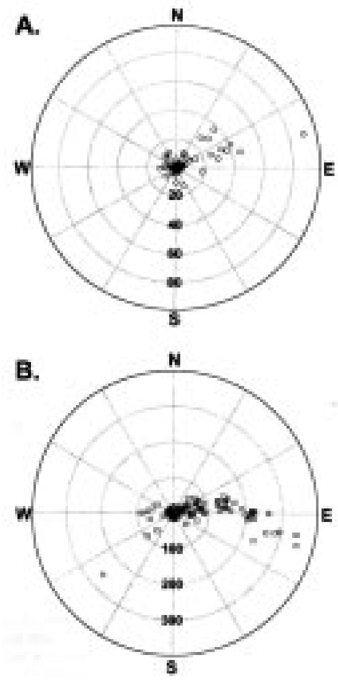


Figure 1. Polar diagrams of red snapper movement for (A) fish not at liberty during Hurricanes Opal and Georges and (B) fish at liberty during those hurricanes. Note scaler differences, in kilometers. From Patterson et al, 2001

Vermilion snapper (*Rhomboplites aurorubens*) is a moderately important reef species of the Gulf and south Atlantic. The stock assessment panels have not been able with certainty to evaluate stock status. However, in the Gulf, it is likely that this species may be heading toward an overfished condition (J. Cowan, chair, GOMFMC Stock Assessment Panel, pers. comm.), although the most recent assessment contained so many uncertainties that the GOMFMC Reef Fish Advisory Panel in 2002 recommended "status quo" on setting a quota until a more reliable assessment could be developed. The species has been managed primarily by a minimum size limitation. There is little information as to its migratory or movement patterns, so the benefits of an nMPA for this species cannot be determined.

Mutton snapper (*Lutjanus analis*) is known to form distinct spawning aggregations. One of the best known is the Riley's hump area near the Dry Tortugas in the Florida Keys. This area is protected during the spawning season, and except for some occasional violations and attendant enforcement problems, the protection will likely benefit the species.

Greater amberjack (*Seriola dumerili*), though listed as a reef species, is better considered a coastal pelagic. Although frequenting reef areas, this active species is very mobile, and its movements, though not extensive long range migrations, do traverse hundreds of kilometers on a regular basis (Ingram, et al., in press), and thus is an unlikely candidate to benefit from any but the most expansive nMPAs.

Red porgy (*Pagrus pagrus*) ranges on both sides of the Atlantic in temperate and tropical seas. It favors live bottom habitats. It is a species of some concern regarding the health of the stocks, especially in the south Atlantic US coast. Recent increases in fishing pressure have resulted in a greatly reduced stock, and a call for reduced fishing mortality. Earlier tagging studies did not indicate extensive migrations. The species is currently under management by the SAFMC, and effort restrictions have been put in place to reduce harvest. Contingent on the results of this management and additional data on population movements, the red porgy is a species that could possibly benefit from an nMPA until stocks are returned to a level more manageable by traditional fishery methods. However, the population appears to be experiencing a substantial rebound (Dr. Robert Mahood, Exec. Dir. SAFMC, pers. com.), and a new stock assessment will be completed in June of 2002.

Gray triggerfish (*Balistes capriscus*) is a temperate-tropical species found on both sides of the Atlantic. The species has received additional fishing pressure in recent years, probably resulting from more stringent management regulations on co-occurring species, especially red snappers and groupers. However, the stocks are not considered overfished, but as a precautionary move, a 12" minimum TL size limit has been implemented by most management agencies. Recent studies (Ingram, 2001) suggest that gray triggerfish are more sedentary than previously thought, more so than red snapper, but nevertheless do display some limited movement. Should future fishing pressures indicate additional limitations on harvest, this species might be the best candidate among the fishes discussed here to benefit from an nMPA, especially given that recent stock assessment data indicate that gray triggerfish may be experiencing local overfishing in some locations in the Gulf of Mexico (J. Cowan, chair, GOMFMC Stock Assessment Panel, pers. comm.).

<u>Other Snapper/Grouper Species.</u>

In the south Atlantic, there are nine species of snappers and groupers (gag grouper, red snapper, speckled hind, snowy grouper, Warsaw grouper, golden tilefish, yellowtail snapper, red grouper, and black grouper) that are considered overfished and overfishing is occurring. The SAFMC has initiated rebuilding plans by imposing catch restrictions on all these species. These plans are generally 10-15 year plans, and most are about five years away from completion. If these traditional management measures fail, nMPAs might be appropriate for some or all of these species. However, migratory patterns of these forms are at present poorly understood. Therefore, establishment of nMPAs at this time is pre mature.

There are an additional 19 snapper/grouper species in the South Atlantic, as well as scores of sympatric species under management (e.g. grunts, porgies), for which the stock status is unknown.

<u>Southeast Drum and Croaker Fisheries.</u>

Black drum, Atlantic croaker, spot, red drum, seatrouts, and kingfishes (whitings) are included in this grouping. Atlantic croaker and red drum are considered overfished, while the other species' status is considered unknown. All these species spawn in higher salinity waters or offshore, and the young enter estuaries where they reside until reaching sexual maturity.

Of the two overfished stocks, management plans are in place for the recovery of both. Croaker (*Micropogonias undulatus*) stocks suffer greatly from by-catch discards, which include about 7.5 billion individuals killed annually (NOAA 1999). Improvement in gear designs will likely reduce this mortality and lead to recovery of the species.

A total harvest ban in federal waters by the South Atlantic and Gulf of Mexico Councils has been put in place for red drum (*Sciaenops ocellatus*). In addition, the states have implemented various restrictive harvest measures. The results suggest that these conservation measures have substantially increased the escapement of juveniles, and the offshore adult stocks are increasing.

Thus there appears no benefit of nMPAs as a management tool for the southeast drum and croaker fisheries.

Other Gulf and south Atlantic species under some form of management include striped mullet, tarpon, and snook. Only regional assessments exist for these species, but none is considered overfished on a range-wide basis, and all have moderate to long range migratory patterns, and would not benefit from traditional nMPAs. However, the juvenile phase of tarpon may benefit from some nursery area protection (Shipp, 1986).

Pacific Coast fisheries (excluding Alaska)

<u>Pacific Coast Pelagic Species.</u>

There are five species included within the Pacific pelagic group (northern anchovy, Pacific sardine, jack mackerel, chub mackerel, and Pacific herring, NOAA, 1999). All are listed as under or fully utilized, none overfished. Therefore, because of their healthy stock conditions and pelagic life history, they would receive no benefits from creation of nMPAs.

<u>Pacific Coast Groundfish Fisheries.</u>

The Pacific groundfish assemblage is a diverse group of species, principally flatfishes and rockfishes. These are mainly long-lived, slow growing species, subject to harvest by both commercial and recreational fishers. Included are about 60 species of rockfishes, principally *Sebastes* and several species of thornyheads (Genus *Sebastolobus*), several cods, the sablefish (*Anolopoma fimbria*) and the lingcod (*Ophiodon elongatus*). Recently, life history data were provided to the Pacific States Marine Fisheries Commission of the nearshore fishes of California (Cailliet, 2000). This, along with several supplementary references, and combined with the NOAA document (1999) and the Report to Congress NMFS 2001) provide the background for determination of the possible impacts of nMPAs on these species.

The Pacific whiting (=Pacific hake, *Merluccius productus*), is a mid to moderate depth species, with relatively extensive movement patterns. It is considered fully but not over exploited, and with extremely variable year class strengths. Because of these factors the species is not likely to benefit from establishment of an nMPA.

The sablefish (*Anaplopoma fimbria*) is an important commercial species, ranging from Japan and the Bering Sea to Baja. The stock status is considered fully exploited, and stock levels are below optimum. However, it is a deep water, often migratory species, thus not likely to benefit from an nMPA.

The lingcod (*Ophiodon elongatus*) is a large member of the greenling family, ranging from Kodiak Island to southern California, but is most abundant in the northern part of its range. It is an extremely important recreational and commercial species, with a high food value, although representing only about 2 % of the Pacific Coast groundfish catch. This species is considered to be over exploited, with stock levels well below that necessary to maintain the long-term projected yield. The species is relatively sedentary, usually in rocky reefs at depths of 10 to 100 m. It is a nest building species, and the males become extremely aggressive during this time, particularly vulnerable to attack by marine mammals. The species is also cannibalistic.

The life history and stock condition indicate that this species could benefit by an nMPA in the more northern part of its range. However, other management measures have been put in place, including protection of spawning and nesting sites during spawning season, minimum size requirements to ensure at least one spawn before subject to harvest, and restricted catch limits through recreational bag limits and commercial quotas. Though recovery is likely to be slow because this is a long-lived species (up to 25 years), these measures are thought to be sufficient to effect recovery (Alaska Dept. of Fish and Game, 1994).

Pacific cod (*Gadus macrocephalus)* is a wide ranging, highly migratory species of commercial importance in the North Pacific. It is considered underutilized, although stock status and long term potential yield are unknown. Therefore, the species would not benefit from establishment of an nMPA.

<u>Pacific Flatfishes.</u>

Pacific halibut (*Hippoglossus stenolepis*) is a carefully managed species, with its center of abundance in the Gulf of Alaska. Landings from the US Pacific Coast (excluding Alaska) average about 570 metric tons, representing a little more than 1% of the total harvest (NOAA, 1999). The species is well managed throughout its range by traditional methods, and recent harvest has been near record. Thus the species would not likely benefit from establishment of an nMPA.

The status of four other US Pacific Coast flatfish species (arrowtooth flounder [*Atheresthes stomias*], Dover sole [*Microstomas pacificus*] , English sole [*Pleuronectes vetulus*] , and petrale sole [*Eopsetta jordani*]) are considered individually while the many additional flatfishes are grouped together (NOAA, 1999). Of these four, none is listed as overfished, and all are wide ranging with extensive offshore movement patterns. For this reason, none would benefit from nMPAs. For the many remaining flatfish species, their stock status is unknown.

<u>Rockfishes.</u>

There are about 65 species of rockfishes endemic to the US Pacific coast, most in the genus *Sebastes*. They live in a diversity of habitats, from clean bays, to depths greater than 400 M. They are long-lived species, with some living well over 50 years. Thus, annual exploitation to attain the management goals of 35-40% spawning biomass per recruit is often as low as about 5-10%. In recent years, the surplus present in most of these stocks has been fished down, resulting in reductions in recommended annual harvest (NOAA, 1999).

In its report to Congress, NMFS (2001) lists 52 species of rockfish. For four species (Pacific ocean perch [*Sebastes alutus*], bocaccio [S. *paucispinus*], canary rockfish [*S. pinniger*], and cowcod [*S. levis*], all but the latter are major stocks) the stocks are overfished but overfishing is not presently occurring and rebuilding programs are in place or under development. These species are all wide ranging forms with extensive portions of their populations in very deep water. Thus for fishery management purposes, nMPAs are likely not needed Only nMPAs of impractical extent both longitudinally and bathymetrically would have any impact on the stocks as a whole.

For three species (darkblotched rockfish [*Sebastes crameri*], silvergrey rockfish [*S. brevispinis*], and yelloweye rockfish [*S. ruberrimus*], all major stocks) overfishing is occurring, but for the former species the stocks are not currently overfished, and for the latter two stock conditions are unknown. Reduced mortality will be required, but currently, rebuilding plans are not yet in place. These three are also very wide ranging, from the Bering Sea to southern California, and out to depths of well more than 500 M, thus nMPAs would be impractical as a management tool. And in fact, due to the bathymetry of the eastern North Pacific coast, many of the areas inhabited by rockfishes are such as to prevent extensive fishing effort, or create a “natural refuge” (see Yolklavich et al. below).

For eight species (seven of which are major stocks) for which assessments exist the stocks are not overfished, nor is overfishing occurring. For the remaining species, most of which are minor stocks, their status and rate of fishing mortality is unknown. Therefore, particular management measures are premature.

The Pacific Fishery Management Council has implemented limits for individual vessels, as well as other measures in an attempt to maintain a year round harvest for most rockfish species.

Life history data and stock assessments for most species are not yet determined. Cailliat (2000) lists data on about 30 species, and about half are known to be resident species. Of the overfished or species experiencing overfishing, movement data are available only for the canary rockfish which is considered transient/resident, with tagged movements of over 259 km documented, and the yelloweye, which is considered a resident species.

General Life History Comments Regarding Rockfish.

In their study of the Soquel Submarine Canyon, off Monterey California, (Yoklavich et al., 2000) suggested that “**rock outcrops of high relief interspersed with mud in deep water of narrow submarine canyons are less accessible to fishing activities and thereby can provide natural refuge for economically important fishes**.” Their study was represented by 52 fish species, of which rockfishes were represented by a minimum of 24 species. In addition, they concluded that “**There was remarkable concordance between some of the guilds identified in Soquel Canyon and the results of other habitat-specific assessments of fishes along the west coast of the United States from central California to Alaska.**” Certainly this suggests that there is an inherent control of fishing effort in these habitats and consideration of more extensive areas designated as nMPAs is pre-mature and likely unnecessary.

Soh et al. (2001) studied the role of marine reserves on Alaskan rockfishes. Although Alaska is beyond the scope of this report, the findings are likely applicable. While predicting that harvest refugia (=MPA) can be used to greatly reduce discards and serial overfishing, they state that the effectiveness of marine refugia “**in fisheries management is poorly understood and concepts regarding their use are largely untested**.”

Discussion

NMPAs may serve many purposes, as described above. But when intended to serve as a fishery management tool, there are several situations for which they may be extremely beneficial, and many others for which more traditional methods are much preferred. These are reviewed briefly as follows.

Benefits of nMPAs as management tools

NMPAs can have a strong beneficial impact for fishery management during periods of active spawning by aggregations, when species may be especially vulnerable to harvest, and when certain components of the stock (e.g. large male gag grouper) may be disproportionately liable to capture. This can lead to imbalanced sex ratios that can further jeopardize a stressed stock. The utility of these is likely to be seasonal, and normally would not require year around catch restrictions.

In instances where a stock is severely overfished and subject to little or no management, an nMPA can be used along with other measures to more rapidly replenish populations. This is especially true in isolated, insular populations (e.g. Roberts et al., 2001, for St Lucia) that are not strongly connected to proximal populations for replenishment.

Where habitats are damaged by fishing practices, establishment of nMPAs may help ensure habitat recovery. This is useful when these habitats, such as submerged aquatic vegetation, reef structures or other hard bottom habitat, are critical for vulnerable life stages. Oftentimes, however, gear restrictions can be enacted to lessen the social impact that would result in declaration of a total no-take zone.

NMPAs may also be beneficial where ecosystem management is employed in fisheries (primarily of near sedentary species) where by-catch of non-targeted species has become excessive, or conversely, where a protected species has reached population levels which increase natural mortality rates of targeted species, preventing a reasonable harvest (see comments on Goliath grouper, above). An nMPA will allow some version of dynamic equilibrium to return. When the equilibrium has been reestablished, then alternate, more traditional management actions may be desirable to allow yield from the system. However, ecosystem based management is still in its infancy, and much research needs to be done before tested management principles can be established.

Liabilities and "non benefits"of nMPAs as management tools

When establishment of an nMPA is intended as a near proxy for a virgin stock, several factors need to be kept in mind. And it might be helpful, in gaining perspective, to recall that some of these principles have been well known for decades or longer, though sometimes forgotten. **First, by definition, a virgin stock provides no yield.** Therefore a perfect proxy would be a negative in terms of management goals to produce an MSY or OY. However, proponents of nMPA usage for management purposes refer to a "spillover effect" of harvestable adults to adjacent areas. The impact of this spillover will always be less than that of a properly managed stock, which generates the optimal yield-per-recruit, again, by definition. These models are discussed in numerous classical and modern texts (e.g. Rounsefell, 1975; Iverson, 1996),

The issue of spillover is addressed briefly by Houde et al. (2001). The authors describe the difficulty of direct confirmation of spillover effects, and suggest models may be more useful in understanding how marine reserves function in a regional context. But they also note that those conclusions are limited by underlying assumptions on which the model is based. For species with low mobility, the spillover is minimal, yet these sedentary species are the very ones for which an nMPA is supposedly most effective.

Another claim is that larvae from an nMPA will be a significant addition to the overall stocks. This may be beneficial, but only for a very seriously depleted stock. In other cases, larval production, always in excess of the carrying capacity of the habitat, does not normally relate to year class strength. Rather density dependent factors usually control ultimate recruitment to the harvestable stock. While this principle has been the subject of scores of books and probably thousands of publications, it was espoused nearly 150 years ago by Darwin and restated frequently in most every fishery text (e.g. Gulland, 1977; Rothschild 1986).

And much more recently, data presented by the GOMFMC Coastal Pelagic Stock Assessment Panel (January 2002) re emphasizes for very practical management purposes, such as in the case of Gulf king mackerel, that egg production does not correlate to an increase in stock size, the panel stating**: " recruitment is assumed to increase to some level of spawning stock, and then to remain at the average recruitment for higher spawning stock values (Figure 2).**"

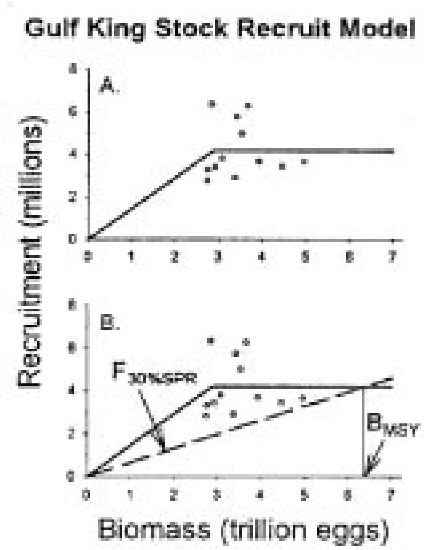


Figure 2. A) Spawner recruit model estimated for Gulf king mackerel. B) Bmsy is estimated at the intersection of the spawner recruit model and F30%SPR replacement line.

Stocks within an nMPA

There are numerous examples in the literature of stock increases within an nMPA (e.g. Johnson et al., 1999; Roberts et al., 2001). However, one must not forget what the point is here in regard to yield. While effective nMPAs may support a stock with relatively greater biomass, perhaps larger individuals, and a higher spawning potential ratio (SPR), **this portion of the stock has been removed from harvest**. Therefore, the overall yield is reduced by whatever fraction could be contributed to overall harvest from this protected stock, and mitigated only by the possibility of spillover or larval contribution, as discussed above.

Pragmatic perspective

Examination of the scores of coastal species from the mid to south Atlantic, Gulf, and US Pacific coasts reveals that very few species are known to be both overfished and/or experiencing overfishing, and are sedentary. Those candidates that are in both categories, and may possibly benefit from and nMPA, are found in widely differing geographic ranges, with optimal potential nMPA sites far apart (e.g. lingcod and surf perch in the Pacific, red porgy in the Atlantic and gray triggerfish in the Gulf). To establish an nMPA for the benefit of those few species would remove harvest potential of the scores of sympatric forms, most of which are not overfished. And while this may not reduce the overall harvest of these species, it would definitely reduce efficiency and increase fishing effort in other, adjacent areas.

Far better would be to impose more traditional methods to restore the overfished stocks, as has been done for many species. This becomes more and more successful as we adopt more precautionary harvest levels, improve our methods of stock assessment, stock/recruit relationships, and life history information.

Current plans or suggestions regarding closure of large areas of the US mainland continental shelf to harvest are simply not scientifically supportable from a fishery management perspective. The suggestion, for example, that as much as 40 % of the Southern California shelf should be designated an nMPA is totally without merit from a fishery harvest perspective. Though there may be other aesthetic benefits, such a closure would severely reduce harvest potentials, shift effort to other areas, and likely have a substantial negative economic impact on both the commercial and recreational fishing industries.

Literature Cited

Bohnsack, J.A. 1996. Marine Reserves, Zoning, and the Future of Management. *Fisheries* 21(9): 14-16.

Bolden, S. K. 2000. Long-distance Movement of Nassau Grouper (*Epinephelus striatus*) to a Spawning Aggregation in the Central Bahamas. *Fish. Bull.* 98:642-645.

Botsford, L. W., L. E. Morgan, D. R. Lockwood, and J. E. Wilen. 1999. Marine Reserves and Management of the Northern California Red Sea Urchin Fishery. *Cal. Coop. Oceanic Fish. Invest. Rep*. 40:87-93.

Cailliet, G.M. 2000. Biological Characteristics of Nearshore Fishes of California: A Review of Existing Knowledge and Proposed Additional Studies. Final Report to the Pacific states Marine fisheries Commission. 103 p.

Coleman, F. C., C. C. Koenig, and L. A. Collins. 1996. Reproductive Styles of the Shallow-water Groupers (Pisces: Serranidae) in the Eastern Gulf of Mexico and the Consequences of Spawning Aggregations. *Env. Bio. of Fishes* 47:129-141.

Colin, P. L. 1992. Reproduction of the Nassau Grouper, *Epinephelus striatus*, (Pisces: Serranidae) and its Relationship to Environmental Conditions. *Env. Bio. of Fishes.* 34:357-377.

DeMartini, E. E., 1993. Modeling the Potential of Fishery Reserves for Managing Pacific Coral Reef Fishes. *Fish. Bull*. 91:414-427.

Fogarty, M.J., J. A. Bohnsack, and P. K. Dayton. 2000. Marine Reserves and Resource Management. In: Sheppard, C (ed.) Seas at the Millennium. Elsevier Science Ltd. London.

Goodyear, C. P. 1995. Red Snapper in U.S. Waters of the Gulf of Mexico: 1992 Assessment Update. NMFS-SEFSC, MIA-92/93-76.

Gulland, J. A. 1977. Fish Population Dynamics. John Wiley and Sons. New York, 372 p.

Hastings, A. and L. Botsford. 1999. Equivalence in Yield from Marine Reserves and Traditional Fisheries Management. *Science* 284:11-2.

Holland, D. S. and R. J. Brazee. 1996. Marine Reserves for Fisheries Management. *Marine Resource Economics* 11:157-171.

Houde, Ed, chair, Committee on the Evaluation, Design, and Monitoring of Marine Reserves and Protected Areas in the United States. Marine Protected Areas, Tools for Sustaining Ocean Ecosystems. 2001. National Academy of Sciences. Washington, DC.

Ingram, G. W. 2001. Movement, Growth, Maturity Schedules and Fecundity of Gray Triggerfish (*Balsites capriscus*) from the North-central Gulf of Mexico. Ph.D. diss. Univ. of South Alabama.

Iverson, E. S. 1996. Living Marine Resources, their Utilization and Management. Chapman and Hall, New York. 403p.

Johnson, D.R., N. A. Funicelli, and J. A. Bohnsack. 1999. Effectiveness of an Existing Estuarine No-take Fish Sanctuary within the Kennedy Space Center, Florida. *N. Amer. J. of Fish. Manag.* 19(2):436-453.

MacCall, D., A. McArdle, J.C. Ogden, J. Roughgarden, R.M. Starr, M.J.Tegner, and M. M. Yoklavich. 1999. No-Take Reserve Networks: Sustaining Fishery Populations and Marine Ecosystems. *Fisheries* 24 (11): 11-25.

Manooch, C.S.,III and W.W. Hassler. 1978. Synopsis of Biological Data on the Red Porgy (*Pagrus pagrus*) Linnaeus. NOAA Tech. Rep. NMFS Circ. 412, 19 p.).

Murray, S.N., R.F. Ambrose, J. A. Bohnsack, L. W. Botsford, M.H. Carr, G.E. Davis, P.K. Dayton, D. Gotshall, D.R. Gunderson, M.A. Hixon, J. Lubchenco, M. Mangel, A. MacCall, D. A. McArdle, J. C. Ogden, J. Roughgarden, R. M. Starr, M. J. Tegner, and M. M. Yoklavich. 1999. No-Take Reserve Networks: Sustaining Fishery Populations and Marine Ecosystems. *Fisheries* 24 (11): 11-25.

National Marine Fisheries Service. 2001. Report to Congress. Status of Fisheries of the United States. Silver Spring Maryland. 119p.

National Oceanic and Atmospheric Administration (NOAA). 1999. Our Living Oceans: Report on the Status of U. S. Living Marine Resources, 1999. NOAA Technical Memorandum NMFS-F/SPO-41. Silbver Spring, MD.

National Resources Defense Council. 2001. Keeping Oceans Wild. April 2001 report.

Nowlis, J. S. and C. M. Roberts. 1999. Fisheries Benefits and Optimal Design of Marine Reserves. *Fish. Bull*. 97:604-616.

Patterson III, W. F., J. C. Watterson, R. L. Shipp, and J. H. Cowan. 2001. Movement of Tagged Red Snapper in the Northern Gulf of Mexico. *Trans. Amer. Fish. Soc*. 130:533-545.

Polacheck, T. 1990. Year Around Closed Areas as a Management Tool. *Natural Resource Modeling* 4:327-354.

Roberts, C. M., J. A. Bohnsack, F. Gell, J. P. Hawkins, and R. Goodridge. 2001. Effects of Marine Reserves on Adjacent Fisheries. *Science* 294:1920-1923.

Robins, C.R., C. G. Ray, and J. Douglass. 1986. A Field Guide to Atlantic Coast Fishes. The Peterson Field Guide Series. Houghton Mifflin, Boston.

Rothschild, B. J. 1986. Dynamics of Marine Fish Populations. Harvard Univ. Press, Cambridge, MA. 272p.

Rounsefell, G. A. 1975. Ecology, Utilization, and Management of Marine Fisheries. C. V. Mosby, St. Louis. 516p.

Sadovy, Y., and A. E. Eklund. 2000. Synopsis of Biological Data on the Nassau Grouper, *Epinephelus striatus* (Bloch, 1792) and the Jewfish, *E. itajara* (Lichtenstein, 1822). NOAA Tech. Rep. NMFS 146. FAO Fisheries Synopsis 157.

Schirripa, M.J, and C.M. Legault. 1999. Status of the Red Snapper Stock in U.S. Waters of the Gulf of Mexico: updated through 1998. NOAA/NMFS, SFD-99/00-75.

Shipp, R. L. 1986. Dr. Bob Shipp's Guide to the Fishes of the Gulf of Mexico. KME Seabooks, Mobile, AL. 186p.

Shipp, R.L. 1999. Status of exploited fish stocks in the Gulf of Mexico, 196-204. *In*: The Gulf of Mexico Large Marine Ecosystem, H. Kumpf, K. Steidinger, and K. Sherman, eds. Blackwell Science, Malden, MA.

Soh, S., D.R. Gunderson, and D. H. Ito. 2001. The Potential Role of Marine Reserves in the Management of Shortraker Rockfish (*Sebastes borealis*) and rougheye rockfish (S. aleutianus) in the Gulf of Alaska. *Fish. Bull.* 99:168-179.

Turner, S.C., C.E. Porch, D. Heinmann, G. P. Scott, and M.Ortiz. 2001. Status of the Gag Grouper Stocks of the Gulf of Mexico: assessment 3.0. NMFS/SEFSC contri. SFD-01/02-134.

Vaughan, D.S., G. R. Huntsman, C.S. Manooch, III, F.C. Rohde, and G.F. Ulrich. 1992. Population Characteristics of the Red Porgy, *Pagrus pagrus*, Stock off the Carolinas. *Bull. Mar. Sci.* 50 (1): 1-20.

Watterson, J. C., W. F. Patterson III, R. L. Shipp, and J. H. Cowan, Jr. 1998. Movement of Red Snapper, *Lutjanus campechanus*, in the North Central Gulf of Mexico: Potential Effects of Hurricanes. *Gulf of Mexico Science* 1998(1):92-104.

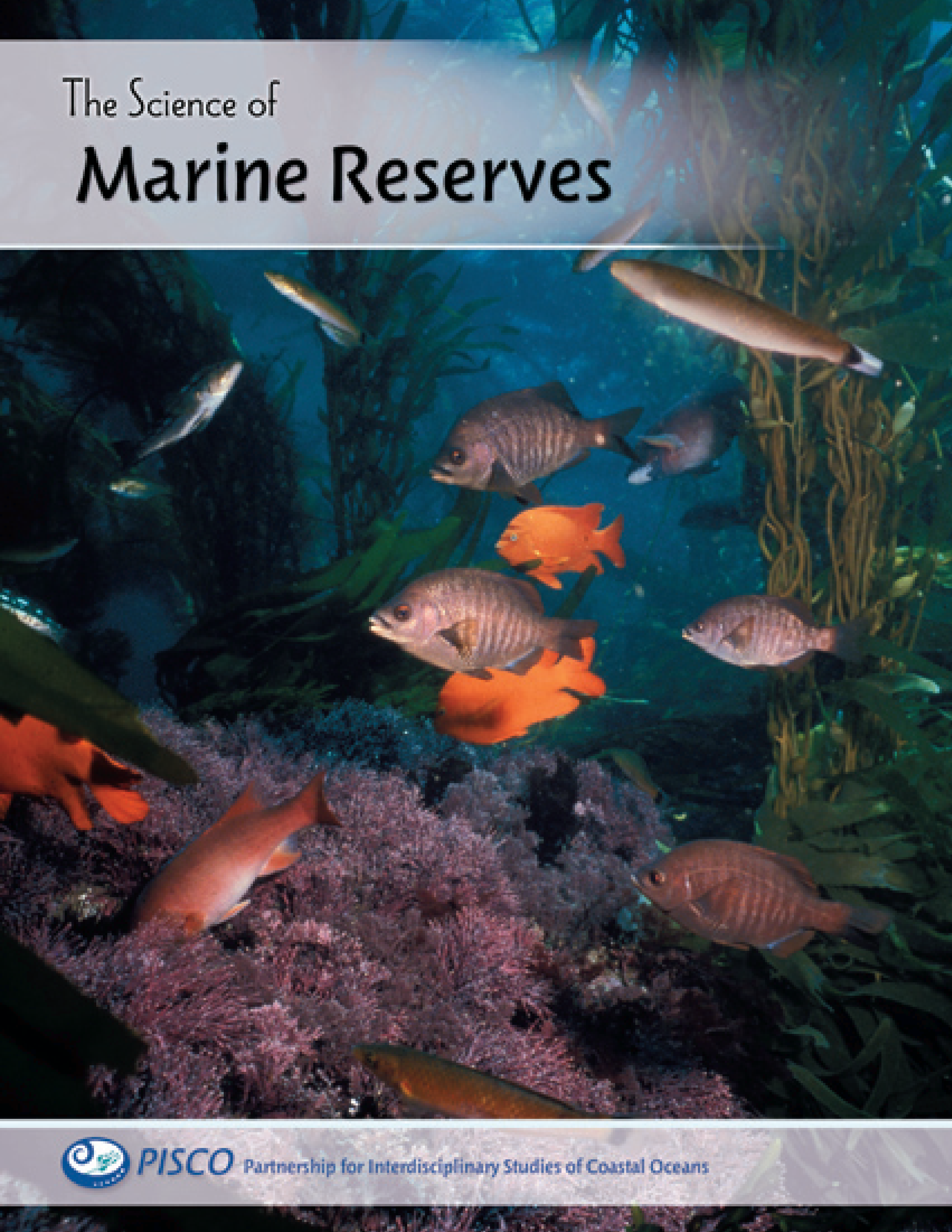
Yoklacich, M.M., H. G. Greene, G. G. Cailliet, D. E. Sullivan, R. N. Lea, and M. S. Love. 2000. Habitat Associations of Deep-water Rockfishes in a Submarine Canyon; an Example of a Natural Refuge. *Fish. Bull*. 98:625-641.

Acknowledgments

I am grateful to Drs. Ray Hilborn, University of Washington, and James Cowan, Louisiana State University for their comments on this manuscript. This research was funded in part by a grant from the FishAmerica Foundation (www.fishamerica.org).

Robert L. Shipp, Ph.D. is chair of the Department of Marine Sciences, University of South Alabama and Director of the Alabama Center for Estuarine Studies. He administers more than $2,000,000 annually of marine and estuarine research funds. He served nine years on the Gulf of Mexico Fishery Management Council, twice as chair, and was chairman of the Council's Essential Fish Habitat Committee. He edited *Systematic Zoology* for 4 years, and was a governor of the American Society of Ichthyologists and Herpetologists for five years. He has published some 40 refereed papers and one book on marine fishes, and has been asked to testify before Senate and National Research Council Committees on fisheries and fishery management.

The Science of Marine Reserves



PISCO Partnership for Interdisciplinary Studies of Coastal Oceans

The Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) produced this report in collaboration with SeaWeb, Communication Partnership for Science and the Sea (COMPASS), and the National Center for Ecological Analysis and Synthesis (NCEAS).

PISCO is a consortium of academic scientists at Oregon State University, University of California at Santa Barbara, University of California at Santa Cruz, and Stanford University. PISCO is dedicated to advancing the understanding of coastal marine ecosystems and to communicating scientific knowledge to diverse audiences.

PISCO thanks the following scientists for their thoughtful reviews: James A. Bohnsack, Mark H. Carr, Michael Dalton, Michael Fogarty, Ray Hilborn, Mark Hixon, George H. Leonard, Marc Mangel, Deborah A. McArdle, Steve Murawski, Steven N. Murray, Michael Orbach, Steve Palumbi, Mary Ruckleshaus, and Dennis Willows. The final content of this brochure is solely the responsibility of PISCO.

A companion 15-minute film, *The Science of Marine Reserves* produced by Sea Studios Foundation, is available from the PISCO Web site.

Senior Editors
Jane Lubchenco, Professor, Oregon State University
Steven Gaines, Professor, University of California at Santa Barbara
Robert Warner, Professor, University of California at Santa Barbara
Satie Airamé, University of California at Santa Barbara
Brooke Simler, Oregon State University

Senior Writer: Peter H. Taylor
Creative Director: Jeff Jones
Senior Designer: Monica Pessino
Designer: Josh Temkin

Funding provided by:
The David and Lucile Packard Foundation
Oregon State University
University of California at Santa Barbara
National Science Foundation

To Cite This Booklet: Partnership for Interdisciplinary Studies of Coastal Oceans. 2002. The Science of Marine Reserves. http://www.piscoweb.org. 22 pages.

Table of Contents

Overview:

Marine environments

worldwide are in the midst of a transformation. There is increasing evidence that ocean ecosystems are being altered beyond their range of natural variability by a combination of human activities, including fishing, pollution, and coastal development. Because of these changes, a growing portion of the global community is inquiring about alternative management options for ocean environments.

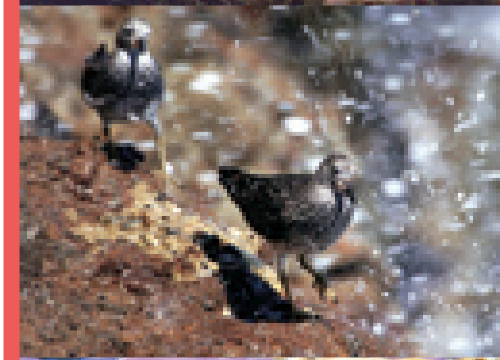
Research shows that marine reserves are one tool that can help to prevent, slow, or reverse negative changes in the ocean. Marine reserves are places in the ocean that are completely and permanently protected from uses that remove animals and plants or alter their habitats. Increasingly, the public, governmental agencies, commercial groups, and scientists are discussing the idea of establishing more marine reserves to complement existing ocean management. The purpose of this report is to provide a summary of the latest scientific information about marine reserves.

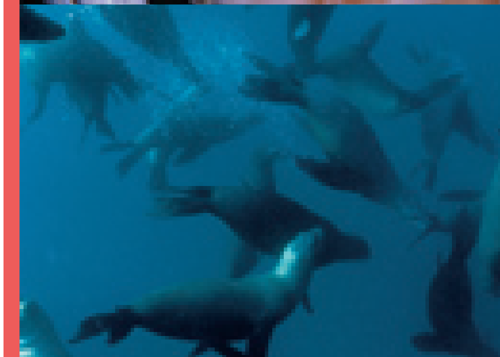
Marine reserves produce different outcomes from other types of management. Reserves protect marine habitats in a particular place and the diversity of animals and plants that live in those habitats. Consequently, many animals and plants in reserves tend to live in greater numbers, grow larger, and reproduce more than their counterparts outside reserves. In contrast, other management strategies attempt to control only some activities or protect only a few species.

Many other kinds of marine protected areas – with names such as marine parks, marine refuges, or marine sanctuaries – exclude some, but often very few, extractive activities. Those areas do not generate the same effects as marine reserves because they provide far less protection.

Marine reserves are one tool for managing ocean ecosystems, but they cannot protect oceans from all human influences. Reserves alone may not address such pervasive problems as pollution and climate change, and they may have fewer direct benefits to some fishes and mammals that move long distances. However, the most recent scientific research shows that marine reserves usually boost the abundance, diversity, and size of marine species living within their borders. This booklet examines the causes and potential consequences of these biological changes.

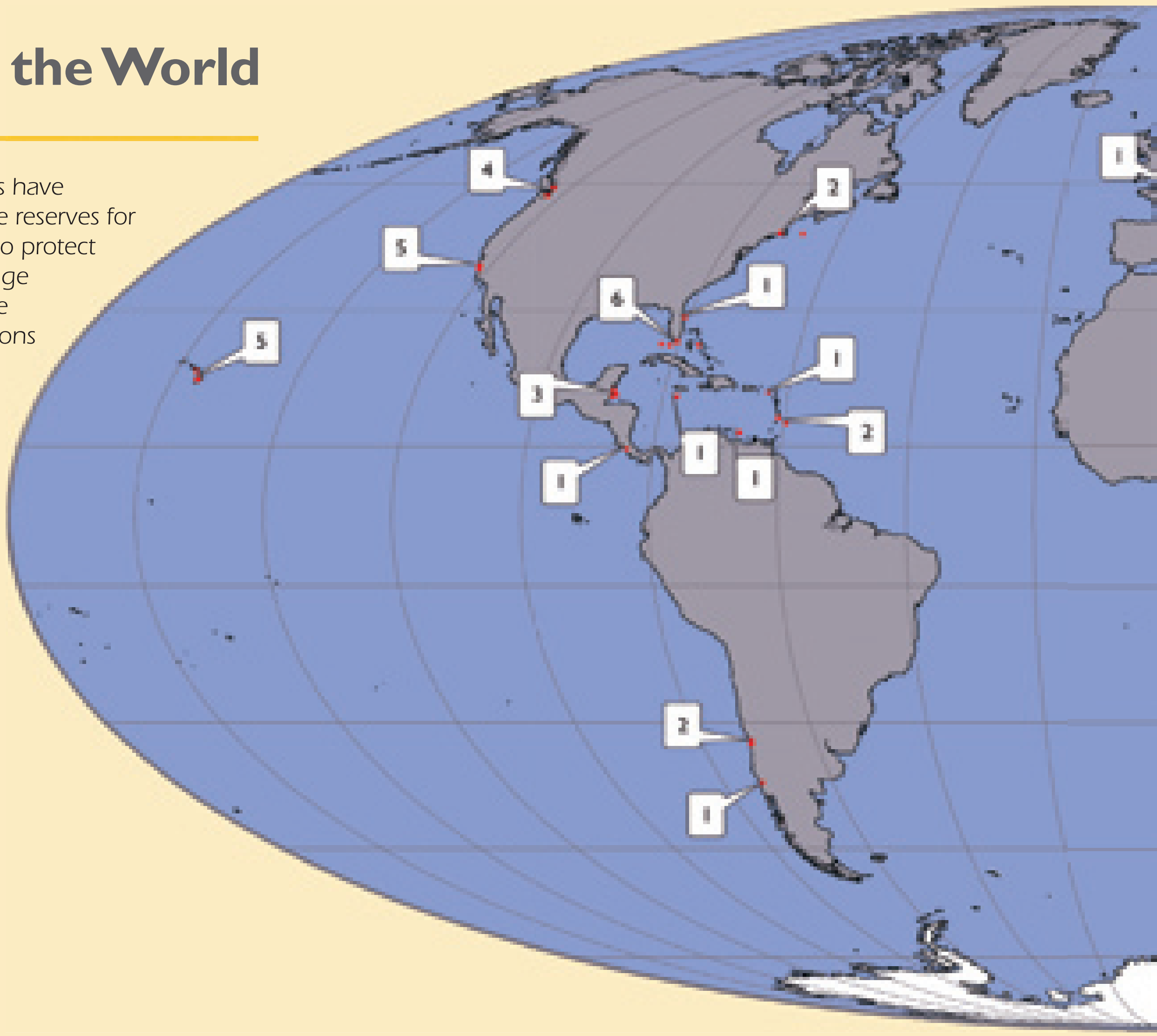
what is a marine reserve?





around the World

At least 23 nations have established marine reserves for various reasons - to protect biodiversity, manage fisheries, or restore depleted populations of marine animals and plants.



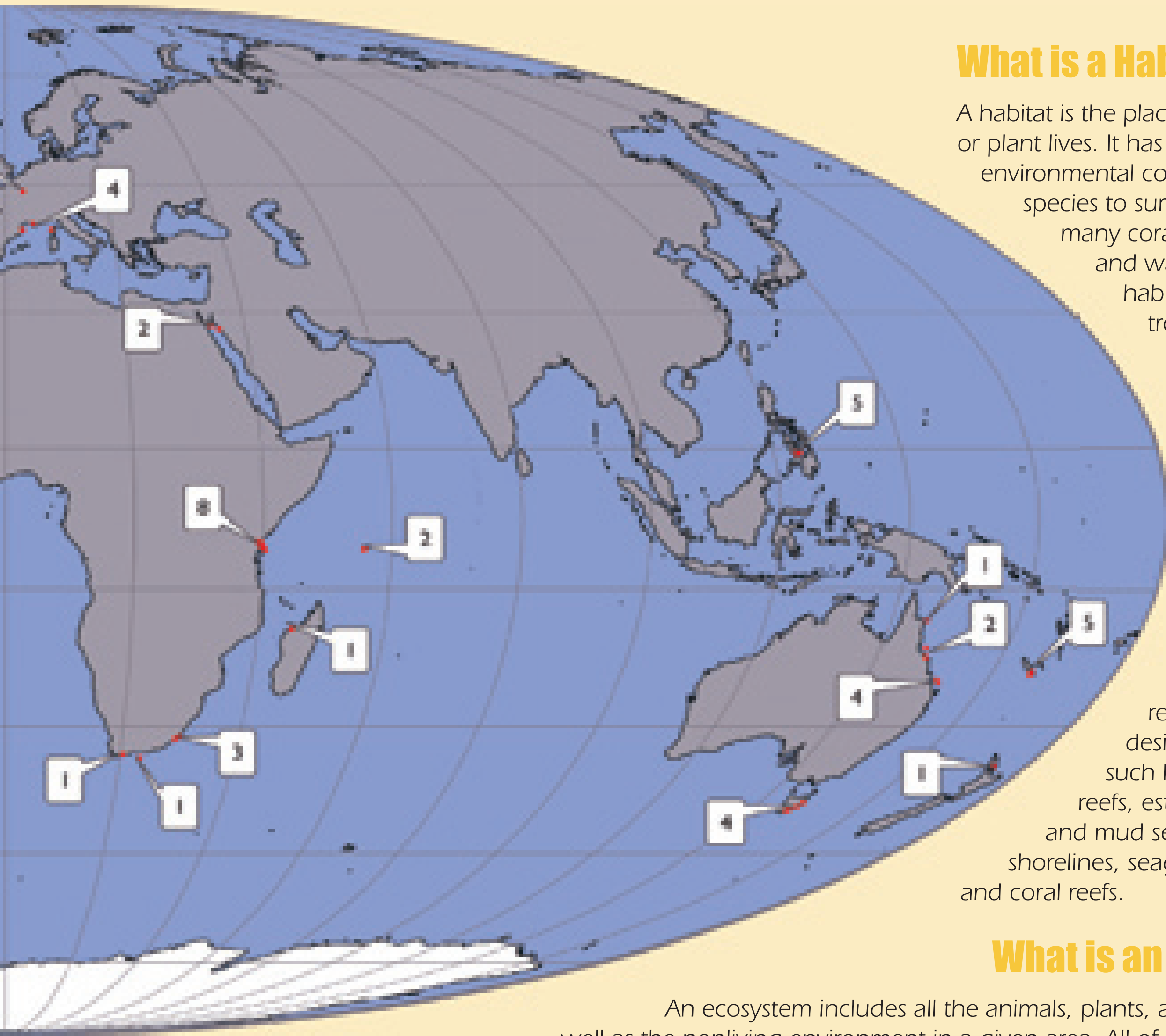
Australia
Bahamas
Barbados
Belize
Canada
Chile
Costa Rica
Egypt
Fiji
France
Japan
Kenya
Madagascar
New Caledonia
New Zealand
Philippines
Saba (Netherlands Antilles)
Saint Lucia
Seychelles
South Africa
Spain
United States
Venezuela

More than 100 marine reserves have been established worldwide.

Marine reserves encompass much less than 1 percent of the world's oceans and less than 0.01 percent of U.S. waters.

Marine reserves range in size from less than a square mile to hundreds of square miles. Currently, most reserves are quite small, and the median reserve size is less than 1.5 square miles.

marine reserves studied around the world



number of reserves studied at each location

What is a Habitat?

A habitat is the place where an animal or plant lives. It has all the necessary environmental conditions for that species to survive. For example, many corals require sunlight and warm water. Their habitats are in shallow tropical seas. Habitats support many different communities of animals and plants. Natural or human-caused activities may change habitats and the species living there. Marine reserves have been designed to protect such habitats as rocky reefs, estuaries, sand and mud seafloors, rocky shorelines, seagrass meadows, and coral reefs.

What is an Ecosystem?

An ecosystem includes all the animals, plants, and microbes as well as the nonliving environment in a given area. All of these elements are connected through biological, chemical, and physical processes. Each species plays a role in an ecosystem. For example, algae, fishes, invertebrates, mammals, and microbes in a kelp forest interact to form a rich marine ecosystem. When one species is reduced or removed, others may be affected. Ecosystems can be large or small. The Gulf of Maine is an example of a very large ecosystem that includes diverse habitats across thousands of square miles.

Scientists have studied some marine reserves extensively. Their findings provide considerable information about the effects of reserves. The above map shows the locations of 80 fully protected marine reserves. Scientists have analyzed data from these reserves and published the results in scientific journals. Approximately 40 percent of these reserves are in temperate waters, while the others are in tropical waters. Many other marine reserves exist but have not been monitored effectively, making it difficult to evaluate their effects.

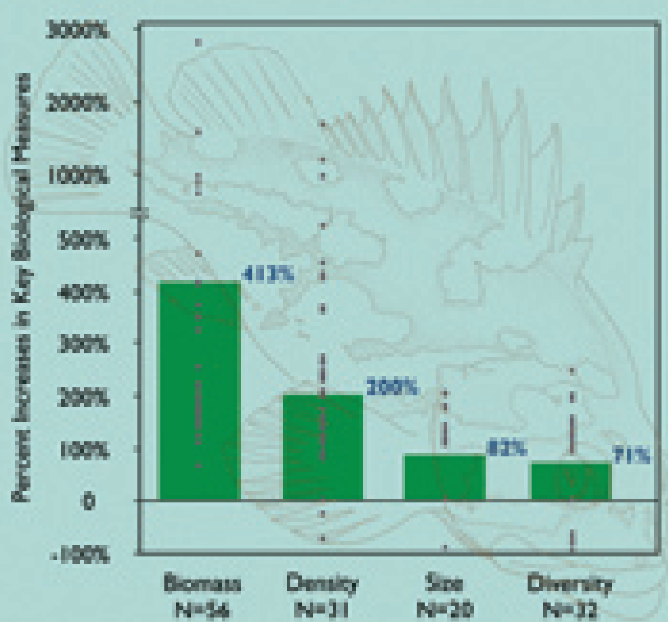
can reserves produce benefits inside their boundaries?

a major purpose for establishing marine reserves is to protect the habitats and to restore animals and plants in particular sites.

Do marine reserves typically accomplish these goals? Scientists have studied the performance of more than 80 marine reserves of many different sizes in a variety of temperate and tropical habitats. A comprehensive review of these studies reveals that most well-enforced marine reserves result in relatively large, rapid, and long-lasting increases in the population sizes, numbers of species, and reproductive output of marine animals and plants. The review found that the average biomass, or weight of all animals and plants studied, is more than four times larger in reserves than in unprotected areas nearby. On average, the density, or number of animals in an area, triples, and the number of species is 1.7 times higher in marine reserves than in unprotected areas. In addition, the average body size of animals is 1.8 times larger in reserves than in fished areas. These findings include not just fished species but other plants, invertebrates, and fishes.

Why do these changes occur within reserves? First, protection from fishing allows animals in reserves to survive longer and grow larger. Second, habitats can recover inside reserves and better sustain the plants and animals that rely on them. Third, the plentiful prey in reserves can support more predators. Marine reserves are currently the only marine management tool that provides this unique combination of effects, promoting the recovery of entire ecosystems.

Why are large populations important? Small populations are more likely to be driven extinct by unpredictable catastrophes, such as oil spills. Large populations include more individuals, so they are more likely to contain individuals that are capable of surviving various stresses. In addition, population size can influence the reproductive success of animals that release their eggs and sperm into the water, such as abalone and sea cucumbers; when these animals are rare, their eggs and sperm can become so diluted that little or no fertilization occurs.

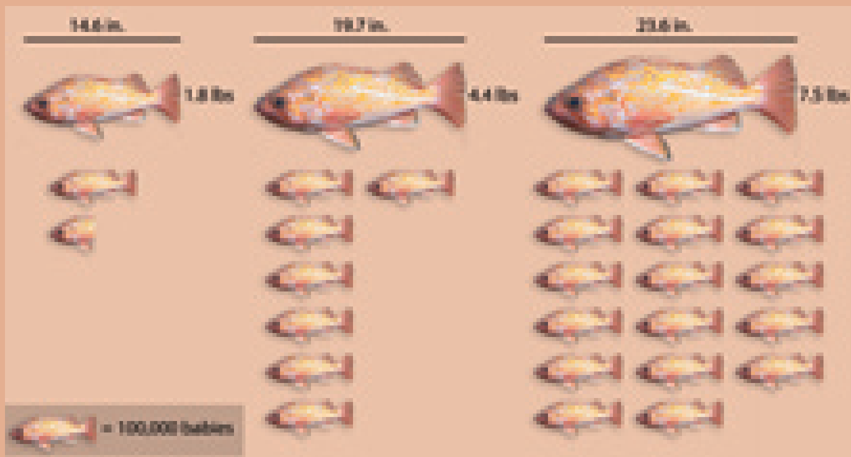


N = the number of reserves in which a particular characteristic was measured

Marine reserves usually increase the biomass, density, size, and diversity of species living within their boundaries. The bar graph (modified from Halpern, in press, and Palumbi, in press) indicates the percent change in key biological measures inside marine reserves. The average increases (green bars) are based on data from marine reserves around the world. The actual changes at particular reserves varied (gray dots), but the vast majority of all reserves showed positive responses in all biological variables.

Key Findings

- In marine reserves, animals and plants usually increase in their biomass, abundance, numbers of species, and body size — factors that can increase ecosystem resilience and productivity.
- Biological changes in marine reserves occur because individuals are not killed by fishing, and because their habitat is protected.
- Larger fishes and invertebrates typically produce substantially more young.
- Many species, not just those that are fished, respond positively to the protection of entire ecosystems in marine reserves.



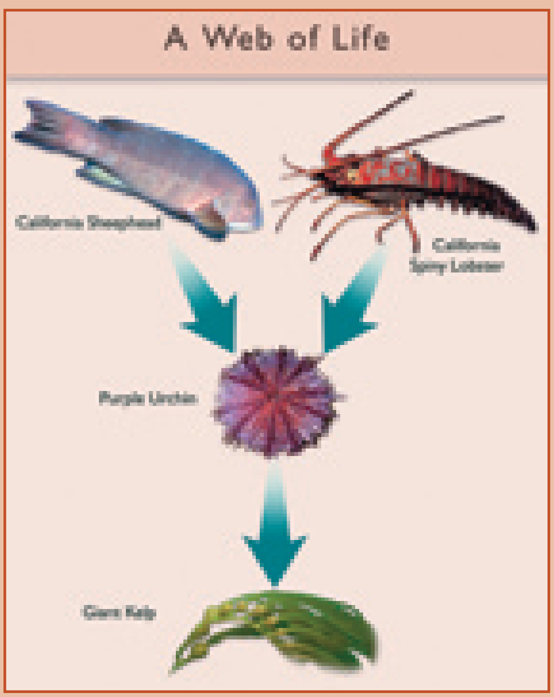
Average numbers of babies produced by three different sizes of vermilion rockfish.

Bigger body size is one of the most important biological changes in marine reserves, because large fishes and invertebrates can produce enormous numbers of young. The relationship between body size and the number of young is well known. For many marine fishes and invertebrates, small increases in body size can lead to large increases in the number of eggs produced. For example, a 23-inch vermilion rockfish can produce 17 times more young than a 14-inch fish. The bigger and more abundant animals living in a marine reserve can produce far more young than their smaller neighbors in unprotected waters. As a result, marine reserves can support higher growth rates.

Will reserves increase the abundance of all species?

Although many fished and nonfished animals and plants become more plentiful within newly established marine reserves, some decline. For example, a fished animal, such as lobster, may increase in number and size in marine reserves and consequently reduce the number of its prey, such as sea urchins (see illustration). In addition, some species that were absent may not become reestablished in a reserve if no viable populations remain nearby.

Although it is difficult to predict the exact changes for any particular species or location, the data from existing reserves show that, on average, increases in abundance, body size, biomass, and the number of species are common outcomes after marine reserves are established.



A food web shows the feeding (or trophic) relationships among species. In southern California, sheephead and lobster eat purple urchins, which consume giant kelp.

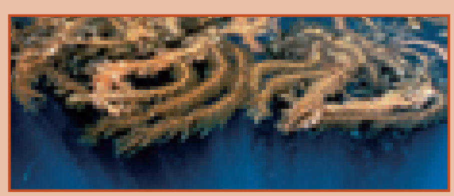
References: 1, 2, 6, 7, 8, 9.

The Importance of Healthy Ecosystems

Healthy ecosystems are the building blocks of productive and resilient oceans. People depend on productive oceans for "goods," such as food and medicines, and essential "services," such as the detoxification of pollutants, recycling of nutrients, control of pest outbreaks and diseases, and regulation of climate, atmospheric gases, and the water cycle. These essentials are called "ecosystem goods and services." Healthy ocean ecosystems provide these goods and services for free. If the ecosystem is damaged, for example by habitat destruction, pollution, or overfishing, the delivery of goods and services is impaired. As a result there may be a loss of productivity, increases in outbreaks of undesirable species, and less resilience to disasters.

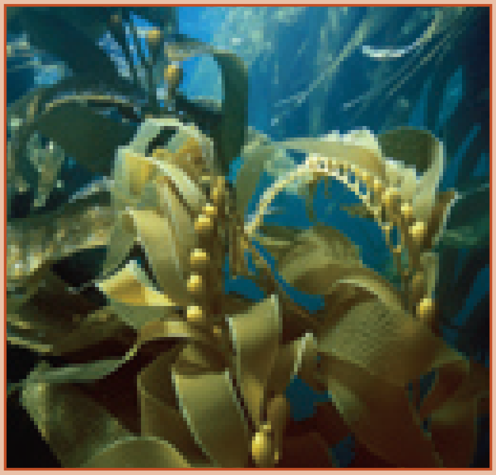
Essential goods and services are provided by many types of ocean ecosystems: coral reefs, kelp forests, mangroves, salt marshes, mud flats, estuaries, rocky shores, sandy beaches, sea mounts, continental shelves, abyssal plains, and open oceans. Each ecosystem contains many types of species that interact with each other and influence the physical and chemical environment. Goods and services are simply byproducts of the functioning of intact ecosystems.

Unlike other management tools, marine reserves protect major portions of an ecosystem, including all the habitats, plants, and animals. This protection allows the environment, the species, and their interactions to function in a manner that provides the ecosystem goods and services that humanity wants and needs.



Case Study: Anacapa Island, California, USA

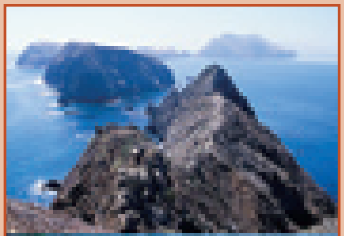
Anacapa Island Natural Area

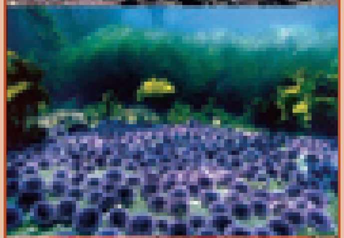


Lessons Learned

- Some important species, such as lobster and California sheephead, are larger and more abundant in the Anacapa Island marine reserve than in surrounding fished waters.
- Inside the reserve, kelp forests flourish because lobsters and sheephead, which are predators, reduce populations of kelp-eating purple urchins.
- As a result, the kelp forest ecosystem in the reserve is more productive and stable over time than kelp forests outside. Outside the Anacapa Island reserve, purple sea urchins have periodically destroyed kelp forests.
- Similar effects through the food web are likely to occur in other reserves because marine animals and plants often strongly affect one another.

Ecosystem Responses in a Marine Reserve



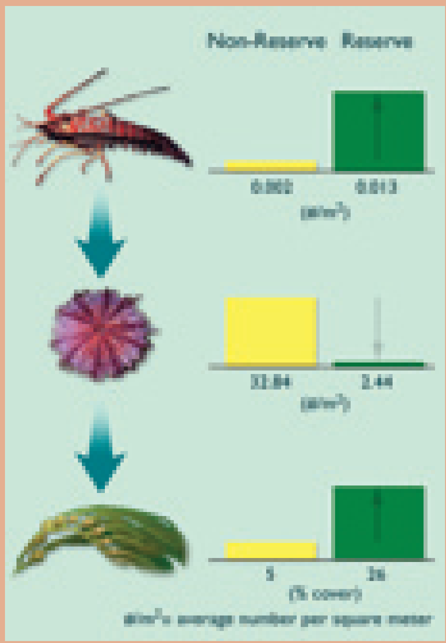


In 1978, the National Park Service established a closed area in the Anacapa Island Ecological Reserve in southern California. The ban on all fishing in the reserve protects lobsters, fish, sea urchins, and many other species living in the rocky reefs and kelp forest habitats of the reserve.

Since 1980, the National Park Service and partner agencies have collected biological data from the Anacapa Island reserve and unprotected areas nearby. The data show that the marine reserve supports some of the richest kelp forests in California's Channel Islands. Lobsters are six times more numerous, red urchins grow 1.7 times larger, and sheephead fish are three times more plentiful in the reserve than in nearby fished waters. Kelp plants, which form crucial habitats for other species, grow five times more densely and persist longer in the reserve than in waters nearby.

6

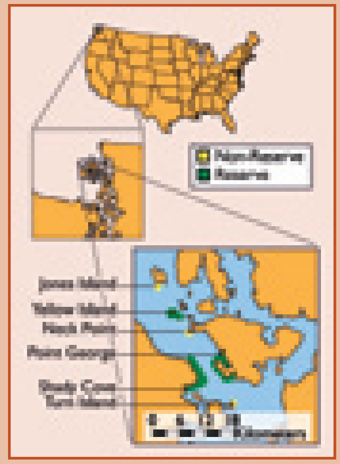
The ecosystem protected in the Anacapa Island reserve now contains most of its animals and plants in a relatively natural state. The populations in the reserve remain more stable over time than those outside the reserve, because interactions among species are not affected by fishing. Lobster and California sheephead protected inside this reserve feed on sea urchins, thereby keeping urchin numbers in check. Reduced numbers of urchins allow stands of kelp to flourish, which in turn support many other species inside the reserve. In contrast, outside reserves where lobster and sheephead are fished, large numbers of urchins periodically overgraze kelp forests, turning reefs into rocky "barrens."



When one species in the food web is fished, other species are affected. For example, when lobsters are fished, sea urchins become abundant and kelp declines. In a reserve, lobsters grow larger and more abundant, keeping the urchin population down and allowing the kelp to grow. K. Lafferty/M. Behrens (USGS/UCSB) analysis of NPS data.

Reference: 16.

Case Study: San Juan Islands, Washington, USA



San Juan Islands Marine Preserves

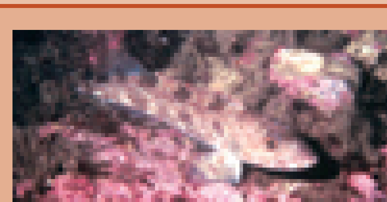
Reserves Boost Abundance, Size & Reproduction

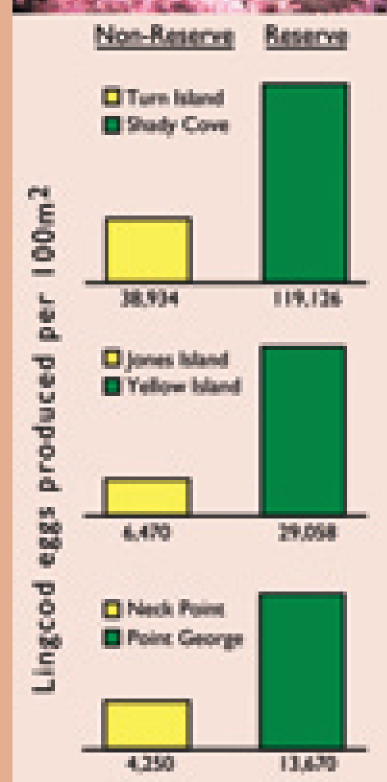
In 1990, the Washington Department of Fish and Wildlife and the University of Washington established five small marine reserves in the San Juan Islands of Puget Sound. They took this action to protect marine biodiversity and to provide undisturbed habitats for scientific research in a region heavily affected by fishing. A decade later, studies show that the San Juan Islands Marine Preserves contain larger and more plentiful fish than unprotected areas. Production of young fish is much greater in the reserves, because both the number and size of fish are larger.

Since establishment of the reserves, lingcod, which had dropped to low levels by the early 1990s because of intensive recreational fishing, increased tremendously. Their biomass is two to four times greater inside the protected areas than outside. Lingcod that are old enough to reproduce are ten times more abundant in reserves. In recent surveys, the biggest lingcod found in a reserve was 110 cm, compared to only 70 cm outside. Each lingcod in the reserves produces an estimated three times as many eggs as those outside.

Quillback and black rockfish have not yet recovered in the reserves. Because of intense fishing, these species are extremely rare in the region. Without breeding stock to provide young to settle in reserves, reserves can offer little immediate aid. However, small numbers of young rockfish have begun to appear in the past few years, offering the potential for future recovery.

Striped surfperch, which are not fished, show no difference in size or abundance inside and outside the reserves. Three times more Puget Sound rockfish, which also are not fished, live outside the reserves than inside. However, lingcod and other large fish eat these small fish. Therefore, rising numbers of lingcod may account for the observed declines of Puget Sound rockfish in the reserves.





The estimated number of lingcod eggs produced per 100 square meters was much larger in marine reserves than in unprotected areas around the San Juan Islands. The total numbers of eggs varied with habitat quality, but habitats in reserves and paired uprotected areas were similar.
Data: E. Eisenhardt (U. Washington)

Lessons Learned

- Lingcod are much bigger and more abundant inside the San Juan Islands Marine Preserves than outside.
- Because of their size and abundance, lingcod in the reserves produce large quantities of young, many more than the number produced in fished areas.
- Quillback and black rockfish are extremely rare in the region. These species have not yet recovered in reserves, probably because they lack breeding stock in the region.

References: 14, 18.

can reserves produce benefits outside their boundaries?

Marine reserves not only affect populations living within their borders but may also influence populations in adjacent waters. Adults and juveniles from a reserve may swim or crawl into neighboring areas. This process is known as "spillover." In addition, tiny newly born animals, called "larvae," and plant "propagules" may drift out of a reserve and "seed" the surrounding waters. This process is called "export." Spillover and export may enable marine reserves to replenish nearby populations. Although not widely documented, spillover and export from reserves are believed to occur commonly.

Key Findings

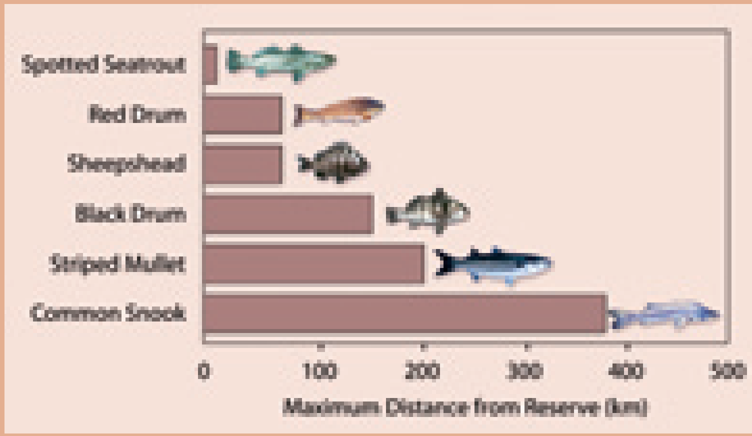
- Animals from marine reserves may swim or crawl outside to supplement surrounding populations.
- Larvae and plant propagules that disperse out of reserves may seed and boost populations in surrounding waters.

Spillover: Movement of Adult & Juvenile Animals

Because marine reserves tend to harbor larger populations than surrounding waters, some animals may move into less-crowded areas nearby to avoid competition for resources such as food and living space. The rate of spillover of adults and juveniles increases with time after reserve establishment as populations become increasingly dense in the protected area. In addition, some fishes, such as rockfishes and lingcod, move from one habitat to another as they grow, regardless of population size, and may leave a reserve for this reason.

Whether or not spillover happens for a given species depends in part on its mobility. Species that are attached to the seafloor as adults, such as mussels and clams, cannot migrate outside reserve boundaries, but swimming and crawling species like fish and crabs can. Transient animals, such as migratory fish, may merely pass through reserves. Thus, their populations are unlikely to build up in reserves and contribute to increased population sizes in adjacent waters.

Studies of animal movement from reserves provide direct evidence that fish and invertebrates spill over. For example, many species of fish tagged in the marine reserve at Florida's Merritt Island National Wildlife Refuge were later caught outside by recreational anglers. Some species, such as the spotted seatrout, moved only short distances from the reserve. However, most species, including two popular sport fish, black drum and red drum, moved between 50 and 200 km from the reserve. A few species, such as common snook, exhibited even longer distance dispersal.

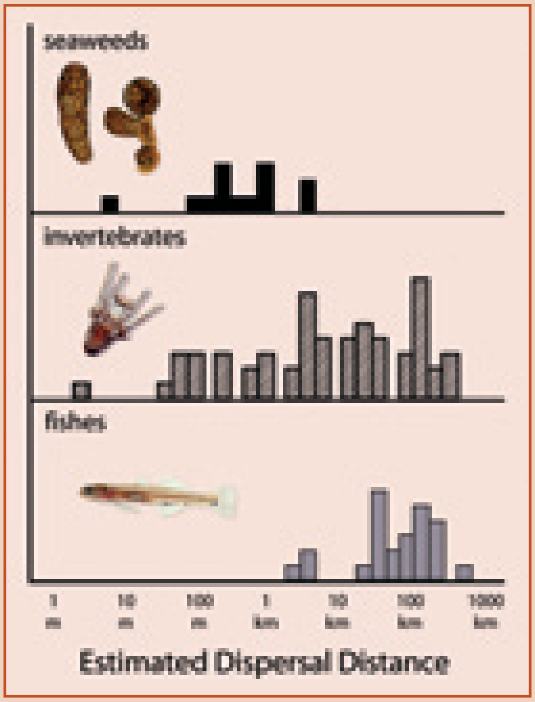


The graph shows the maximum distance traveled (km) by over 125 sport fish tagged in the Merritt Island National Wildlife Refuge. Some species (e.g., spotted seatrout) move only short distances, while others (e.g., common snook) travel much farther. Many tagged fish moved out of the Merritt Island reserve into nearby fishing grounds.

Does spillover actually augment populations outside reserves?

If so, animals should be most abundant inside reserves and just across their boundaries. Indeed, this pattern has been found for fishes and invertebrates at several marine reserves in the United States, Kenya, Barbados, Philippines, Japan, and elsewhere. Moreover, fishing boats often congregate along the borders of marine reserves, because that is where catches are highest. This practice of "fishing the line" has been observed at marine reserves in California, Florida, New England, Spain, Belize, New Zealand, and other places.

References: 10, 11, 12, 13.



This graph shows the average dispersal distance for young marine plants, invertebrates, and fish, estimated from genetic data. In general, plants do not disperse as widely as animals. Young invertebrates exhibit a wide range of dispersal distances. Some young invertebrates do not disperse more than a few hundred feet from their parents. In contrast, sea urchin larvae can move distances over 100 kilometers. Young fish tend to have higher dispersal; some kinds move more than 100 kilometers, on average. Data: B. Kinlan & S. Gaines (UCSB)

Export: Dispersal of Young from Reserves

Fishes and invertebrates typically produce hundreds of thousands of microscopic young that drift on ocean currents for weeks or months, potentially traveling hundreds of miles. Most fishes, mussels, clams, sea urchins, and numerous other animals pass through this early life stage of dispersal. Eventually, some of the larvae settle onto a reef, or other appropriate habitat, where they can grow into juveniles and adults. Most marine plants also produce microscopic young that can be dispersed by currents.

Species vary in how far their larvae travel (see graph). Distances that larvae go depend on their behavior, how long they drift, and the prevailing currents. Depending on the species and the local conditions, larvae may stay close to their parents or they may disperse far away. Because of larval and propagule dispersal, marine reserves can seed populations in surrounding regions.

For example, reserves in the coastal waters of Nova Scotia and the Bay of Fundy protect just 10 percent of the lobster population, but these protected animals are estimated to account for over 50 percent of the larvae produced in the entire region. Currents distribute the larvae across the region, and many of the young lobsters settle in places outside the reserve.

Can Reserves Benefit Migratory Fish?

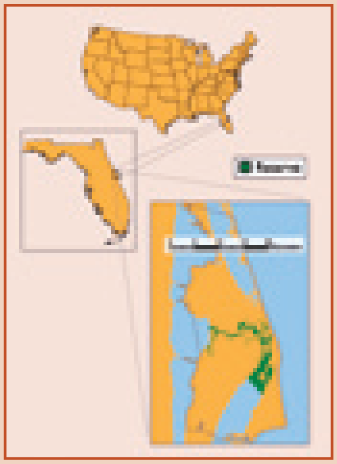
Some fish are homebodies. But others swim dozens, hundreds, or even thousands of miles each year depending on their breeding and feeding habits. How can marine reserves, which are fixed in certain locations, play a role in aiding animals that may routinely enter and leave the protected areas?

Although migratory fish move great distances and can be distributed across expanses of ocean, entire populations become extremely vulnerable to fishing when they aggregate in spawning grounds, migratory pathways, nursery areas, or other sites. Because the animals come together in large numbers in such places, often returning to the same locations year after year, fishermen can catch them more readily, and a large fraction of a population can be killed in a short period of time.

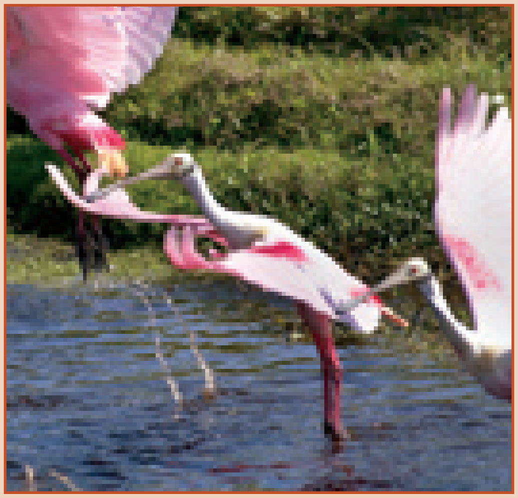
If reserves are established at key locations, they can protect migratory fish during these vulnerable stages. Wildlife refuges on land protect migratory birds at breeding and feeding sites in a similar manner. Marine reserves have the potential to enhance catches of migratory fish in unprotected areas. For example, the nursery grounds of the migratory, flat-bodied fish called plaice were protected in the North Sea for over ten years and catches in the large region outside these protected zones increased an estimated eight percent. Similar measures to protect spawning grounds of Nassau groupers in the Caribbean are currently underway in the Bahamas. Tuna are another migratory fish that could benefit greatly from protection of their breeding grounds.

Marine reserves provide outcomes that supplement those of traditional fisheries measures. In some cases, marine reserves might be unable to protect fish that swim frequently out of the reserves. However, if reserves are large enough, or interconnected in a network of reserves that protects critical habitats, mobile species may benefit by spending a substantial portion of time in reserves.

Case Study: Merritt Island, Florida, USA



Merritt Island
National Wildlife Refuge



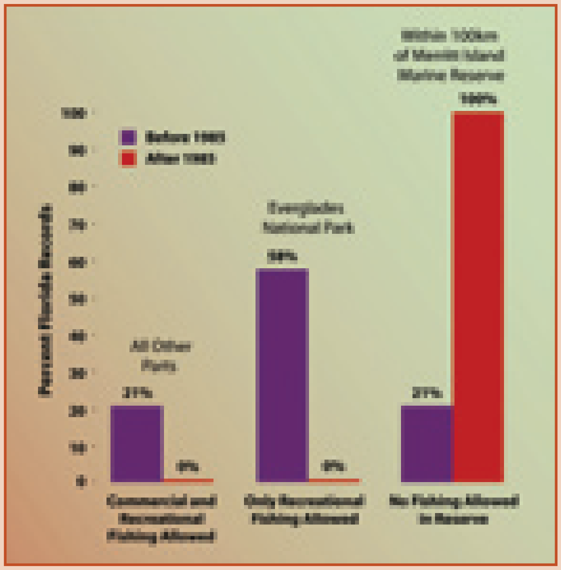
Lessons Learned

- The Merritt Island marine reserve has older, bigger, and more abundant game fish than fished waters outside the reserve.
- Several decades after the reserve was established, recreational fishermen are catching more world-record game fish near the reserve.
- Today, the majority of Florida's record-breaking fish are caught near the reserve.

Spillover: Reserve Supplies Trophy Fishes

Historically, the estuaries at Merritt Island were popular places for recreational fishing. In 1962, the U.S. government banned all access to portions of the Merritt Island National Wildlife Refuge to create a security zone at Cape Canaveral. Today the site on the Atlantic Coast of Florida is one of the oldest fully protected marine reserves in the United States. Studies show the protected zone now produces enormous game fish that live in and move outside the reserve into nearby fishing grounds.

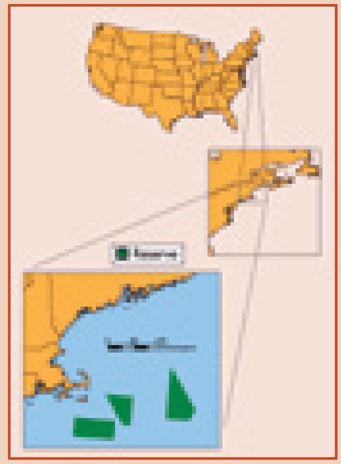
The changes at Merritt Island developed over a period of decades after protection, because the game fish are slow growing and long lived. In the late 1980s, biologists compared the marine reserve to nearby fished waters and found that fish in the reserve were older, bigger, and 2 to 13 times more abundant. Fish tagged inside the reserve were recaptured outside, demonstrating spillover of adults and juveniles. More world records of some popular sport fish are caught near marine reserves than in all other areas of Florida combined. The rest of the state has yielded no new world records for black drum since 1985, despite a variety of statewide management measures, while areas near the reserve continue to produce bigger and bigger fish. Red drum and spotted seatrout show similar results; a disproportionate number of Florida's recent record-breaking fish come from waters near the reserve.



In recent years, far more world-record fish have been caught near the Merritt Island marine reserve than in the Everglades National Park, where only recreational fishing is allowed. Similar habitats in other places in Florida, where both commercial and recreational fishing are allowed, have produced even fewer world records.

References: 15, 19, 20.

Case Study: Georges Bank, New England, USA



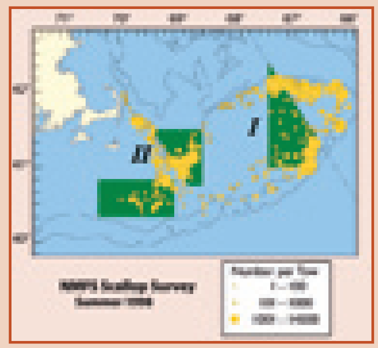
Georges Bank Closed Areas

Middle photograph, above left: Scallops caught inside and outside closed areas on Georges Bank.

Export: Closed Areas Boost Scallop Fishery

Georges Bank rises from the continental shelf to form the southeastern boundary of the Gulf of Maine. For centuries the area has ranked among the world's premier fishing grounds for cod, haddock, scallops, and numerous other species. However, by the early 1990s catches of cod and other groundfish in the region had decreased considerably. Resource managers and fishermen suspected that fishing gear used to catch groundfish and scallops contributed to this decline by damaging habitats of the seafloor. These places supported many different animals, including sponges, clams, worms, crustaceans, sea stars, anemones, and young fish, but trawling and dredging degraded these habitats. In addition, gear intended to catch scallops often took fish incidentally, and vice versa. To address these issues, the U.S. government banned all fishing gear except lobster traps from three large areas, totaling 6,500 square miles, in 1994. While these closed areas are not fully protected marine reserves, scientists have been able to use the closed areas to study the process of larval export at Georges Bank.

Although intended to restore cod and other groundfish, the closures dramatically affected other species as well. For example, within four years, there were 14 times more scallops in the closed areas than in surrounding waters. The scallops in closed areas grew far larger than people had thought possible. Scallops also became five times more numerous in neighboring waters.



Adult scallop abundance inside and near closed areas on Georges Bank.

Lessons Learned

- Within five years, the abundance and body size of some species, including scallops, dramatically increased in the closed areas on Georges Bank.
- Large and abundant scallops in the closed areas can produce more young than smaller scallops outside the closed areas.
- These young boost populations of scallops in the closed areas and some drift into surrounding waters.
- After the closures were established, scallop abundance rose in unprotected waters nearby.
- Using known habitats and current patterns, scientists predicted the places that young scallops, produced in the closed areas, can settle and grow inside the closed areas and in adjacent waters.
- The actual distribution of scallops in waters around the closed areas matches the scientist's predictions.

What do these changes tell us?

The scallops provide some insight into how reserves can supply young to surrounding areas. Because the scallops in the closed areas are larger and more abundant, they can produce many more young than small scallops in surrounding waters. A portion of young scallops may stay and grow up near their parents, while others are carried outside the closed areas by ocean currents. Scientists use known current patterns and locations of suitable habitat to predict where scallops will make their homes and have the most successful growth (see maps). The distribution of adult scallops matches these predictions, demonstrating the potential impact of closed areas on surrounding waters.

Potential scallop settlement on Georges Bank from larvae originating in Closed Area I.

Potential scallop settlement on Georges Bank from larvae originating in Closed Area II.
Data: C.V. Lewis (UC Berkeley)

Reference: 17.

considerations for reserve design

How Long Does It Take To See a Response?

What causes species to differ in their rates of recovery in marine reserves?

Key factors are the availability of breeding stock to initiate a recovery and certain characteristics of their life cycles, including how fast individuals grow, when and how they reproduce, and how many young each individual produces. Some animals grow quickly, mature at an early age, and produce large numbers of young. These animals, such as scallops and sea urchins, may multiply rapidly after protection, sometimes increasing significantly within a year or two. Other animals grow slowly and mature later in life. These species, such as rockfish and cod, may take years or even decades to increase noticeably in a reserve.

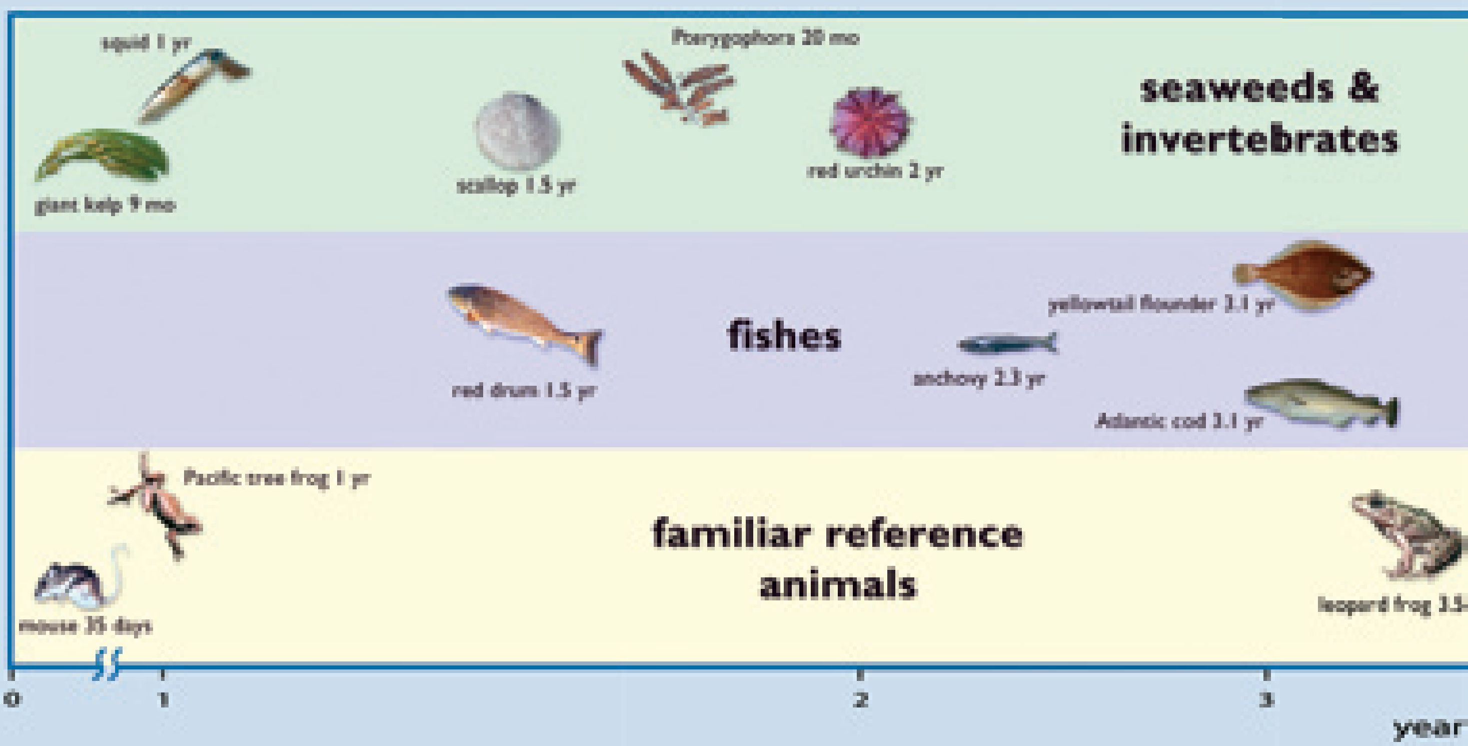
General Principles

- Fast-growing animals that mature quickly and produce many young can respond rapidly to protection within reserves.
- Slow-growing animals that mature at a relatively old age and produce few young take longer to respond.

An example comes from Georges Bank off New England, where the federal government closed three areas to most types of fishing in 1994. The scallop populations in the closed areas grew 14-fold by 1998. The rapid recovery of scallops is due to the fact that they reproduce at a young age. Cod, which develop more slowly and reproduce later in life, are beginning to recover in the closed areas, but not as quickly.

Slow-growing species are especially vulnerable to overfishing. Populations of cowcod, a large rockfish, have been severely overfished in southern California. Because it takes 10 to 15 years for cowcod to mature and begin to reproduce, these populations could take decades to recover after fishing is stopped.

Age of Maturity for Selected Species



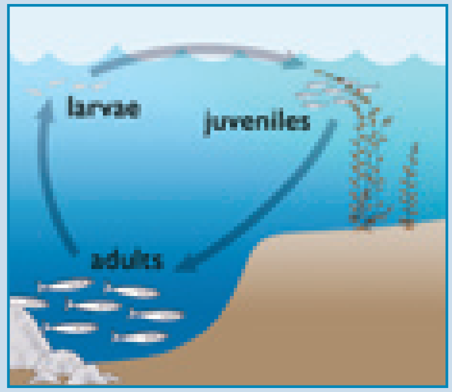
Do All Habitats Need Protection?

The marine environment is a mosaic of different habitats. Beach, mud flat, salt marsh, seagrass bed, kelp forest, and rocky shores fit together like puzzle pieces. Each habitat is home to a different and often unique community of plants and animals, all of which have their own environmental requirements. For example, clams, sand dollars, and burrowing worms thrive in sandy bottoms, whereas abalone and mussels live in rocky habitats.

An important reason to protect a variety of habitats is that different habitats often influence each other. For example, estuaries serve as nursery habitats for some fishes of the open ocean. Organic matter produced in estuaries can flow into the ocean, fertilizing coastal marine ecosystems. Fragments of kelp from rocky reefs wash up on beaches, providing food and shelter for animals that live there. Some habitats, such as estuaries and mangroves, trap sediments moving down rivers, preventing these sediments from entering the ocean. Without these habitats, sediments could accumulate in the coastal waters, smothering life on coral and rocky reefs.

Another reason to protect a variety of habitats is that most marine animals use more than one habitat during their lives. As animals grow, they may require different kinds of food and shelter, and animals meet these changing needs by moving between different habitats. Each habitat used by an animal or plant is important for its survival. An organism may not be able to complete its life cycle if any one of these habitats is degraded. For example, as adults, many fish live in deep reefs offshore, while their larvae drift in the open waters on the surface of the ocean. The young fish move into shallow coastal waters as they grow and subsequently to deep waters, where they remain as adults.

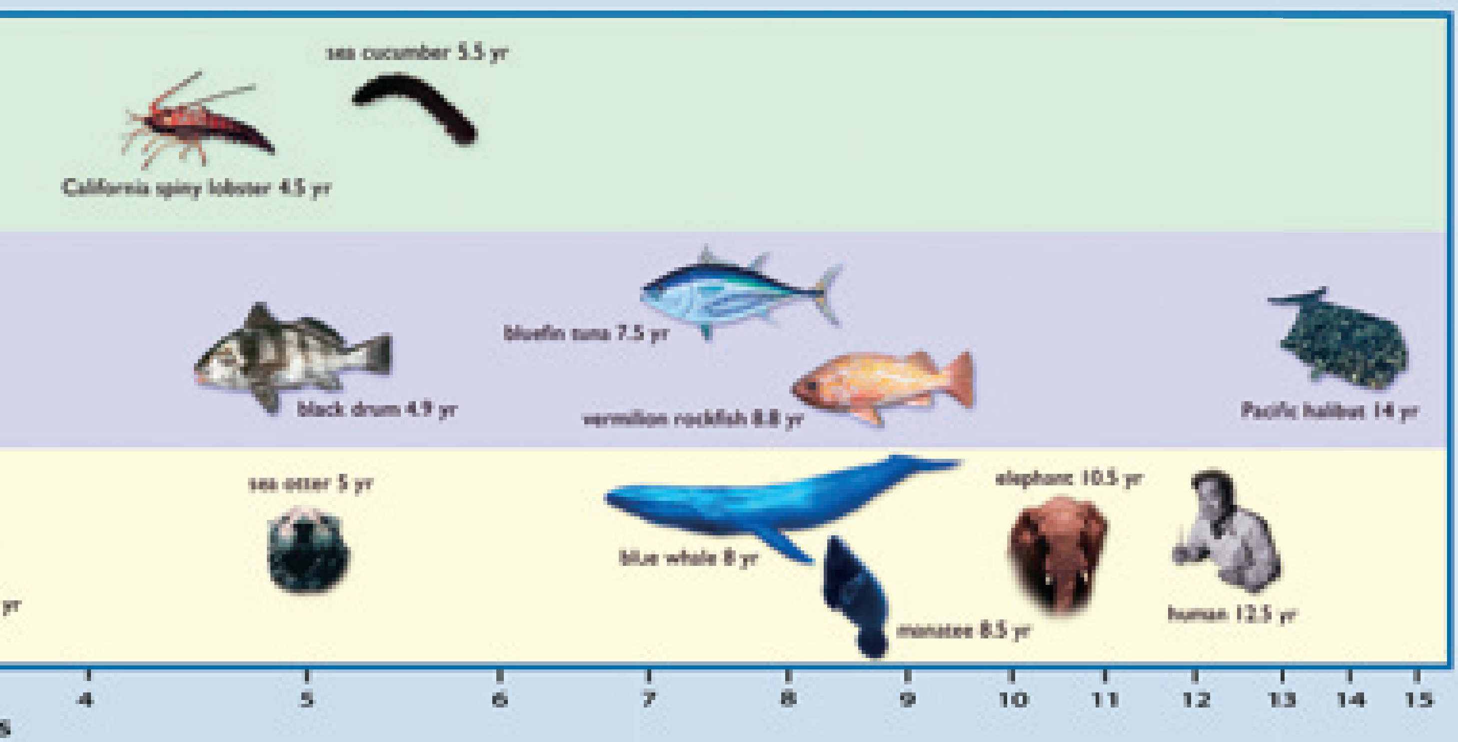
Since the ocean contains so many different kinds of animals and plants, all habitats play an important role. In order to support a variety of ocean life, it is essential that at least some of each habitat is preserved in a natural state. Marine reserves that include several adjacent habitats allow animals to move between habitats while remaining in protected areas.



Marine animals often use a variety of different habitats during their life cycles. For example, some adult fish live on deep reefs offshore while their larvae drift above in the open ocean. The young fish eventually settle in shallow kelp forests and later move into deeper waters to complete their life cycle.

General Principles

- Each habitat supports a unique community of plants and animals.
- Many animals use more than one habitat during their lives, and if any one of these habitats is degraded, these animals may not be able to complete their life cycles.
- Marine reserves that include several different types of habitats can be an effective way of protecting entire ecosystems.



How Do Ocean Processes Influence Reserve Design?

Ocean processes strongly affect where animals and plants live in the ocean. These processes include movement of water and changes in water properties, such as temperature and salinity. Knowledge of local ocean processes can help determine where marine reserves should be located.

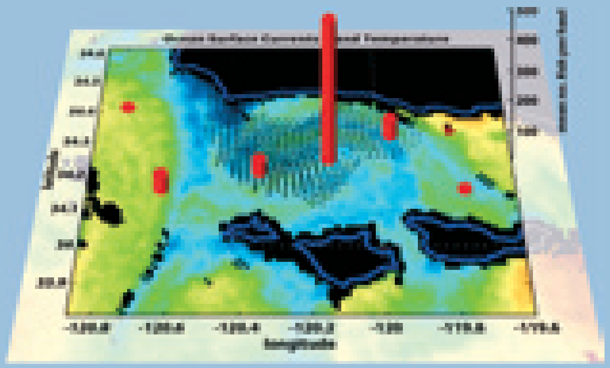
Flowing water commonly transports the larvae or propagules of marine animals and plants. This transport affects their geographic distributions in the ocean. In some regions, currents travel predominantly in one direction for great distances. For example, the California Current flows southward along the west coast of North America, while the Gulf Stream flows to the north and east along the Atlantic coast. Winds and coastal landforms can affect currents on a smaller scale, causing the water to change direction and speed.

General Principles

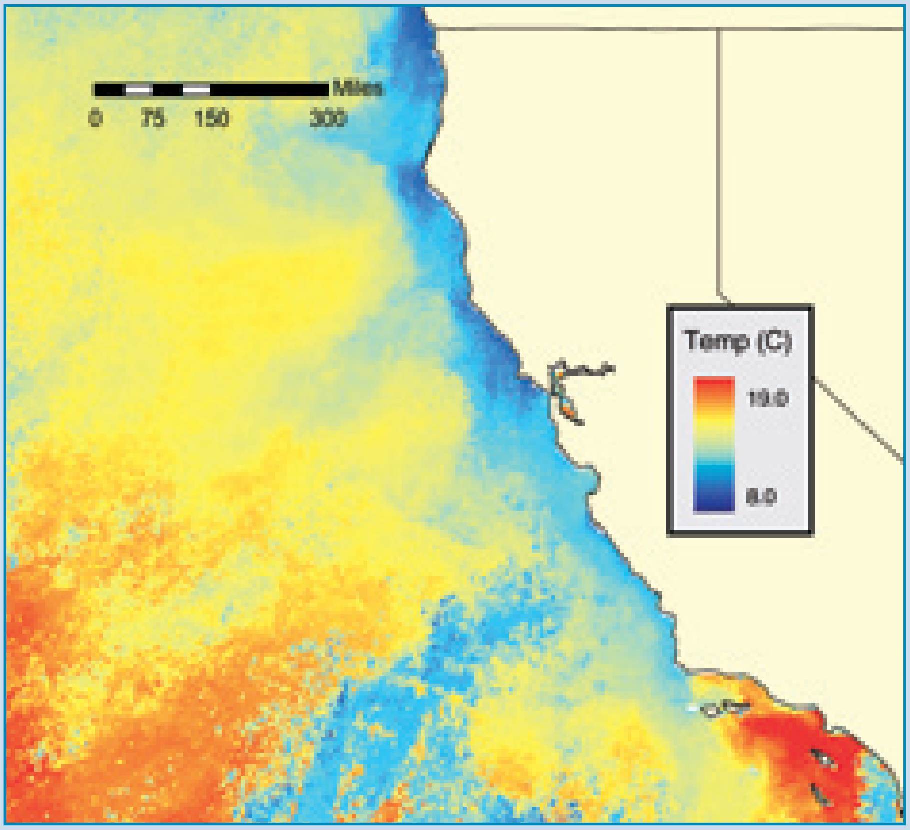
- Currents carry larvae and nutrients, providing connections between different places in the oceans.
- Ocean water properties, such as temperature, can determine the types of animals and plants are found in a particular area.

Currents can carry larvae from place to place or concentrate them at specific locations. For example, in the summer of 1998, many young rockfish were found in the center of the Santa Barbara Channel off southern California. Circular water flow occurring in the channel at that time appears to have retained the young fish in this spot. As they grew bigger, some of the young fish settled in nearby habitats. At other times, currents transport the young rockfish out of the Channel.

Data: M. Nishimoto & L. Washburn (UCSB)



The red bars indicate the numbers of young rockfish in the Santa Barbara Channel at one time during the summer of 1998. The black arrows indicate the predominant currents at the same time. When circular currents form, they may retain young rockfish.



Sea surface temperature for the California coast.

Water temperature also affects the distributions of plants and animals in the ocean. Water temperature is influenced by latitude and by major currents. Ocean temperatures within one region can be very different (sometimes 5-10°C) if the region is influenced by two (or more) major currents. The distributions of animals and plants in regions like this are strongly influenced by these changes in water temperature. For example, off the coast of Point Conception in southern California the cool waters of the southward-flowing California Current collide with the warm waters of a northward-flowing current. As a result, subtropical fish rarely occur north of Point Conception, while rockfish live primarily in the cooler waters to the north.

What Size & How Many Reserves Are Needed?

Reserve size affects the level of protection for ecosystems. Decisions about the size and number of marine reserves for a given place often depend on local environmental, socioeconomic, and regulatory factors. However, several general ecological concepts based on scientific studies can help guide these decisions on reserve size and location.

Even small marine reserves can have positive effects on the abundance, size, diversity, and biomass of animals and plants within their boundaries. However, large reserves include more and larger habitats, more species, and a greater number of individuals of each species. Thus, large reserves protect more of the local ecosystem. In addition, larger populations are less likely to be wiped out by catastrophic events such as big storms and oil spills.

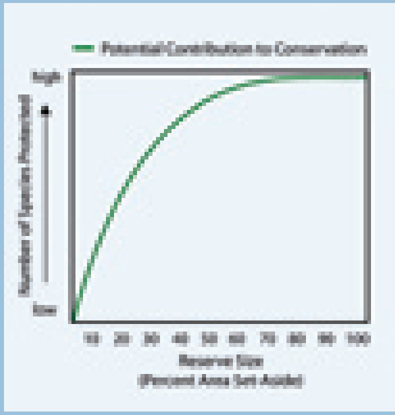
To receive full protection from fishing, a particular animal or plant must be able to complete all vulnerable stages of its life cycle inside a reserve. A large reserve or several reserves, located in critical habitats, may be necessary to protect populations of animals that move long distances. A few species complete their life cycles in very small areas (less than 1 square mile) and smaller reserves can protect such species. In many cases, however, scientists do not know how far species actually move during their lives. One strategy to protect these species is to set aside a portion of all habitats that are necessary for the species to complete its life cycle. As the reserve size increases, the number of different kinds of species protected also increases (top graph, right). Large reserves that encompass and protect many different kinds of habitats are most effective for conservation, but large reserves also may concentrate fishing into small areas.

General Principles

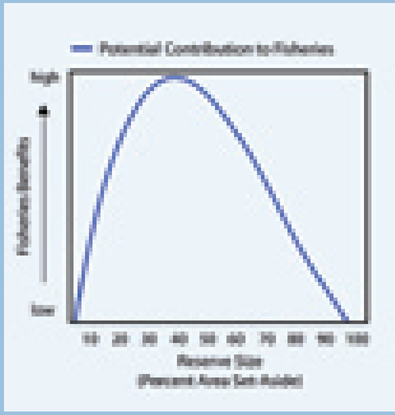
- Small reserves can have positive effects within their boundaries. However, when a reserve is small, the overall benefits are small since few species are protected.
- If a reserve is very large, it will likely satisfy conservation goals, but fishing effort may be crowded into small spaces.
- Reserve areas of moderate size can protect and restore important habitats, plants, and animals while leaving substantial areas of the ocean open to fishing.

The criteria for choosing reserve size to maximize catch in surrounding waters are different from those used to design a reserve for conservation. Small reserves generally have little positive effect on surrounding fisheries, because the number of animals that eventually swim or drift out of the reserve becomes diluted in the large area around the reserve. If a reserve is large enough and includes the necessary habitats to support various species, it can become a "source" of these species for surrounding waters. However, if reserves are extremely large, little area will be left open to fishing. Therefore, to be an effective tool for fisheries management, reserves must be small enough that surrounding waters can still support commercial and recreational fishing, but large enough to become a source of fish and invertebrates (bottom graph, right).

Although priorities for fisheries and conservation are different, recommended reserve sizes are often similar. Existing models of marine reserves for fisheries management suggest that the highest sustained catch and the lowest risk of population collapse occur when reserves include approximately 20 to 60 percent of the total population of a target species. One way to attain this goal for many species is to set aside the equivalent percent of all habitats. The range of sizes reflects variability among species and differences in the success of management strategies outside reserve boundaries. Importantly, the greatest increase in protection for conservation purposes occurs over a similar range of reserve sizes. Small reserves protect few species, while moderate to large reserves are likely to conserve the majority of species in a particular area. A network of several reserves of different sizes, strategically located in critical habitats, may provide the best combination of conservation and fishery benefits.



As reserve size increases, more species (or populations) will be protected.



As reserve size increases, the potential fisheries benefit from spillover and larval production will increase. After a certain point, the reserve becomes so large that spillover and export no longer offset the losses to fisheries due to the reduction in fishing grounds.

References: 6, 7, 9, 21.

General Principles

- A "network" includes a series of marine reserves connected by larval dispersal or juvenile and adult migration.
- To be an effective network, reserves must be located in critical and productive habitats, such as breeding grounds, and spaced appropriately to assure larval transport between them.
- Although mathematical models and our knowledge of life history and ecology of marine species suggest that networking is likely to be an effective strategy, few reserves actually have been established as networks.

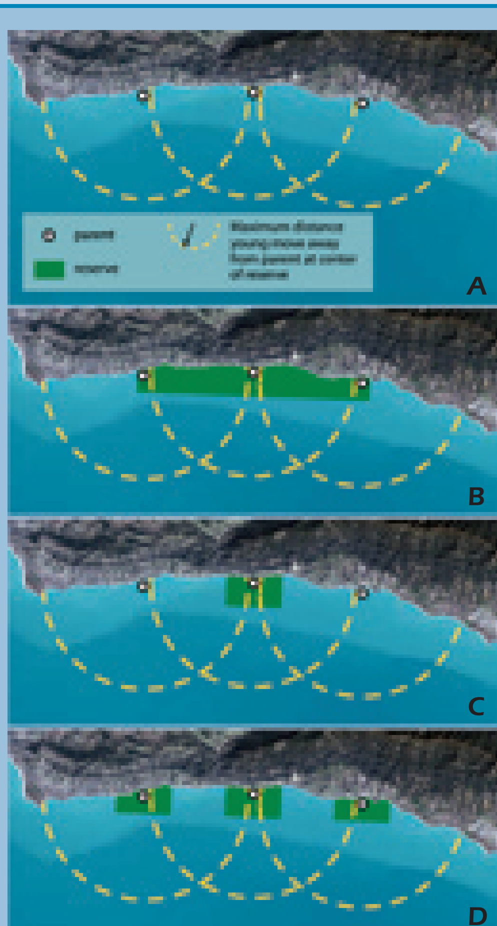
Why Use Networks of Several Reserves?

By themselves, small reserves do not tend to support fish and invertebrate populations that are large enough to sustain themselves. To ensure that young are available to replenish and sustain populations within reserves, the area protected within reserves must be fairly large. However, in some regions, economic constraints may make it impractical to create a single large reserve that can support viable populations. Establishing networks of several smaller reserves can help reduce economic impacts without compromising conservation and fisheries benefits.

A network includes several reserves of different sizes, located in critical habitats, and interconnected by movement of animals and plant propagules. A network can contain critical components of a particular habitat type, or portions of different kinds of important habitats, depending on the goals for the network. To be an effective network, animals and plant propagules must be able to travel beyond the boundaries of a single reserve into other reserves. To facilitate this movement, a network should be designed within a naturally defined ecosystem, such as a bay, gulf, sound, or biogeographic region.

By using different sizes and spacing of reserves, a network can protect species with different characteristics. For example, a network of reserves may include feeding habitats in open waters and breeding and nursery grounds in shallow bays. If marine reserves protect these critical habitats, the resident animals are likely to grow larger and have greater reproductive success.

This diagram shows the relationship between reserve design and movement of plants and animals dispersed in the water.



(A) Currents often carry young animals and plant propagules away from their birthplace. The yellow dashed lines indicate the spread of young from their birthplace.

(B) Young produced in a large reserve are likely to stay in the reserve, which contributes to conservation. However, large reserves reduce the area open to local commercial and recreational fishing.

(C) A small reserve may protect animals while they are in the reserve, but most young may settle and grow in surrounding waters. If reserves are too small, few populations in the reserves will be able to sustain themselves, and the reserves are unlikely to contribute many young to adjacent fishing grounds.

(D) An alternative is to establish a network of reserves that are connected to each other through movement of animals and plant propagules. Some animals and plants will be protected in reserves and others will move into surrounding waters.

Because of the many different patterns of movement and habitat use among species, models suggest that one of the most effective strategies for protecting many species is to establish a network of multiple reserves of different sizes that are strategically placed in critical habitats.

References: 21, 22, 23.

Scientific Criteria for Reserve Design

Once a group decides that marine reserves might be part of a solution, what is the next step? How might they begin to put lines on a map?

If the objectives of marine reserves are to restore and protect biodiversity and to enhance sustainable fisheries, it is possible to use scientific criteria to evaluate different areas and to generate possible reserve scenarios. The following chart lists and defines important criteria, and explains how and why they should be considered in reserve design. Ecosystem protection will be diminished if any one of these criteria is excluded from the design of marine reserves.

	Scientific Criteria	Definition	Application
✔	Biogeographic representation	The inclusion of different regions characterized by particular sets of habitats, environmental conditions, and species	Protecting all biogeographic regions can help protect the biological communities associated with each region.
✔	Habitat representation	The inclusion of different types of habitats (e.g., estuary, rocky shore, kelp forest, sandy bottom)	Protecting a variety of different habitat types can help protect the various plants and animals in those habitats, and allow them to complete their life cycles.
✔	Vulnerable habitats	Rare or threatened habitats susceptible to stresses	Marine reserves offer additional protection to vulnerable habitats.
✔	Vulnerable life stages	Important life stages, such as breeding, juvenile, or migration periods	Protecting habitats where these vulnerable stages live can help boost abundance, size, and population growth rates.
✔	Species or populations of special concern	Species that are of economic or recreational value, are globally rare, or live in small geographic ranges	Protecting habitats where these species live can help boost abundance, size, and population growth rates.
✔	Reserve size	The area covered by a single reserve or a network of reserves	The choice of reserve size depends on the objectives for reserves. Larger reserves produce proportionately greater effects. A network of several smaller reserves may be a good compromise.
✔	Ecosystem linkages	The exchange of nutrients, plants, and animals that connects many ecosystems	Identifying important linkages among ecosystems can help locate potential reserve sites.
✔	Reserve networks	A system of reserves in critical habitats that are linked by movement of animals and plant propagules	A network of marine reserves protects critical habitats that are used by plants and animals during different stages of their life cycles.
✔	Ecosystem services	Beneficial services that people use directly, such as removal of pollutants from the water and climate control	Reserves should include critical habitats that sustain ecological services.
✔	Human threats	Human actions that endanger an ecosystem and cannot be prevented or reversed by establishing a reserve (e.g., pollution and habitat loss)	Sites affected by human threats, such as pollution and coastal development, are not likely to be effective marine reserves. Other types of management may be necessary to control these threats.
✔	Natural catastrophes	Events such as large storms, harmful algal blooms, disease epidemics, and climate changes	Sites subjected to frequent catastrophes are unlikely to be effective marine reserves. Establishing multiple reserves in different locations can reduce the overall risk from natural catastrophes.
✔	Social and economic criteria	Social and economic values expressed by community members affected by ocean management	Social and economic criteria should be incorporated into reserve design in order to maximize social and economic benefits, and minimize costs.

References: 6, 7, 21, 23.

where should reserves be located?

Science Can Provide Options

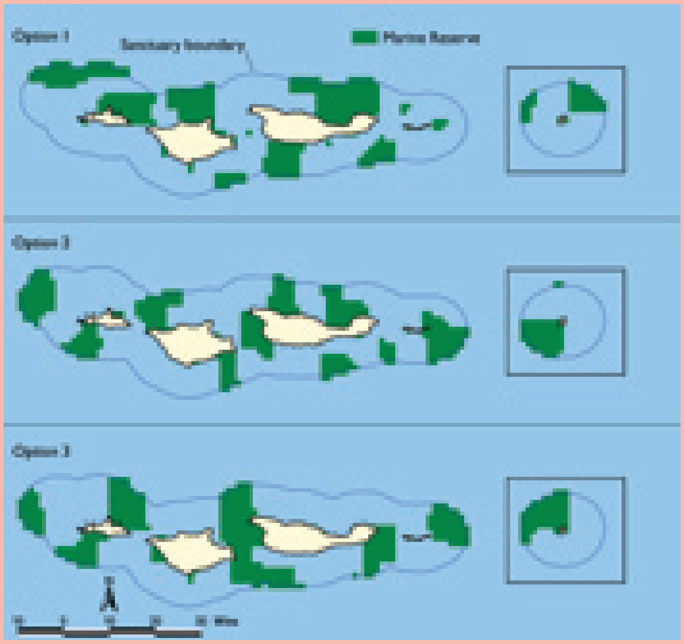
The reserve planning process often involves collaboration among many groups, including resource managers, government agencies, natural and social scientists, commercial and recreational fishermen, environmentalists, and other community members. Various scientific tools can provide options for the design of reserves or reserve networks, but decision-makers ultimately must weigh tradeoffs among short- and long-term goals, costs, and benefits.

Science can provide options through the use of models that analyze data and assist in the design of marine reserves. One such computer model, known as SITES or MARXAN, has been used to design reserve options in California's Channel Islands, the Florida Keys, and the Great Barrier Reef. This tool can identify many possible arrangements of reserve sites that satisfy particular management objectives. Maps of possible reserve sites produced by the program can help resource managers and stakeholders review many different options. This approach uses scientific criteria, but provides flexibility for reserve design.

General Principles

- Reserve design can be based upon ecological, economic, and personal knowledge.
- Useful ecological criteria have been identified (see checklist on previous page) to guide reserve design.
- Models are available to help resource managers identify various options.
- There are often many options for reserve design that meet a particular set of goals.

In the Channel Islands of southern California, for example, a group of federal and state agencies, fishermen, conservationists, and other members of the community initiated a process to design a network of marine reserves in 1999. The group selected a panel of marine scientists to gather and evaluate biological information from this region. These scientists used the SITES model to generate hundreds of options for marine reserves. The three maps on this page are among the many options produced using SITES for a potential marine reserve network covering 30 percent of the Channel Islands National Marine Sanctuary. These options are based on the goals established by the community, and the options satisfy the ecological criteria for reserve design, including different biogeographic regions, habitats, and vulnerable species.



Three of the hundreds of options for marine reserves in the Channel Islands National Marine Sanctuary, developed using the SITES computer model.

References: 22, 23, 24, 25, 26, 27.

Human Values and Community Involvement Are Important

The social and natural science of marine reserves indicates that a great deal of flexibility often exists in reserve design. In many cases, this flexibility makes it possible to accommodate the behaviors, livelihoods, and lives of many ocean users.

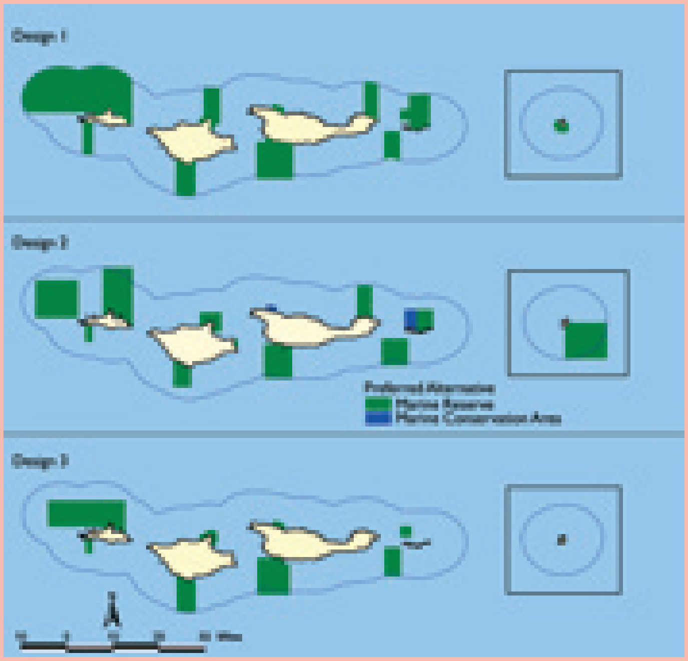
Full community involvement is one of the most important aspects of successful reserve design. Science can help us learn what reserves do, but communities must work together to decide how to apply this knowledge. A variety of questions must be considered before reserve design can satisfy the goals of diverse communities.

- **How will marine reserves affect commercial and recreational activities?**
- **How will current management regulations affect reserve design?**
- **What other management strategies will be needed to complement marine reserves?**
- **Who has the authority to establish and enforce marine reserves?**
- **How will the reserves be enforced?**
- **How will an agency or community secure adequate funding for establishment, maintenance, monitoring, and evaluation of reserves?**
- **What kinds of monitoring will take place in the reserve?**

The breadth of knowledge and values in each community can help to answer some of these questions. Personal knowledge can fill some of the gaps in scientific data. Economic modeling, based on data from landing records and logbooks, can be used to evaluate the potential short- and long-term economic impacts of reserves. Societal values can influence the design of reserves so that our traditional relationships with the ocean are protected and sustained.

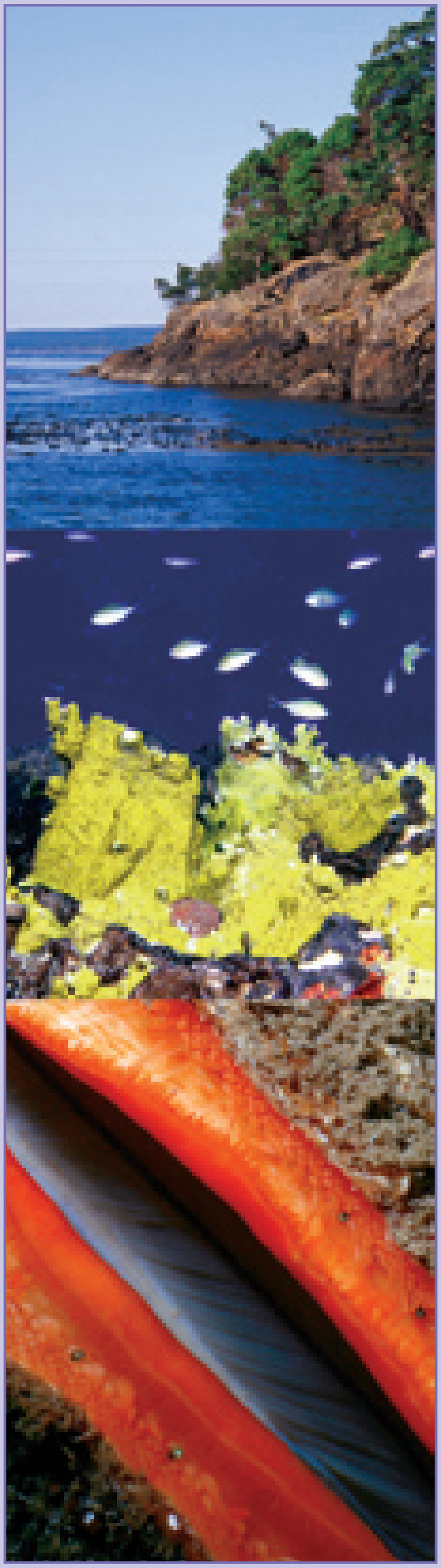
Consider an example of how these questions were integrated into the design of marine reserves. In the Channel Islands of southern California, a group of regional community representatives developed various designs to protect marine ecosystems and address fisheries concerns. The representatives used the options developed by the SITES computer model (previous page) and additional scientific recommendations, as well as economic data and personal knowledge, to develop reserve designs.

Some of the designs (e.g., Designs 1 and 2) meet most of the ecological criteria, while accommodating different interests in the community. However, some designs (e.g., Design 3) do not satisfy all of the ecological criteria because of the way that economic and social factors were incorporated. Design 3 does not include habitat protection in some areas that are popular for recreational fishing, and this limits the effectiveness of the reserve network. Eventually, decision-makers must evaluate potential short- and long-term ecological and economic costs and benefits of reserves, and make the necessary choices given the trade-offs among these factors.



Three of nearly 40 designs for marine reserves in the Channel Islands National Marine Sanctuary. The community worked together to develop these designs using the ecological and economic data, as well as personal knowledge.

how do marine reserves fit into the big picture?



marine reserves work on many different levels of biological organization, affecting individual animals and plants, populations, communities, and ecosystems.The benefits of marine reserves can include:

- **protection of habitat**
- **conservation of plants and animals that live in protected habitats**
- **recovery of depleted populations of fished species that live in reserves**
- **movement of animals from reserves to surrounding fished waters**
- **insurance against environmental or management uncertainty**
- **provision of ecosystem services**
- **protection of places to provide baseline information**
- **provision of sites for enjoyment and inspiration**

Marine reserves produce this unique combination of benefits because they limit where fishing, drilling for oil or gas, and other extractive activities can occur, rather than how much or when those activities occur. Moreover, they prohibit other activities such as dumping, which can pollute or destroy habitat. By eliminating extractive and other destructive activities in particular locations, reserves can protect significant portions of entire ecosystems at once. Traditional approaches tend to focus on single species independent of other elements of the ecosystem. The most effective protection for even a single species requires an ecosystem approach, because every species interacts with numerous other species and the environment.

Reserves can protect habitat and produce dramatic increases in populations living inside their borders, offering insurance against local extinctions and declines. Marine reserves also may affect areas beyond their borders by supplying larvae, juveniles, and adults to adjacent waters.

Research demonstrates that marine reserves can be a useful management and conservation tool, if they are properly designed and enforced. However, other types of management are still critical. Traditional practices such as fishing quotas, seasons, and gear restrictions are important to achieve sustainable fisheries in surrounding waters. Scientists are developing fisheries management models that incorporate both marine reserves and more traditional methods of regulating fishing effort.

Marine reserves cannot address all that ails the oceans. Problems such as pollution, invasive species, disease epidemics, and climate change affect whole regions and require complementary solutions. However, by protecting critical habitats, reserves can contribute to the protection and restoration of healthy marine ecosystems.

selected references

General

1. Allison, G., et al. 1998. Marine reserves are necessary but not sufficient for marine conservation. Ecological Applications 8(1): S79-S92.
2. Daily, G. C. [Ed.] 1997. Nature's services: Societal dependence on natural ecosystems. Island Press. Washington, DC.
3. Jackson, J. B. C., et al. 2001. Historical overfishing and the recent collapse of coastal ecosystems. Science 239: 629-637.
4. Lubchenco, J., et al. In press. Plugging a hole in the ocean: The emerging science of marine reserves. Ecological Applications.
5. Murray, S., et al. 1999. No-take reserve networks: Sustaining fishery populations and marine ecosystems. Fisheries 24: 11-25.
6. National Research Council (NRC). 2001. Marine protected areas: Tools for sustaining ocean ecosystems. National Academy Press, 2101 Constitution Avenue, NW, Lockbox 285, Washington, DC 20055, USA. 272 pages. Available at www.nap.edu.
7. Roberts, C. M. and J. P. Hawkins. 2000. Fully-protected marine reserves: A guide. WWF Endangered Seas Campaign, 1250 24th Street, NW, Washington, DC 20037 and Environment Department, University of York, York, YO10 5DD, UK. 134 pages. Available at www.panda.org.

Can Reserves Produce Benefits Inside Their Boundaries?

8. Halpern, B. H. In press. The impact of marine reserves: Do reserves work and does reserve size matter? Ecological Applications.
9. Palumbi, S. R. In press. Marine reserves: An ecosystem tool for marine management and conservation. Pew Oceans Commission, Arlington, VA.

Can Reserves Produce Benefits Outside Their Boundaries?

10. Davis, G. E., and J. W. Dodrill. 1980. Marine parks and sanctuaries for spiny lobster fisheries management. Proceedings of the Gulf and Caribbean Fisheries Institute 32: 194-207.
11. Grantham, B., et al. In press. Dispersal profiles of marine invertebrates communities: Implications for marine reserve design. Ecological Applications.
12. Kinlan, B. P., and S. D. Gaines. In press. A comparative analysis of dispersal scale in marine and terrestrial systems. Ecology.
13. Palumbi, S. R. In press. Population genetics, demographic connectivity and the design of marine reserves. Ecological Applications.

Case Studies

14. Eisenhardt, E. 2001. Effects of the San Juan Islands Marine Preserves on demographic patterns of nearshore rocky reef fish. M.S. Thesis. University of Washington, Seattle.
15. Johnson, D. R., et al.1999. Effectiveness of an existing estuarine no-take fish sanctuary within the Kennedy Space Center, Florida. American Journal of Fisheries Management 19: 436-453.
16. Lafferty, K. D., and D. J. Kushner. 2000. Population regulation of the purple sea urchin, *Strongylocentrotus purpuratus*, at the California Channel Islands. Pp. 379-381 in Brown, D. R., K. L. Mitchell and H. W. Chang, Eds. Proceedings of the Fifth California Islands Symposium. Minerals Management Service Publication #99-0038.
17. Murawski, S., et al. 2000. Large-scale closed areas as a fishery-management tool in temperate marine systems: The Georges Bank experience. Bulletin of Marine Science 66(3): 775-798.
18. Palsson, W. A., and R. E. Pacunski. 1995. The response of rocky reef fishes to harvest refugia in Puget Sound. Proceedings, Volume 1: Puget Sound Research '95. Puget Sound Water Quality Authority, Olympia, Washington, USA.
19. Roberts, C. M., et al. 2001. Effects of marine reserves on adjacent fisheries. Science 294: 1920-1923.
20. Stevens, P. W., and K. J. Sulak. 2001. Egress of adult sport fish from an estuarine reserve within Merritt Island National Wildlife Refuge, Florida. Gulf of Mexico Science 19(2): 77-89.

What Size & How Many Reserves Are Needed?

21. Roberts, C. M., et al. 2001. Designing reserve networks: Why small, isolated protected areas are not enough. Conservation Biology In Practice 2(3): 10-17.

Scientific Criteria for Reserve Design

22. Roberts, C. M. et al. In press. Ecological criteria for evaluating candidate sites for marine reserves. Ecological Applications.
23. Roberts, C. M. et al. In press. Application of ecological criteria in selecting marine reserves and developing reserve networks. Ecological Applications.

Where Should Reserves Be Located?

24. Airamé, S., et al. In press. Applying ecological criteria to marine reserve design: A case study from the California Channel Islands. Ecological Applications.
25. Ball, I. R., and H. P. Possingham. 2002. MARXAN - A reserve system selection tool. www.ecology.uq.edu.au/marxan.htm.
26. Beck, M. W., and M. Odaya. 2001. Ecoregional planning in marine environments: Identifying priority sites for conservation in the northern Gulf of Mexico. Aquatic Conservation: Marine and Freshwater Systems 11: 235-242.
27. Leslie, H., et al. In press. Using siting algorithms in the design of marine reserves. Ecological Applications.

Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO)

For more information:
Web site: www.piscoweb.org
E-mail: pisco@piscoweb.org

PISCO
University of California, Santa Barbara
Marine Science Institute
Santa Barbara, CA 93106-6150
Tel (805) 893-5175
Fax (805) 893-8062

PISCO
University of California, Santa Cruz
Long Marine Laboratory
100 Shaffer Road
Santa Cruz, CA 95060
Tel (831) 459-5022
Fax (831) 459-3383

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
Tel (541) 737-9173
Fax (541) 737-3360

Image Credits: Ansel Adams (13), Shane Anderson (6), Morgan Ball CINMS(NOAA) (1), Cary Bucklin (1), Frank and Joyce Burek FGBNMS(NOAA)(20), Mark Carr (9), CINMS(NOAA) (5), Sue Cocking (10), Mark Conlin (cover), Mark Conlin CINMS(NOAA) (5, 6), Annie Crawley CINMS(NOAA)(6), Nan Deal CINMS(NOAA) (1), Ginny Eckert (9), Eric Eisenhardt (20), Kees Ekeli (12), www.fishbase.org (13), Steven R. Fisher (7, 22), Don Flescher (8, 10), Laura Francis CINMS(NOAA) (1, 6), William L. High NMFS - NOAA archives (9), Jeff Jones and Shane Anderson (11, 20), Adrian Marsden (8, 10, 12), Dan Martin (9), Christine McConnell (6), NASA (10), NEFSC (NMFS) (12, 13), Linda Nelson (4), Wayne A. Palsson (7), Robert Patzner (8), Bearez Philippe (8), Dan Reed (9, 12), Dan Richards CINMS(NOAA) (1), Donna Schroeder (5), Mike White FKNMS(NOAA) (22), Norbert Wu (22), Norbert Wu CINMS(NOAA) (1).

Paper stock contains 50% recycled content, 15% post-consumer content. Printed with linseed oil-based inks.

Released on March 21, 2005

Scientific Consensus Statement on Marine Ecosystem-Based Management

Prepared by scientists and policy experts to provide information about coasts and oceans to U.S. policy-makers

Executive Summary: **The current state of the oceans requires immediate action and attention. Solutions based on an integrated ecosystem approach hold the greatest promise for delivering desired results. From a scientific perspective, we now know enough to improve dramatically the conservation and management of marine systems through the implementation of ecosystem-based approaches.**

Coastal and ocean ecosystems are vitally important to U.S. interests and they are at risk. Over half of the U.S. population lives along the coast, and more than $200 billion in economic activity was associated with the ocean in 2000.[1] Despite their economic significance, U.S. oceans, like those around the world, are changing in unprecedented ways. Recently, the Pew Oceans Commission and the U.S. Commission on Ocean Policy concluded that a combination of human activities on land, along the coasts, and in the ocean are unintentionally but seriously affecting marine ecosystems by altering marine food webs, changing the climate, damaging habitat, eroding coastlines, introducing invasive species, and polluting coastal waters. These changes threaten the ability of ocean ecosystems to provide the benefits Americans expect from marine ecosystems. Currently, each activity or threat is typically considered in isolation; coordinated management of cumulative impacts is rare. **Both commissions call for a more comprehensive, integrated, ecosystem-based approach to address the current and future management challenges of our oceans**. Both commissions describe ecosystem-based management as the cornerstone of a new vision for healthy, productive, resilient marine ecosystems that provide stable fisheries, abundant wildlife, clean beaches, vibrant coastal communities and healthy seafood for all Americans.

What Is Ecosystem-Based Management for the Oceans?

Ecosystem-based management is an integrated approach to management that considers the entire ecosystem, including humans. The goal of ecosystem-based management is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services humans want and need. Ecosystem-based management differs from current approaches that usually focus on a single species, sector, activity or concern; it considers the cumulative impacts of different sectors. Specifically, ecosystem-based management:

- emphasizes the protection of ecosystem structure, functioning, and key processes;
- is place-based in focusing on a specific ecosystem and the range of activities affecting it;
- explicitly accounts for the interconnectedness within systems, recognizing the importance of interactions between many target species or key services and other non-target species;
- acknowledges interconnectedness among systems, such as between air, land and sea; and
- integrates ecological, social, economic, and institutional perspectives, recognizing their strong interdependences.

1 U.S. Commission on Ocean Policy (2004) Appendix C: Living Near and Making a Living from the Nation's Coasts and Oceans

BACKGROUND

The scientific understanding of marine ecosystems has advanced considerably over the last few decades. We now have a much greater appreciation of how the oceans support and sustain human life by providing services such as seafood; medicine; nutrient cycling; water purification; protection of shores from erosion and storm damage; moderation of climate and weather; recreation; and spiritual, religious, and other nonmaterial benefits. The interactions among species within ecosystems generate these services. Healthy, intact, resilient marine ecosystems have a greater capacity to provide the full range of benefits that Americans say they want from oceans.

Management that emphasizes the protection of ecosystem structure, functioning, and key processes is much more likely to ensure the long-term delivery of these important services. From a governance perspective, implementation of an ecosystem approach will enable more coordinated and sustainable management of activities that affect the oceans. Ecosystem-based management should reduce duplication and conflicts, and in the long run will likely be more cost-effective. A delay in implementing management based on an ecosystem approach will result in continued conflicts over resources, degradation of ocean ecosystems, disruption of fisheries, loss of recreational opportunities, health risks to humans and wildlife and loss of biodiversity.

This document reflects our scientific understanding about marine ecosystems and the concepts of ecosystem-based management, specifically (1) what the term 'ecosystem-based management' means, (2) what is an ecosystem, (3) core scientific knowledge about ecosystems, (4) key elements of ecosystem-based management, and (5) actions consistent with an ecosystem approach.

WHAT IS AN ECOSYSTEM?

An ecosystem is a dynamic complex of plants, animals, microbes and physical environmental features that interact with one another. Humans are an integral part of ecosystems, marine and terrestrial. The "interconnectedness" within and among ecosystems is provided both by the physical environment (for example, currents transporting larvae from one part of the ecosystem to another) and by biological interactions (for example, kelps or seagrasses creating habitat or predators consuming prey).

Ecosystems come in many sizes, often with smaller systems embedded within larger ones. For example, a kelp forest in southern California represents a small habitat ecosystem that is nested within the larger California Current Large Marine Ecosystem. At the largest scale, ecosystems are often categorized as Large Marine Ecosystems (LMEs). Approximately 64 LMEs have been recognized globally, and 10 of these are in U.S. waters[2]. The boundaries of each LME are defined primarily by oceanographic and topographic features. All LMEs include multiple habitats such as sandy beaches, kelp forests, rocky shores, seagrass beds, or pelagic habitat. Individuals of a few marine species spend their entire life within a single habitat such as a kelp forest, but most have larval or juvenile stages that are transported across habitats but within an LME. Thus, even if the adult stage is sedentary, the individual uses multiple habitats within an LME over its lifespan.

[2] The 10 Large Marine Ecosystems within the U.S. Exclusive Economic Zone (in whole or in part) are the Beaufort Sea, Chukchi Sea, Eastern Bering Sea, Gulf of Alaska, California Current, Insular Pacific Hawaiian, Gulf of Mexico, Caribbean Sea, South East U.S. Continental Shelf, and North East U.S. Continental Shelf.

Some wide-ranging animals, including certain large fish, sea turtles, and marine mammals, cross LME boundaries just as migrating birds move across tundra, forest and prairie ecosystems on land.

CORE SCIENTIFIC KNOWLEDGE ABOUT ECOSYSTEMS

Our scientific understanding of ecosystems in general, and marine systems specifically, has advanced substantially over the last few decades. A wealth of experience with ecosystem-based management on land is available to inform implementation of marine ecosystem-based management. The following are key concepts that form the foundation for an ecosystem approach to management.

- **The key interactions among species within an ecosystem are essential to maintain if ecosystem services are to be delivered.** Ecosystems are highly interactive and strongly linked. Removing or damaging some species can dramatically affect others and disrupt the ability of the system to provide desired services. However, not all interactions are equally important. The consequences of some species' interactions strongly influence the overall behavior of ecosystems. Small changes to these key interactions can produce large ecosystem responses. For example, the absence of large-bodied predators at the apex of marine food webs can result in large-scale changes in the relative abundances of other species. Ecosystem-based management therefore entails identifying and focusing on the role of key interactions, rather than on all possible interactions.

- **The dynamic and complex nature of ecosystems requires a long-term focus and the understanding that abrupt, unanticipated changes are possible.** The abundances of species are inherently difficult to predict, especially over longer time periods, in part because they may change abruptly and with little warning. For example, decadal-scale changes (such as the North Atlantic Oscillation or the Pacific Decadal Oscillation) significantly alter ecosystem dynamics and population sizes. Such long-term changes tend to be less predictable because they are associated with large-scale environmental changes. Management must thus anticipate and be able to adjust to these changes.

- **Ecosystems can recover from many kinds of disturbance, but are not infinitely resilient.** There is often a threshold beyond which an altered ecosystem may not return to its previous state. The tipping point for these irreversible changes may be impossible to predict. Thus, increased levels of precaution are prudent as ecosystems are pushed further from pre-existing states. Features that enhance the ability of an ecosystem to resist or recover from disturbance include the full natural complement of species, genetic diversity within species, multiple representative stands (copies) of each habitat type and lack of degrading stress from other sources.

- **Ecosystem services are nearly always undervalued.** Although some goods (fish and shellfish) have significant economic value, most other essential services are neither appreciated nor commonly assigned economic worth. Examples of services that are at risk because they are undervalued include protection of shorelines from erosion, nutrient recycling, control of disease and pests, climate regulation, cultural heritage and spiritual benefits. Current economic systems attach no dollar values to these services; they are typically not considered in policy decisions and many are at risk.

KEY ELEMENTS OF ECOSYSTEM-BASED MANAGEMENT

The U.S. Commission on Ocean Policy and the Pew Oceans Commission articulated a number of key elements of marine ecosystem-based management. They include:

- Make protecting and restoring marine ecosystems and all their services the primary focus, even above short-term economic or social goals for single services. Only intact, healthy ecosystems can provide the complete range of benefits that humans want and need over long periods of time.
- Consider cumulative effects of different activities on the diversity and interactions of species.
- Facilitate connectivity among and within marine ecosystems by accounting for the import and export of larvae, nutrients, and food.
- Incorporate measures that acknowledge the inherent uncertainties in ecosystem-based management and account for dynamic changes in ecosystems, for example as a result of natural oscillations in ocean state or shifts in the frequency or intensity of storms. In general, levels of precaution should be proportional to the amount of information available such that the less that is known about a system, the more precautionary management decisions should be.
- Create complementary and coordinated policies at global, international, national, regional, and local scales, including between coasts and watersheds. Ecosystem processes operate over a range of spatial scales, and thus appropriate scales for management will be goal-specific.
- Maintain historical levels of native biodiversity in ecosystems to provide resilience to both natural and human-induced changes.
- Require evidence that an action will not cause undue harm to ecosystem functioning before allowing that action to proceed.
- Develop multiple indicators to measure the status of ecosystem functioning, service provision and effectiveness of management efforts.
- Involve all stakeholders through participatory governance that accounts for both local interests and those of the wider public.

ACTIONS CONSISTENT WITH ECOSYSTEM-BASED MANAGEMENT

Implementing ecosystem-based management will involve many steps and the use of diverse tools. The following overarching actions are consistent with an ecosystem-based approach to management. Some of these individual steps are already being taken in the U.S. and around the world. However, they have not been implemented in a comprehensive, integrated way. Enough is known now about marine ecosystems to put an ecosystem-based approach into practice immediately.

- Initiate **ecosystem-level planning** that involves multiple stakeholders and takes into account the cumulative impacts of multiple important human activities on ecosystems, as well as the effects of long-term environmental changes.

- Establish **cross-jurisdictional management goals** through formal agreements and mechanisms across local, state, federal and tribal authorities. Goals within ecosystem-based management should reflect interagency management at all levels, as opposed to focusing on specific jurisdictions within an ecosystem (for example, parks, refuges, and sanctuaries).

- Initiate **zoning** of regions of the ocean, for example LMEs, by designating areas for particular allowable uses in both space and time, including networks of fully protected marine reserves and other types of marine protected areas. Zoning that reduces conflict among users of different services should account for and integrate the effects of key activities. This regional planning should be carried out in a comprehensive manner. Area-based management approaches are valuable tools for coordinating the management of multiple uses within the larger land- or seascape context. **Networks of marine reserves** are uniquely capable of protecting biodiversity and habitats, producing the large-bodied individuals who contribute disproportionately to reproductive output, providing insurance against management uncertainties, and providing a benchmark for evaluating the effects of activities outside of reserves.

- Expand and improve the coordination of **habitat restoration** in coastal ecosystems such as wetlands, seagrass beds, and kelp and mangrove forests where habitats have been lost or ecosystem functioning has been diminished. These activities, currently under the purview of a plethora of governmental agencies, should be coordinated in a comprehensive manner that considers their cumulative effects on ocean and coastal ecosystems and includes a rigorous program of research, monitoring and evaluation.

- Adopt **co-management** strategies in which governments (federal, state, local, and tribal) and diverse stakeholders (local resource users, academic and research scientists, conservation interests, community members with traditional knowledge, and other stakeholders) share the responsibility for management and stewardship. Potential advantages include decision-making that is better informed, more flexible, and incorporates traditional ecological knowledge.

- Incorporate **adaptive management** into ecosystem plans as an approach to learning from management actions that allows for scientifically based evaluation, testing of alternate management approaches, and readjustment as new information becomes available from carefully designed monitoring programs. Management should explicitly acknowledge that our current understanding is incomplete and will continue to improve. Likewise, institutions must be adaptable when ecosystems or knowledge change.

- Establish **long-term ocean and coastal observing, monitoring and research** programs to collect continuously and integrate relevant biogeophysical, social, and economic data. These programs are needed to understand better the workings of marine ecosystems, changes in ocean dynamics, and the effectiveness of management decisions.

If you would like to add your name to this statement and are an academic with a PhD or JD degree and based at a US institution, please contact Karen McLeod (karen.mcleod@science.oregonstate.edu)

Citation for this statement:

McLeod, K. L., J. Lubchenco, S. R. Palumbi, and A. A. Rosenberg. 2005. Scientific Consensus Statement on Marine Ecosystem-Based Management. Signed by 217 academic scientists and policy experts with relevant expertise and published by the Communication Partnership for Science and the Sea at http://compassonline.org/?q=EBM.

APPENDIX A: FREQUENTLY ASKED QUESTIONS

WHAT BENEFITS DO HUMANS DERIVE FROM MARINE ECOSYSTEMS?

Humans depend upon oceans and coasts for their existence and well-being. Marine ecosystems benefit humans by providing services such as food (fish, shellfish and seaweed); medicines; water purification; protection of shorelines from erosion and storm damage; control of diseases and pests; nutrient cycling; moderation of climate and weather; recreation; and spiritual, religious and other nonmaterial benefits. The interactions within an ecosystem produce these services. Each ecosystem provides a range of services.

HOW DO HUMANS IMPACT MARINE ECOSYSTEMS?

Humans affect marine ecosystems through a wide variety of activities on land, on the coasts, and in the ocean. The impacts of these activities interact, often in synergistic ways. Land-based activities have major impacts on marine ecosystems via run-off and atmospheric deposition of nutrients and chemical pollutants, alteration of coastal habitats such as wetlands and estuaries, alteration of flows of water and sediment to coastal areas, deposition of marine debris, and global climate change. Among coastal and oceanic activities (such as aquaculture, coastal development, fishing, military activities, and shipping), fishing has the most obvious impact. Ecosystem effects of fishing result from the removal of substantial amounts of life, reduction of the average size and age of individuals within a population (thereby reducing productive capacity), removal of a large percentage of top predators (thereby altering the function of marine food webs), collateral damage to non-target species (often including endangered species) via bycatch, and degradation or destruction of bottom habitats by some fishing gear. These can in turn affect the structure and functioning of ecosystems, reduce productivity of the system, and impede the delivery of services.

IS 'ECOSYSTEM-BASED MANAGEMENT' DIFFERENT FROM 'ECOSYSTEM MANAGEMENT'?

The term "ecosystem management" implies that it is possible to control and manage an entire ecosystem. In view of the fact that humans cannot control ocean currents or most animals within a marine ecosystem, it is scientifically more accurate to speak of "ecosystem-based management" or an "ecosystem approach to management." Ecosystem-based management focuses on managing human activities, rather than deliberately manipulating or managing entire ecosystems.

HOW DOES 'ECOSYSTEM-BASED MANAGEMENT' (EBM) DIFFER FROM 'ECOSYSTEM-BASED FISHERY MANAGEMENT' (EBFM)?

EBM and EBFM are different, but complementary. Managing individual sectors, such as fishing, in an ecosystem context is necessary but not sufficient to ensure the continued productivity and resilience of an ecosystem. Individual human activities should be managed in a fashion that considers the impacts of the sector on the entire ecosystem as well as on other sectors. The longer-term, integrated, cumulative impacts of all relevant sectors on an ecosystem must be evaluated, with a mechanism for adjusting impacts of individual sectors.

APPENDIX B: GENERAL REFERENCES

Bertness, M.D., S.D. Gaines, and M.E. Hay (eds.). 2001. *Marine Community Ecology.* Sinauer, Sutherland, MA.

Chapin III, F.S., E.S. Zavaleta, V.T. Eviners, R.L. Naylor, P.M. Vitousek, H.L. Reynolds, D.U. Hooper, S. Lavorel, O.E. Sala, S.E.Hobbie, M.C. Mack, and S. Diaz. 2000. Consequences of changing biodiversity. Nature 405:234-242.

Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S.R., D'Antonio, C.M., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.H., Turner, M.G., Woodmansee, R.G. 1996. The report of the Ecological Society of America committee on the scientific basis for ecosystem management. Ecological Applications 6:665-691.

Cicin-Sain, B. and R.W. Knecht. 2000. *The Future of US Ocean Policy: Choices for the New Century*. Island Press, Washington DC.

Costanza, R., Andrade, R., Ataunes, P., van den Belt, M., Boersma, D., Boesch, D.F., Catarino, R., Hanna, S., Limburg, K., Low, B., Molitor, M., Pereira, J.G., Rayner, S., Santos, R., Wilson, J., and M. Young. 1998. Principles of sustainable governance of the oceans. Science 281:198-199.

Ecosystem Principles Advisory Panel. 1999. Ecosystem-based fishery management: a report to Congress by the Ecosystem Principles Advisory Panel, National Marine Fisheries Service, Washington DC.

Link, J.S. 2002. What does ecosystem-based fisheries management mean? Fisheries 27:18-21.

Mangel, M., L.M. Talbot, G.K. Meffe, M.T. Agardy, D.L. Alverson, J. Barlow, D.B. Botkin, G. Budowski, T. Clark, J. Cooke, R.H. Crozier, P.K. Dayton, D.L. Elder, C.W. Fowler, S. Funtowicz, J. Giske, R.J. Hofman, S.J. Holt, S.R. Kellert, L.A. Kimball, D. Ludwig, K. Magnusson, B.S. Malayang III, C. Mann, E.A. Norse, S.P. Northridge, W.F. Perrin, C. Perrings, R.M. Peterman, G.B. Rabb, H.A. Regier, J.E. Reynolds III, K. Sherman, M.P. Sissenwine, T.D. Smith, A. Starfield, R.J. Taylor, M.F. Tillman, C. Toft, J.R. Twiss, Jr., J. Wilen, and T.P. Young. 1996. Principles for the conservation of wild living resources. Ecological Applications 6:338-362.

Millennium Ecosystem Assessment. 2005. Island Press, Washington DC; http://www.MAweb.org

NRC (National Research Council). 1999. *Our Common Journey: A Transition Toward Sustainability*. National Academy Press, Washington DC, 363 pp.

NRC (National Research Council). 1999. *Sustaining marine fisheries*. National Academy Press, Washington DC, 184 pp.

Pew Oceans Commission. 2003. *America's Living Oceans: Charting a Course for Sea Change*. Pew Oceans Commission, Arlington, VA.

Pikitch, E.K., C. Santora, E.A. Babcock, A. Bakun, R. Bonfil, D.O. Conover, P. Dayton, P. Doukakis, D. Fluharty, B. Heneman, E.D. Houde, J. Link, P.A. Livingston, M. Mangel, M.K. McAllister, J. Pope, K.J. Sainsbury. 2004. Ecosystem-based fishery management. Science 305:346-347.

Sherman, K., L. M. Alexander, and B. D. Gold, eds. 1990. Large Marine Ecosystems: Patterns, Processes, and Yields. American Association for the Advancement of Science, Washington DC.

U.S. Commission on Ocean Policy. 2004. *An Ocean Blueprint for the 21st Century*. Final Report of the U.S. Commission on Ocean Policy to the President and Congress, Washington DC.

The following scientists and policy experts have approved this statement. All hold either Ph.D. or J.D. degrees and are based at U.S. academic institutions.[3]

Initial Signatories

Karen L. McLeod
Oregon State University

Stephen R. Palumbi
Stanford University

Donald F. Boesch
University of Maryland

Biliana Cicin-Sain
University of Delaware

Larry B. Crowder
Duke University

Steven D. Gaines
University of California, Santa Barbara

Charles F. Kennel
Scripps Institution of Oceanography

Jane Lubchenco
Oregon State University

Andrew A. Rosenberg
University of New Hampshire

Mark H. Carr
University of California, Santa Cruz

David O. Conover
Stony Brook University

David L. Fluharty
University of Washington

Mark A. Hixon
Oregon State University

Simon A. Levin
Princeton University

[3] Institutions are listed for purposes of identification only.

Jeffrey S. Levinton
Stony Brook University

John C. Ogden
Florida Institute of Oceanography
and University of South Florida

Ellen K. Pikitch
University of Miami

Enric Sala
Scripps Institution of Oceanography

Robert R. Warner
University of California, Santa Barbara

Marc Mangel
University of California, Santa Cruz

Charles H. Peterson
University of North Carolina, Chapel Hill

Nancy N. Rabalais
Louisiana Universities Marine Consortium

Robert S. Steneck
University of Maine

Additional Signatories

Satie Airamé
University of California, Santa Barbara

Dennis M. Allen
University of South Carolina

Don Anderson
Woods Hole Oceanographic Institution

Alice Alldredge
University of California, Santa Barbara

Richard Ambrose
University of California, Los Angeles

Todd W. Anderson
San Diego State University

William D. Anderson, Jr.
College of Charleston

Richard B. Aronson
University of South Alabama

Jerald S. Ault
University of Miami

John C. Avise
University of Georgia

Andrew Bakun
University of Miami

Richard T. Barber
Duke University

Jack A. Barth
Oregon State University

James P. Beets
University of Hawaii at Hilo

Richard S. Appledorn
University of Puerto Rico

Larry P. Atkinson
Old Dominion University

Peter J. Auster
University of Connecticut

Matthew P. Ayres
Dartmouth College

Paul H. Barber
Boston University

James P. Barry
Monterey Bay Aquarium Research Institute

Robert C. Beardsley
Woods Hole Oceanographic Institution

Steven A. Berkeley
University of California, Santa Cruz

Eric L. Berlow
University of California, San Diego

Giacomo Bernardi
University of California, Santa Cruz

Mark D. Bertness
Brown University

Charles Birkeland
University of Hawaii at Manoa

Carol A. Blanchette
University of California, Santa Barbara

George Boehlert
Oregon State University

P. Dee Boersma
University of Washington

Louis W. Botsford
University of California, Davis

Malcolm J. Bowman
Stony Brook University

Matthew E. S. Bracken
University of California, Davis

Beth Bryant
University of Washington

Ronald S. Burton
Scripps Institution of Oceanography

James E. Byers
University of New Hampshire

James T. Carlton
Williams College

Stephen R. Carpenter
University of Wisconsin

Jennifer Caselle
University of California, Santa Barbara

Francis Chan
Oregon State University

Celia Y. Chen
Dartmouth College

Sallie W. Chisholm
Massachusetts Institute of Technology

Norman L. Christensen, Jr.
Duke University

Christopher W. Clark
Cornell University

William C. Clark
Harvard University

Felicia C. Coleman
Florida State University

Keith R. Cooper
Rutgers University

Benjamin E. Cuker
Hampton University

Lisa M. Curran
Yale University

Gretchen C. Daily
Stanford University

Paul K. Dayton
Scripps Institution of Oceanography

Christopher F. D'Elia
University of South Florida

Megan N. Dethier
University of Washington

Paul A. Dinnel
Western Washington University

Andrew P. Dobson
Princeton University

Jenifer E. Dugan
University of California, Santa Barbara

David O. Duggins
University of Washington

Phillip Dustan
College of Charleston

Ginny L. Eckert
University of Alaska, Southeast

Paul R. Ehrlich
Stanford University

Richard B. Emlet
University of Oregon

Ron J. Etter
University of Massachusetts

Stephen C. Farber
University of Pittsburgh

Graham Forrester
University of Rhode Island

Jerry F. Franklin
University of Washington

James N. Galloway
University of Virginia

Brian Gaylord
University of California, Davis

Leah Gerber
Arizona State University

Anne E. Giblin
Marine Biological Laboratory, Woods Hole

Sarah Gilman
University of South Carolina

Michael H. Graham
Moss Landing Marine Laboratories,
California State Universities

J. Frederick Grassle
Rutgers University

Charles H. Greene
Cornell University

Nancy B. Grimm
Arizona State University

Richard K. Grosberg
University of California, Davis

Donald R. Gunderson
University of Washington

Sally D. Hacker
Oregon State University

Michael G. Hadfield
University of Hawaii at Manoa

Benjamin S. Halpern
University of California, Santa Barbara

C. Drew Harvell
Cornell University

Alan Hastings
University of California, Davis

Mark E. Hay
Georgia Institute of Technology

Brian Helmuth
University of South Carolina

Selina Heppell
Oregon State University

Scott A. Heppell
Oregon State University

Carlton H. Hershner
Virginia Institute of Marine Science

Helen Hess
College of the Atlantic

John E. Hobbie
Marine Biological Laboratory, Woods Hole

Robert W. Howarth
Cornell University

Peter A. Jumars
University of Maine

Les Kaufman
Boston University

Ann Kinzig
Arizona State University

Terrie Klinger
University of Washington

Barbara A. Knuth
Cornell University

Christopher C. Koenig
Florida State University

Gretchen E. Hofmann
University of California, Santa Barbara

Jeremy B. C. Jackson
Scripps Institution of Oceanography

Ronald H. Karlson
University of Delaware

Judith T. Kildow
California State University, Monterey Bay

Bjorn Kjerfve
Texas A & M University

Nancy Knowlton
Scripps Institution of Oceanography

Mimi A.R. Koehl
University of California, Berkeley

Gordon H. Kruse
University of Alaska, Fairbanks

Rikk Kvitek
California State University, Monterey Bay

Ralph J. Larson
San Francisco State University

Hunter S. Lenihan
University of California, Santa Barbara

Heather Leslie
Princeton University

Lisa A. Levin
Scripps Institution of Oceanography

Gene E. Likens
Institute of Ecosystem Studies

David E. Lincoln
University of South Carolina

Romuald N. Lipcius
Virginia Institute of Marine Science

Milton Love
University of California, Santa Barbara

Christopher Lowe
California State University, Long Beach

Lawrence P. Madin
Woods Hole Oceanographic Institution

Nancy H. Marcus
Florida State University

Pamela Matson
Stanford University

Bonnie J. McCay
Rutgers University

Jerry McCormick-Ray
University of Virginia

Judith E. McDowell
Woods Hole Oceanographic Institution

Margaret Anne McManus
University of Hawaii at Manoa

Jerry M. Melillo
Marine Biological Laboratory, Woods Hole

Fiorenza Micheli
Stanford University

Kristen L.D. Milligan
Oregon State University

Steven G. Morgan
University of California, Davis

Roz L. Naylor
Stanford University

Karina J. Nielsen
Sonoma State University

Gordon H. Orians
University of Washington

Marcia K. McNutt
Monterey Bay Aquarium Research Institute

Bruce A. Menge
Oregon State University

Kathy Ann Miller
University of California, Berkeley

Harold Mooney
Stanford University

Steven N. Murray
California State University, Fullerton

Joseph E. Neigel
University of Louisiana-Lafayette

Mark D. Ohman
Scripps Institution of Oceanography

Gail Osherenko
University of California, Santa Barbara

David W. Owens
College of Charleston

Dianna K. Padilla
Stony Brook University

Julia K. Parrish
University of Washington

Linwood H. Pendleton
University of California, Los Angeles

Catherine Ann Pfister
University of Chicago

Mary E. Power
University of California, Berkeley

G. Carleton Ray
University of Virginia

Alison Rieser
University of Maine School of Law

Michael L. Pace
Institute of Ecosystem Studies

Margaret A. Palmer
University of Maryland

Gustav Paulay
University of Florida

Christopher W. Peterson
College of the Atlantic

Stuart L. Pimm
Duke University

H. Ron Pulliam
University of Georgia

Robert H. Richmond
University of Hawaii at Manoa

Jennifer Ruesink
University of Washington

J.B. Ruhl
Florida State University of College of Law

Paul W. Sammarco
Louisiana Universities Marine Consortium

Gorka A. Sancho
College of Charleston

Eric Sanford
University of California, Davis

Donald Scavia
University of Michigan

Oswald J. Schmitz
Yale University

David H. Secor
University of Maryland

Alan Shanks
University of Oregon

Lynda P. Shapiro
University of Oregon

Sandra E. Shumway
University of Connecticut

Daniel Simberloff
University of Tennessee

Craig R. Smith
University of Hawaii at Manoa

L. David Smith
Smith College

George N. Somero
Stanford University

Erik E. Sotka
College of Charleston

Wayne P. Sousa
University of California, Berkeley

J. Gustave Speth
Yale University

John J. Stachowicz
University of California, Davis

Robert W. Sterner
University of Minnesota

William J. Sydeman
Scripps Institution of Oceanography

Sean K. Todd
College of the Atlantic

Robert L. Vadas
University of Maine

Cindy Lee Van Dover
College of William and Mary

Les Watling
University of Maine

Su Sponaugle
University of Miami

Eleanor Sterling
American Museum of Natural History

Richard R. Strathmann
University of Washington

G. David Tilman
University of Minnesota

Alan R. Townsend
University of Colorado, Boulder

Kathryn L. Van Alstyne
Western Washington University

Libe Washburn
University of California, Santa Barbara

Judith S. Weis
Rutgers University

Gerald M. Wellington
University of Houston

Martin Wikelski
Princeton University

A.O. Dennis Willows
University of Washington

Jon D. Witman
Brown University

J. Timothy Wooton
University of Chicago

Steven L. Yaffee
University of Michigan

Joy Zedler
University of Wisconsin

Ali Whitmer
University of California, Santa Barbara

Susan L. Williams
University of California, Davis

James Wilson
University of Maine

Sarah Ann Woodin
University of South Carolina

Dawn J. Wright
Oregon State University

Oran R. Young
University of California, Santa Barbara

Richard G. Zingmark
University of South Carolina

NFCC Consensus Statement

Integrating Marine Reserve Science and Fisheries Management

NFCC Consensus Conference

June 7-9, 2004
Long Beach, California

Consensus Statement
June 7-9, 2004

Integrating Marine Reserves Science and Fisheries Management

National Fisheries Conservation Center

Photo of Fuca Pillar, Cape Flattery, Olympic Coast National Marine Sanctuary courtesy of NOAA Photo Library

What is A Consensus Conference?

In late 2002, NFCC proposed a two-and-a-half-day consensus conference—modeled after the National Institutes of Health Consensus Development Conferences—to improve the integration of marine reserve science and fisheries management.

This style of consensus conference is designed to answer questions that require weighing scientific evidence in dispute. The consensus statement that emerges is intended to advance understanding of the scientific issues in question and to be useful to marine resource managers and the public.

As convenor, NFCC empanelled a planning committee to draft the questions and recommend review panelists. The non-advocate panel of experts based its findings on (1) presentations by investigators working in areas relevant to the consensus questions during a 2-day public session, (2) questions and statements from conference attendees during open discussion periods that were part of the public sessions, and (3) closed deliberations by the panel during the remainder of the second day and morning of the third.

This statement is an independent report of the consensus panel and is not a policy statement of NFCC or the organizations or institutions of the panelists.

Reference Information

For making bibliographic reference to this consensus statement, it is recommended that the following format be used, with or without source abbreviations, but without authorship attribution:

Integrating Marine Reserve Science and Fisheries Management. NFCC Consensus Statement, June 7-9, 2004, Long Beach, California.

Publication Information

The marine reserve science consensus statement, background materials prepared for the conference, and other NFCC publications are available by visiting our web site at http://nfcc-fisheries.org.

Disclosure Statement

All of the panelists who participated in this conference and contributed to the writing of this consensus statement were identified as having no financial or scientific conflict of interest, or any prior decision-making record on designation of marine reserves. Unlike the expert speakers who presented scientific data at the conference, the individuals invited to participate on the review panel were selected because they were not professionally identified with specific positions or research directions with respect to marine reserves science.

Abstract

Objective

The objective of this Consensus Statement is to inform the fishery management, ecological research, and marine protected area management communities of the results of the NFCC Consensus Conference on Integrating Marine Reserve Science and Fisheries Management. The statement provides an objective examination and assessment of the information regarding potential biological, social, and economic consequences of marine reserves, their potential effectiveness as a fishery management tool in the U.S., the methods for integrating their application with existing U.S. fisheries management and how marine reserves might be designed, monitored and evaluated. In addition, the statement addresses sources and magnitudes of uncertainty associated with marine reserves and conventional management approaches, and recommends areas for further study.

Participants

The conference included scientists and policy experts representing the fields of biological oceanography, marine ecology, fish biology, population dynamics, stock assessment, fishery management, fishery economics, and marine environmental law. The conference's seven-member review panel was made up of scientists and policy experts not currently engaged in research or advocacy in the field of marine reserves. The conference's ten-member presentation panel was made up of scientists and policy experts that are currently engaged in research or advocacy in the field of marine reserves. In addition to conference panelists, an audience of about 100 fishers, scientists, and policy makers was observed and contributed comments.

Evidence

The Communication Partnership for Science and the Sea (COMPASS) at Oregon State University conducted the literature search for the planning committee and the consensus conference and prepared an extensive bibliography for the panel and conference audience. COMPASS staff also prepared abstracts and topic syntheses for the panel with relevant citations from the literature.

Consensus Process

The panel, answering predefined questions, developed their conclusions based on the scientific evidence presented in open forum and the scientific literature. The panel composed a draft statement that was summarized and presented to the experts and the audience for comment. Thereafter, the panel resolved conflicting recommendations and released a summary of its revised statement at the end of the conference. The panel finalized the revisions after the conference. The draft statement was made available on the World Wide Web after panel revisions.

Conclusions

Marine reserves should be considered in the broader context of the development of ecosystem-based management in the U.S. From that perspective, marine reserves have clear application for meeting objectives for ecosystem conservation and protection of marine biodiversity in addition to whatever benefits they may have for achieving fishery management objectives. Furthermore, marine reserves are a category of area management options—including less restrictive and less permanent alternatives—that may be used in order to achieve ecosystem- or species-based management objectives.

With regard to fishery effects, studies of marine reserves and other area closures, most of which are from lower latitudes, have now shown that fishery target species have increased in abundance and expanded age structure within the closed area in a preponderance of cases (the so-called “reserve effect.”). This is particularly the case where the resource species are significantly overfished. Evidence for effects outside closed areas, either by movement of adults across the reserve boundaries (“spillover”) or larval “export” is more limited and effects on stocks within larger regions can only be deduced by models at this point. This is because of the limited size of existing reserves and inherent difficulties in measuring and interpreting such broader effects. In general, knowledge is sufficient to proceed with the design and evaluation of marine reserves and other marine protected areas and their incorporation into regional ecosystem-based management. More sophisticated modeling and analysis is required for better understanding of spatial movement rates, export of reproductive products, and adaptations by fishers.

Marine reserves clearly offer some advantages for simultaneously incorporating habitat protection and maintenance of ecosystem structure and function within the protected area. They may offer some advantages for multi-species management and as a hedge against environmental surprise or management failure.

Marine reserves are most likely to be an effective management tool for relatively sedentary species with broad larval dispersal, which are recruitment limited, and for mobile species with high site fidelity. They may also be effective for protecting rare habitats vulnerable to human disruption or in protecting aggregations of animals (e.g., when spawning), when exploited populations have been severely depleted, or where bycatch is high. Closed areas may also be useful in achieving broad demographic representation in spawning populations if large animals have limited movement potential relative to reserve boundaries, and when they can maintain populations of highly fecund, older females with strong reproductive potential. They may be more feasible to implement either when reduced yields have already restricted fishing activities and other management measures have been ineffective or when they address special needs within otherwise productive regions.

Marine reserves and other protected areas should be integrated with existing and emerging management measures as part of a coherent ecosystem-based approach to management of commercial and recreational fisheries and should not be simply layered over existing regulations. Careful consideration of the effects on allocation of resources among users, displacement of fishing activity, the requirements for surveys and stock assessment, and the costs of monitoring and enforcement should be made in considering protected area options and design.

The Panel found it difficult to limit its considerations to marine reserves as strictly defined, i.e. areas permanently protected from all extractive activities. We found that management actions need to be openly evaluated against stated goals and where goals are not being met changes in management must at least be considered. The design requirements for marine reserves depend heavily on the environmental context and specific management goals, including the overriding goal of sustainability and high yields of economically important species. Robust experimental design will be critical in order to determine the effects of displaced fishing pressures and enhancement effects on populations outside of reserves in before-after-control-impact assessments.

We have been hampered in evaluating the use of marine reserves as a tool for fishery management by the lack of experiments explicitly designed to address reserve effects on fisheries. These explicit experiments are urgently needed. There are numerous uncertainties associated with our understanding both of important biological and socioeconomic processes and with monitoring, analysis, prediction, and implementation. Some important uncertainties for marine reserves include the degree of effective dispersion and reproductive seeding and the ability to resolve spatial and temporal interactions in monitoring and modeling.

Further study is required on several key issues if closed areas are to assume a more important role in ecosystem approaches to fisheries management and biodiversity protection. These include high quality, synthetic bottom mapping with which to define vulnerable habitats that closed areas might best protect; study of dispersal rates; synthesis of effects of closures in northern temperate and boreal systems.

Many authors have speculated that marine reserves offer more precaution against management and scientific uncertainty than traditional measures. At this point, this is an assertion, and no studies using common definitions and metrics of precaution have been conducted. Given the importance of this issue, there is a need to conduct such work, applying biology and social science, particularly as it relates to findings from existing marine closures.

Introduction

The widespread degradation of coastal ocean ecosystems, attendant losses in biodiversity, and depleted status of many fishery stocks led the U.S. Commission on Ocean Policy to call for a new era of ecosystem-based management. Ecosystem-based management encompasses all ecosystem components, including human and non-human species and their environments. In its July, 2004 report, the Commission recommends such management be based on principles of sustainability, precaution, adaptation, and participatory governance and use the best available science.

Marine reserves, areas completely protected in perpetuity from all extractive and destructive activities, are being widely considered as a component of ecosystem-based management. While using marine reserves for biodiversity and ecosystem conservation is generally accepted, their potential role in fisheries management is controversial. Conservation advocates and some scientists have argued that marine reserves protect multiple stocks from over-exploitation in ways that conventional management methods that limit fishing effort or catches cannot or have not been able to do. Commercial and recreational fishing interests consider marine reserves as one more means to permanently limit their access to renewable resources. Some fishery scientists have argued that many fishery management objectives of marine reserves can be attained by effectively employing conventional measures and that marine reserves alone do not ensure sustainable fisheries management.

This two-and-a-half-day conference examined the current state of knowledge regarding the integration of marine reserve science and U.S. fisheries management. Experts presented the latest research findings to an independent Consensus Development Panel. After weighing this scientific evidence, the panel drafted a statement, addressing the following key questions:

1. What is the current state of knowledge of the potential biological, social, and economic consequences, both positive and negative, of marine reserves?
2. Under what circumstances could marine reserves be an effective fishery management tool in the U.S.?

3. How could marine reserves be integrated with existing fisheries management tools?

4. What general approaches to reserve design would meet fisheries objectives, taking into account social, economic, biological, and environmental factors?

5. What are the sources and magnitudes of uncertainty associated with marine reserves and conventional management approaches, and what are their implications for practical application of reserve design tools within the fishery management system?

6. What monitoring actions are needed to evaluate the results of marine reserves as a fishery management tool?

The Panel found it difficult to limit its considerations to marine reserves as strictly defined, i.e. areas permanently protected from all extractive activities, and found the issue of permanence the most highly contentious part of its overall charge.

(1) What is the current state of knowledge of the potential biological, social, and economic consequences of marine reserves?

Spatial closures have a long history as fishery management tools. They have been established to protect spawning aggregations, lower overall fishing mortality rates, minimize bycatch interactions, and reduce human impacts on vulnerable bottom habitat types. In the last decade, their use has expanded as fishery management objectives have widened, for example, to include essential fish habitat (EFH) protection. These closures range from narrowly focused prohibitions for particular gears to large-scale marine reserves prohibiting any removals from the three-dimensional reserve areas. Spatial closures by themselves are not marine reserves. However, since there are few studies examining the broad impacts of marine reserves explicitly, we also considered studies of closures. There have been many such closures and their results can inform us of the likely impacts of marine reserves on the species within them and the fisheries around them.

Knowledge about the biological and human-related consequences of marine reserves comes from two primary sources: (1) case studies of existing spatial closures, and (2) modeling studies evaluating the potential effects of reserves, either alone or in combination with other management measures. In general, these studies concentrate on impacts on yields and stock sizes of fishery target species, although some case studies have evaluated wider effects on associated species. Evidence presented to the panel indicates that available case studies for marine reserves are concentrated in the lower latitudes. Relatively few case studies exist from northern temperate and boreal waters. Many reserves and closures may not have existed for sufficient time to evaluate the potential consequences on long-lived component species.

Analysis of existing closures reveals that “reserve effects” (increased abundance and expanded age/size structures of resources and increased diversity in biological communities within the closed areas) commonly occur following spatial closures. Although this is not universal for all monitored species, in all regions, it is nonetheless surprisingly consistent. In many cases, significant, “reserve effects” have occurred where resource species were extensively overfished; thus the closure dramatically reduced fishing mortality on part or all of the stock. Such contrasts may not be observed with closures in areas where resource species are currently well managed. Other potential reserve effects include “spillover” (density-induced movement of adults across reserve boundaries into open areas) and larval “export” (movement of eggs and larvae to areas outside the reserve). Evidence for these latter effects is more limited than that for reserve effects; in particular, documenting export is a daunting technical challenge.

Spatial closures have been designed and established either to rebuild and maintain fishery populations, or to protect ecosystems and resources. In the case of closures for fishery enhancement, the federal fishery management process establishes target and threshold levels for stock size and fishing mortality as performance criteria, enabling evaluation of a closure’s (or a combination of measures) efficacy. Performance criteria for overall ecological effects of closures have no similar well-defined (statutory) targets and thresholds.

In general, we find that there currently is sufficient knowledge to proceed with the design and evaluation of reserves for the purposes of addressing primary fishery management goals (achievement of fishing mortality rate targets and stock biomass maintenance). In the United States (and in most of the developed world) detailed data exist on where target species are located, the spatial pattern of species abundance, general life history data (including longevity, maturity, dispersal of reproductive products, fecundity, and somatic growth rates), and some limited information on habitats in which the various life history stages occur. The design and evaluation of potential marine reserves requires these data in order to make first-order calculations of the biological impacts that alternative closed areas could have.

More sophisticated modeling and analysis of marine reserves require information on spatial movement rates, particularly across reserve boundaries; potential for export of reproductive products; and the likely behavioral adaptations by fishers (e.g., effort redistribution and its biological and socioeconomic impacts) to the establishment of marine reserves. Additionally, there are important, but unresolved, scientific questions regarding the functional value (relative productivity) of various habitat types, density-dependence at high levels of stock biomass (e.g., associated with reserve effects), and sub-stock structure within species. Few empirical studies exist with which to make generalizations regarding these effects. The Panel considers that studies of these factors represent a critical but heretofore-unmet research need. The lack of both a commonly agreed-to set of goals and clear performance measures regarding the effects of marine reserves on ecosystem function hampers the design and evaluation of closures for these purposes.

Below we briefly comment on the state of knowledge with respect to specific consequences of closures for the:

Population resilience of exploited species: Resilience measures are derived from life history information, stock-recruitment curves and similar knowledge. Such information exists for many species of fishery interest. Information regarding the relative efficacy of closures vs. alternative precautionary management measures to affect resiliency comes exclusively from modeling studies.

Variation in yield over time: Relatively low fishing mortality rates should result in less variability in annual yields, while high fishing mortality rates result in more dependency on variable incoming recruitment. Rotating open-closed areas can effectively buffer against yield variation where spatial patterns of recruitment may be variable, as in the management of some bivalve populations. There is little current information on the effects of reserves on yield variation (e.g., from adjacent open areas as a result of spillover and export), with the exception of some modeling studies.

Multispecies management: Bycatch avoidance has motivated the establishment of many existing closures, and such closures can be an effective strategy to reduce problematic bycatch in mixed species fisheries, and to avoid interactions with protected species. The consequences of closures on trophic dynamics have been evaluated in models, but few empirical case studies have produced information on this issue.

Habitat protection: Obviously spatial closures can afford high degrees of protection to benthic habitats, and some case studies document habitat changes following closures. However, the consequences of habitat protection to productivity of harvested species are generally poorly known. Some modeling studies have addressed the potential for fishing effects to reduce carrying capacity, and the effects that reserves might have on catch and biomass production under such conditions.

Protection of ecosystem services, structure, and function: Goals for ecosystem services, structure, and function have generally not been specified, nor have the effects of existing closures on these attributes been documented. In general, some modeling results indicate reserves should enhance these services and modifications of structure and function are more likely for reserves than other forms of spatial closures.

Insurance against environmental "surprise" or management failure: The concept of "insurance" in the context of resource management is ill-defined and thus a continuing source of ambiguity and contention. Overall, there is an open question regarding the proposition that marine reserves should, a priori, afford greater protection against perturbations or management failure than do precautionary management alternatives.

(2) Under what circumstances could marine reserves be an effective fisheries management tool?

Below, we outline the situations when marine reserves are likely to be ecologically beneficial and socio-economically feasible tools for fishery management. We assume that reserves will not be used alone for fisheries management but will be used in conjunction with other tools. Our discussion highlights the most critical and obvious circumstances; it is not intended to be an exhaustive list.

Biologically, the reserves may be most likely to be an effective tool for fishery management when:

♦ Species are sedentary or have high site fidelity (post-settlement) and have high larval dispersal. These species are the most likely to achieve long-term benefits (growth and survival) within reserves and to export these benefits through larval dispersal.

♦ Populations are recruitment limited.

♦ There are impacts to rare or key habitats. When the distributions of these habitats are limited, they are easier to manage with marine reserves.

♦ There are aggregations that can be managed within specific areas. The utility of reserves increases as more species occur in the aggregations and the aggregations occur at critical life history stages (e.g., nursery or spawning grounds).

♦ There is spatial consistency in the use of areas (e.g., in spawning grounds) by the population(s) to be managed. When there is less spatial overlap among populations, it will require a larger total area of reserves to protect the same amount of each population.

♦ When the protection of highly fecund (i.e., older and larger) individuals is desirable. These individuals have a disproportionately large contribution to larval supply in many populations and reserves can contribute to their development and/or protection. Traditional management measures (e.g., slot sizes) can also offer protection to these size classes but not if there are high post-release impacts (e.g., mortality) to released fishes.

♦ When stocks are depleted. Theoretical work indicates that the yield from reserves is most likely to be demonstrable when the MSY has been exceeded.

♦ Bycatch is high.

Socio-economically reserves are more likely to be an effective tool for fishery management when:

♦ Reserves meet multiple objectives (e.g., either for several stocks, fishery sustainability, habitat protection).

♦ Stocks are in sufficiently poor condition that limits on fishing have little added consequence.

♦ The economic condition of the fishery is good and reserves will have little direct economic impact.

♦ Spatial enforcement is feasible (e.g., there has been a history of spatial management).

♦ Their implementation does not add to a cumulative burden of regulations.

♦ Effort can be displaced with little economic impact.

♦ Fixed spatial management offers simplicity. In countries without complex fishery management systems, reserves are simpler to implement than stock-specific time, area, and gear regulations, which can be difficult to develop, communicate, and enforce.

♦ Information is limited and precaution is mandated.

♦ Other management measures have been ineffective.

♦ Fleet overcapacity is concurrently addressed.

(3) How could marine reserves be integrated with existing fishery management tools?

Several contextual elements underlie the integration of marine reserves with fishery management. The panel assumes that marine reserves would not be implemented as independent management tools in the absence of other management measures, but would be added to existing management. The panel finds, therefore, that they should be designed and implemented to integrate with existing management, create an internal coherence, and contribute to meeting the objectives of a fishery management plan. As with all fishery management tools, the cost and benefits of marine reserves should be evaluated in the context of their application within the specific fishery management plan.

Because they are layered over a set of regulations already in place, marine reserves will contribute to the cumulative effects of regulation. The economic condition of the fishery will be critical to the impact of these cumulative effects. The more economically healthy the fishery, the more likely that its participants will support marine reserve development and comply with its implementation. To this end, the panel finds the existence of ITQs or other forms of property rights will promote the economic conditions that encourage long-term investments in conservation.

(3A) Under what circumstances could marine reserves enhance or detract from conventional management approaches?

Marine reserves have the potential to enhance conventional fishery management in several ways. Setting aside areas from use can provide a buffer against management mistakes and scientific uncertainty. These areas can serve not only as hedges against risk, they can also be a means to provide direct protection for multiple species when this is required. In cases where weak stock protections limit harvest of other species, reserves could also provide the needed protection to these stocks so that outside-reserve harvest could continue. We note that an obvious area in which reserves can enhance conventional management is in cases where fishing disrupts or damages habitat in ways that diminish productivity of the resource. Finally, the panel finds that establishing marine reserves on a regional, rather than fishery-specific, basis could enhance management across several fishery management plans.

Marine reserves also have the potential to detract from conventional fishery management by increasing management costs without concomitant increases in benefits. The creation of additional costs may occur through the added complications resulting from poor design and a failure to integrate them into the fishery regulatory and economic context.

The panel finds that implementing marine reserves in fully utilized fisheries will have allocative effects that may detract from management effectiveness. Depending on their extent and location, reserves may alter the distribution of seafood landings in ways that diminish economic activity in fishing communities. The removal of areas from fishing may also create differential impacts on particular gear types or scales of operation. For example, marine reserves in nearshore areas can force small vessels to fish farther offshore under less safe conditions. Regulatory impacts on both communities and safety are addressed in National Standards 8 and 10, which fishery management plans must meet.

The displacement of fishing effort out of marine reserve areas and its concentration in outside-reserve areas is another potential detractor from fishery management effectiveness. The magnitude of this effect depends on the relative size of the area removed and the extent to which vessels have alternative areas to fish. In fully capitalized or overcapitalized fisheries, concentrating fishing effort could damage non-reserve areas. The potential for displacement to work against the management objectives requires attending to the potential for capacity management in conjunction with the development of reserves.

Finally, we note that marine reserves introduce additional requirements for monitoring and enforcement. Monitoring is necessary to assess the within-reserve response to protection and the progress toward meeting management objectives. Enforcement of reserves either through at-sea policing or vessel monitoring systems systems (VMS) on fishing vessels is necessary to ensure full protection. Both monitoring and enforcement introduce additional costs to management.

(3B) Would the use of marine reserves affect the application of conventional management and stock assessment?

The Magnuson-Stevens Fishery Conservation and Management Act requires that stocks be assessed individually. It is reasonable to expect that this requirement will continue, even with the multiple-species protections provided by marine reserves. Stock assessments make use of both fishery dependent (from landings) and fishery independent (from at-sea surveys) data. Depending on the size and extent of marine reserves, methods for collecting data from both sources may need to be changed to ensure adequate representation. Marine reserves, by setting aside areas from fishing, weaken the basic assumption under which fishery-dependent data are used—that the demographics of the fishery reflect the demographics of fish stocks. If reserve areas are large, stock-wide, rather than fishery-represented, abundance will need to be surveyed. This will increase the importance of fishery independent data and decrease the importance of fishery dependent data in stock assessment. The panel finds that new and restratified survey designs will need to be developed to reflect the new spatial patterns of the fishery. These changes will carry costs for redesign, new data collection, and analysis.

(4) What general approaches to reserve design would meet fisheries objectives?

Design of marine reserves, or any spatial management system, will be driven by specific goals. For fisheries management, sustainability is an overriding goal. We note, however, that more explicit, and occasionally non-fisheries, management goals may be sought. Consequently, the design process will be unique for each occasion; yet, for any management decision process, certain general guidelines will likely diminish confusion and maximize consensus among stakeholders. These include:

- Concisely articulating management goals
- Ensuring objectives are measurable and scientifically verifiable
- Allowing and planning for changes if objectives are not met
- Engaging all stakeholders in the process from the onset.

Inherent in these guiding principles is an adaptive management plan built on specific goals. As multiple spatial and conventional management actions may be applied to achieve objectives, there must be a view of the whole process that ensures separate management actions are coherent, and ideally, synergistic. Moreover, there should be an explicit plan for monitoring and assessing specific performance indicators (see Question 6 for more detail).

The panel recognized that many design criteria relevant to spatial management options (e.g., area, location, duration, etc.) are highly specific to explicit management goals. Therefore, it is only possible to make general recommendations concerning design criteria. First, because reserves will affect multiple species and multiple users, associated costs and benefits may introduce conflicts. Therefore, to minimize costs, efforts to reduce conflicts with and among users should be applied without compromising the management goals. Second, the concept of permanence with respect to reserves implies inflexibility when applied to fisheries management goals. Where possible, management planning should invoke the option for adaptive change in reserve design on a timeframe that allows for realistically assessing reserve effectiveness. However, it must be recognized that the multi-species and ecosystem nature of some management goals may require long time frames. Third, under circumstances of a given total area requirement, multiple, smaller reserves (i.e. networks) will generally better spread risks and costs than will a single large reserve. While ensuring individual reserves are large enough to be effective, placement of multiple reserves across the entire management region will reduce localized costs while simultaneously offering expanded benefits by spreading the risk of reduced reserve effectiveness that may result from localized perturbations.

Use of marine reserves and other spatial management options is likely to increase as management focus trends toward ecosystem-based options and processes. Expanded oversight of the management process should include efforts to minimize duplication by recognizing where different management goals may overlap and/or compete. The Panel finds that management processes that follow the above approaches including both planning and evaluation should facilitate realization of desired effects while minimizing negative impacts and conflict.

(5) What are the sources and magnitudes of uncertainty associated with marine reserves and conventional management approaches?

We recognize that the biological and socioeconomic processes related to the full range of fishery management approaches are all inherently knowable. All approaches, however, contain uncertainties that, if left unacknowledged or unaddressed, will lead us to misrepresent both our knowledge about these systems and our ability to manage them with reasonable confidence. It is important, therefore, to try to provide a framework for characterizing this uncertainty so that we might better understand and address it.

We also recognize that knowledge, and therefore uncertainty, in the context of fisheries management expresses itself at several levels.

Specifically, uncertainty exists in our fundamental understanding about the processes governing the ecosystem, the fishery that uses ecosystem resources, and the management methods used to govern the fishery. Uncertainty also exists in our ability to monitor these processes through data collection; analyze this information through estimation, modeling, and interpretation; make predictions given this analysis; and then implement and enforce management controls once the state of the system has been reasonably determined.

The panel proposes a means to contrast the various sources and magnitudes of uncertainty as illustrated in the table below. The descriptions in Table 1 (at right) are meant as a starting point for characterizing the uncertainty associated with these systems rather than an exhaustive presentation of the subject.

Uncertainty among several of the factors appears lower for use of marine reserves than for conventional methods. However, this perception may reflect our greater experience with conventional methods. More experience with marine reserves will better characterize both the sources and degree of uncertainty associated with their use.

Some suggest marine reserves will reduce the level of monitoring and evaluation needed for management. However, even areas closed to fishing require monitoring and evaluation to apprise managers of population and ecosystem trends. Given this continual need, the loss of information otherwise typically available from fishery dependent sources, and the higher dimensionality inherent in evaluating spatially referenced information, the effort and costs required to achieve reasonable information levels may prove higher than expected

Implementation uncertainty is not clearly identifiable at this time, but may be generally examined at various levels. We know that regulatory structures associated with conventional methods can become quite convoluted. Gear regulations, in particular, often prompt changes in fishing methods in response, resulting in a series of ad hoc modifications to existing policies. Regulations identifying no-fishing zones for marine reserves would seem inherently simpler and less subject to alteration through the evolution of fishing practices, and this may be so. Other aspects of implementation, such as the political will to site a marine reserve in contrast to imposition of stricter catch or effort control measures would also appear simpler. However, implementing reserves at the

Table 1. Comparison of Uncertainty

	Marine Reserves	Conventional
Ecological & socioeconomic processes		
Sources of uncertainty	Movement Dispersion Spillover Export Reserve size and location Home range Reproductive capacity	Natural mortality Fishing mortality Growth Selectivity Catchability Reproductive capacity
Magnitude of uncertainty	Low to moderate	Moderate to high
Monitoring		
Sources of uncertainty	Spatial and temporal Commercial and sport CPUE Survey indices Total harvest	Temporal Commercial and sport CPUE Survey indices Total harvest
Magnitude of uncertainty	Moderate	Moderate
Analysis		
Sources of uncertainty	Spatial-temporal modeling Production models Size or age structured models Stock recruitment Yield per recruit Growth	Temporal modeling Production models Size or age structured models Stock recruitment Yield per recruit Growth
Magnitude of uncertainty	High	High
Prediction		
Sources of uncertainty	Spatial-temporal modeling	Temporal modeling
Magnitude of uncertainty	High	High
Implementation		
Sources of uncertainty	Political will to initiate Regulation structure Enforcement	Political will to initiate Regulation structure Enforcement
Magnitude of uncertainty	High	High

locations and sizes needed to reduce fishing mortality to levels comparable to those currently sought through reductions in catch or effort may not be as easy to achieve.

In the end, the panel finds that identifying one of these approaches as being more precautionary than the other may be premature, strictly in terms of fishery management. Taking a broader set of factors into account, such as stabilizing trophic structure or preserving biodiversity, may tip the weighted risks and benefits in favor of utilizing a marine reserve. This forces us again to consider a broader set of goals and objectives with regard to managing these systems, and these must be clearly specified for each case prior to the debate over which mix of management procedures to consider.

(6) What monitoring actions are needed to evaluate the use of marine reserves as fishery management tools?

Monitoring and evaluating the ecological and socioeconomic impacts of marine reserves are essential aspects of the process of creating and implementing these spatial management tools. A monitoring plan should be developed during the design phase for the marine reserve and should clearly reflect its objectives.

The panel finds that any monitoring program should be based on clearly measurable and verifiable performance criteria or indicators that reflect reserve objectives and consider both socioeconomic and ecological aspects. Fishers and other interested groups should be involved in the selection of the performance indicators, as well as in the design and implementation of the monitoring program. We note that fishers can play a special role in data collection, assisting with the need for high resolution, spatially-oriented information.

The designers of the marine reserve must agree on the characteristics and timeframe of “success” as reflected by the measurable performance indicators. Management decisions and adaptations will follow from the monitoring plan and the evidence offered by the performance indicators. We note further, particularly in the context of federal legislation, that a variety of management alternatives to the proposed closures must be evaluated for their ability to meet biological objectives and all ten of the national standards under the Magnuson-Stevens Fishery Conservation and Management Act.

Performance indicators must embody the objectives of the marine reserve and should evaluate short- and long-term, positive and negative socioeconomic and ecological effects. They must consider the internal and external effects of the reserve. Economic indicators should attempt to quantify both market and non-market values and attempt to isolate benefits and costs to different users, e.g. displacement of effort; changes in fleet size, target species, and overall income. Ecological indicators must reflect both spatial and temporal changes in appropriate parameters, e.g. species and genetic diversity, abundance, biomass, and age structure. All indicators must be quantifiable and scientifically rigorous.

The monitoring plan should be linked to a broader research program that will address key uncertainties and causal linkages. The panel recommends that such a research program must embody careful experimental designs with control and replication experiments that recognize the limitations of "Before-After-Control-Impact" designs, as well as correct for potential effects due to displaced effort and export and or spillover to areas outside of the reserves.

We have been hampered in evaluating the use of marine reserves as a tool for fishery management by the lack of experiments explicitly designed to address reserve effects on fisheries. We have instead evaluated closures and marine reserves—often in ad hoc or crisis situations—the effects of which in these contexts is confounded and difficult to evaluate. Reserves show enough promise as fishery management tools to justify the explicit development of experiments to directly evaluate their effectiveness.

Conclusions

Marine reserves, areas of the ocean completely protected in perpetuity from all extractive and destructive activities, should be considered in the broader context of the development of ecosystem-based management for the Exclusive Economic Zone of the United States. From that perspective, marine reserves have clear application for meeting objectives for ecosystem conservation and protection of marine biodiversity in addition to whatever benefits they may have for achieving fishery management objectives. Furthermore, marine reserves are a category of area management options—including less restrictive and less permanent alternatives—that may be used in order to achieve ecosystem- or species-based management objectives.

With regard to fishery effects, many studies of marine reserves and other area closures, most of which are from lower latitudes, have now shown that fishery target species increased in abundance and their age structure expanded within the closed area in a preponderance of cases (the so-called “reserve effect.”). This is particularly the case where the resource species are significantly overfished. Evidence for effects outside closed areas, either by movement of adults across the reserve boundaries (“spillover”) or larval “export” is more limited and effects on stocks within larger regions can only be deduced by models at this point. This is because of the limited size and duration of existing reserves and inherent difficulties in measuring and interpreting such broader effects. Reserves show enough promise as fishery management tools to justify the explicit development of experiments to directly evaluate their effectiveness. More sophisticated modeling and analysis is required for better understanding of spatial movement rates, export of reproductive products, and adaptations by fishers.

Marine reserves clearly offer some advantages for simultaneously incorporating habitat protection and maintenance of ecosystem structure and function within the protected area. They may offer some advantages for multi-species management and as a hedge against environmental surprise or management failure in contrast to other precautionary fisheries management approaches, but these have not yet been empirically demonstrated and are likely to be context-specific.

Marine reserves are most likely to be an effective management tool for relatively sedentary species with broad larval dispersal, which are recruitment limited, and for mobile species with high site fidelity. They may also be effective for protecting rare habitats vulnerable to human disruption or in protecting aggregations of animals (e.g., when spawning), when exploited populations have been severely depleted, or where bycatch is high. Closed areas may also be useful in achieving broad demographic representation in spawning populations if large animals have limited movement potential relative to reserve boundaries, and when they can maintain populations of highly fecund, older females with strong reproductive potential. They may be more feasible to implement either when reduced yields have already restricted fishing activities and other management measures have been ineffective or when they address special needs within otherwise productive regions.

Marine reserves and other protected areas should be integrated with existing and emerging management measures as part of a coherent ecosystem-based approach to management of commercial and recreational fisheries and should not be simply layered over existing regulations. In general, the coupling of quotas or effort control with protected areas will likely produce more benefits to stocks and help foster the economic conditions that encourage such conservation approaches. Careful consideration of the effects on allocation of resources among users, displacement of fishing activity, the requirements for surveys and stock assessment, and the costs of monitoring and enforcement should be made in considering protected area options and design.

The Panel found it difficult to limit its considerations to marine reserves as strictly defined, i.e. areas permanently protected from all extractive activities. We found that management actions need to be openly evaluated against stated goals and where goals are not being met changes in management must at least be considered. The design requirements for marine reserves depend heavily on the environmental context and specific management goals, including the overriding goal of sustainability and high yields of economically important species. Management goals should be clear, objectives measurable and scientifically verifiable, and plans adaptable if objectives are not met. Development of the design should involve stakeholders at the outset, identify specific performance outcomes, and include sufficiently rigorous monitoring and assessment. Because most reserves would be intended to address multiple conservation, species-specific, and user goals, designs will require clear optimization procedures that do not unduly compromise key goals. Moreover, designs will have to take into account the regional network perspective in which the proposed specific reserve is included.

There are numerous uncertainties associated with our understanding both of important biological and socioeconomic processes and with monitoring, analysis, prediction, and implementation of all fishery management approaches. Although these uncertainties may be different between marine reserves and conventional management approaches, in general they are no greater for marine reserves and in some respects may be lower. Some important uncertainties for marine reserves include the degree of effective dispersion and reproductive seeding and the ability to resolve spatial and temporal interactions in monitoring and modeling.

Monitoring and evaluating the ecological and socioeconomic consequences of marine reserves is essential in this stage of their development as an ecosystem-based management tool. Monitoring should assess indicators of the performance outcomes included in the reserve design that support evaluations of “success” and subsequent adaptive management. Robust experimental design will be critical in order to determine the effects of displaced fishing pressures and enhancement effects on populations outside of reserves in before-after-control-impact assessments.

Research Recommendations

There are a number of specific and general areas requiring additional research if marine reserves are to assume a more important role in ecosystem approaches to fisheries management and biodiversity protection:

1. Throughout the U.S. there is limited information on bottom substrates and communities that structure fish habitats. There is a pressing need for high quality bottom mapping and assessment in order to define vulnerable habitats that might merit closure.

2. The fidelity of species to particular habitats is a major issue in designing effective areal closures. Spillover of harvestable animals requires that boundaries be established that allow some animals to range beyond the reserve, while building spawning populations within the closure area may depend on low dispersal rates. The use of modern technologies (chemical, molecular, etc.) to determine dispersal patterns and rates should be expanded.

3. While there are a number of well-documented studies of marine reserves and their effects in tropical or low latitudes, the amount of information for northern temperate and boreal systems is limited. Given that most of the high volume fisheries exist in these more poleward waters, there is a pressing need to develop a synthesis of the effects of area closures in such environments.

4. Few empirical studies, sophisticated modeling or analyses exist with which to make generalizations regarding the effects of marine reserves on spatial movement rates, particularly across reserve

boundaries; potential for export of reproductive products; and the likely behavioral adaptations by fishers (e.g., effort redistribution and its biological and socioeconomic impacts). Additionally, there are important, but unresolved, scientific questions regarding the functional value (relative productivity) of various habitat types, density-dependence at high levels of stock biomass (e.g., associated with reserve effects), and sub-stock structure within species. The Panel considers that studies of these factors represent a critical but heretofore-unmet research need.

5. Many authors have speculated that marine reserves offer more precaution (insurance) against management and scientific uncertainty than do traditional measures. At this point, this is an assertion and no studies using common definitions and metrics of precaution have been conducted. Given the importance of this issue, there is a need to conduct such work, applying biology and social science, particularly as it relates to findings from existing marine closures.

Review Panel

Don Boesch, Chair President, Center for Environmental Science, University of Maryland

http://www.umces.edu/President/

Dr. Boesch is an internationally known marine ecologist who has conducted extensive research in coastal and continental shelf environments. He has published two books and more than 60 papers on a wide range of scientific and science policy topics. He has been a member of the Marine Board and the Ocean Studies Board of the National Research Council, and he has chaired three prominent NRC committees. Dr. Boesch has also served on national advisory boards for the Department of the Interior, Environmental Protection Agency, National Science Foundation, the National Oceanic and Atmospheric Administration and the President's National Science and Technology Council.

Mike Beck, Senior Scientist, Marine Initiative, The Nature Conservancy

www.nature.org/initiatives/marine

Since 1998Mike has led several marine programs and initiatives atThe Nature Conservancy and isa research associate at the University of California Santa Cruz. Mike has trained and worked at the University of Virginia, Dauphin Island Sea Lab, Florida State University, and the University of Sydney. In his research, Mike examines factors that control the diversity and abundance of animals in seagrass, mangrove, rocky intertidal, and salt marsh habitats. He has served as a member of advisory committees for EPA, the Heinz Center, the European Union, NatureServe, and the Commission for Environmental Cooperation.

Bob Cowen, Professor and Maytag Chair of Ichthyology, University of Miami

His research has concentrated on ecology and early life history of fishes and the biological and physical oceanographic processes affecting the retention and transport of larval fishes, in terms of examining larval dynamics, population replenishment and connectivity. Dr. Cowan also worked on the reproductive and population biology of hermaphroditic (sex-changing) fishes, as well as community ecology of kelp bed systems. Recently he has focused on the role of juvenile habitat in the recruitment of fishes, population connectivity in marine fishes, and early life history dynamics of billfish.

Susan Hanna, Professor, Dept. of Agricultural and Resource Economics, Oregon State University

http://marineresearch.oregonstate.edu/assets/page_folders/faculty_page/hanna_hp.htm

Dr. Hanna teaches fishery economics, fishery management, history of fishery policy, and property rights. Her writing has focused on promoting the economic and ecological productivity of marine resources by improving management performance. She has served as a scientific advisor to the Pacific Fishery Management Council, Northwest Power Planning Council, National Marine Fisheries Service, Minerals Management Service, and National Oceanic and Atmospheric Administration. She is a member of the National Research Council's Ocean Studies Board and several NRC Committees, including the Committee to assess Pacific Northwest salmonids and the committee to Review Individual Quotas in Fisheries. She is president of the International Association for the Study of Common Property and a member of the Executive Committee of the International Institute of Fisheries Economics.

Steve Murawski, Chief, Population Dynamics Branch, Northeast Fisheries Science Center, NOAA Fisheries.

Dr. Murawski's areas of concentration are in fisheries science and management. He has led numerous stock assessment projects for the Northeast Fisheries Science Center in Woods Hole. He has direct experience with design and evaluation of large closed areas in New England.

Patrick J. Sullivan, Professor Dept. of Natural Resources, Cornell University

http://www.dnr.cornell.edu/people/faculty/profiles/sullivan.html

The dynamics of natural populations and communities is the central focus of his teaching and research. Using statistical methods, such as survey sampling, nonlinear population modeling and assessment, and spatial statistics, to observe and model the dynamics of natural systems in a quantitative way, he is particularly interested in how variation can be used to characterize natural systems, address uncertainty and determine risk in order to improve environmental management. His research has focused mainly on fisheries problems in marine and freshwater environments. These include statistical methods for population assessment and modeling, methods for data acquisition and utilization, spatial modeling of habitat and abundance, and formulating mechanisms for making better use of information in the management arena.

Daniel Suman, Professor of Marine Affairs and Policy, University of Miami

http://www.bio.miami.edu/info/ESC/suman.html

A member of the IUCN Commission on Environmental Law, Dr. Suman's research Interests include adaptability of the fishing sectors in Chile, Peru, and Ecuador to ENSO ("El Niño") climate variability, mangrove management in Latin American and Caribbean countries, and establishment of MPAs. His work places emphasis on integrating ecological, policy, economic, and legal aspects of complex resource management problems.

Presenters

Dick Allen is a New England fisherman with a 36-year commercial fishing career, in lobster, surf clam, groundfish, herring, and menhaden fisheries. He holds a BS in Natural Resource Development and MS in Marine Affairs from the University of Rhode Island. He served on the New England Fishery Management Council for 9 years, was a commissioner on Atlantic States Marine Fisheries Commission for 11 years, a member of the US Department of Commerce Marine Fisheries Advisory Committee. Most recently Allen was awarded a Pew Fellowship focusing on facilitating science-industry collaboration by introducing computer simulation models of the lobster fishery to the lobster fishing community. www.fisheryconservation.com

Jon Kurland is the Assistant Regional Administrator for Habitat Conservation with the National Marine Fisheries Service in Juneau. He oversees the Habitat Conservation Division, which carries out the agency's mandates to conserve habitats that support living marine resources. His group identifies and conserves Essential Fish Habitat (EFH) through fishery management, and provides technical advice to other agencies and the public on ways to minimize the effects of development activities on habitats that support commercially harvested fish as well as marine mammals. Before moving to Alaska in 2002, Jon was the national EFH Coordinator for NMFS in the headquarters office in Silver Spring, Maryland.

Loo Botsford is Professor of Wildlife, Fisheries and Conservation Biology at the University of California, Davis. His Research focus is the application of age, size and spatially structured population models to practical problems, usually problems in marine conservation of fisheries. Combines modeling approaches with field work to better understand critical aspects of dynamics. Retrospectiveanalyses of past data includes primarily calculations of the degree of covariability between environmental and biological variables. Has developed influential models that describe and predict the performance of marine reserves under different situations.http://wfcb.ucdavis.edu/www/faculty/Loo/BotsfordSiteFiles/BotsfordMain.html

Ken Frank is with Canada's Department of Fisheries and Oceans Bedford Institute of Oceanography. His Many years of management experience with DFO,include stock assessments of haddock fishery and evaluation of the large haddock closure in the North Atlantic. Current research focus on fisheries ecology, resource conservation, biogeographic theory, fisheries oceanography, and marine ecosystem assessment.

Arne Fuglvog is President of the Petersburg Vessel Owner's Association. A lifelong resident of Petersburg, Alaska, he has been fishing commercially since 1975, primarily longlining for halibut and sablefish, but has participated in salmon, herring and crab fisheries throughout the state of Alaska. He is a member of the North Pacific Fishery Management Council after serving 9 years on its advisory panel. Fuglevog also serves on the Research Advisory Board to the International Pacific Halibut Commission. He was named one of National Fisherman's "highliners of the year" for 2003.

Rod Fujita is a Senior Scientist at Environmental Defense. He has worked on acid rain, ozone depletion, global climate change, and protecting marine ecosystems. Fujita initiatedEnvironmental Defense's Coral Reef Project, and played a lead role in establishing the Florida Keys National Marine Sanctuary. He leads efforts to create sustainable fisheries along the Pacific coast of the U.S., in Hawaii, and in international waters. Fujita is currently working to stop overfishing and to create networks of marine reserves to increase fishery yields while protecting marine biodiversity and ecosystem health.

Mark Hixon is a Professor in the Department of Zoology at Oregon State University. He is a marine ecologist expert on coastal marine fishes, with research on mechanisms that naturally regulate populations and sustain biodiversity of marine fish. Collated research on potential fisheries benefits of existing West Coast marine reserves. Hixon serves on several advisory boards, including the MPA Federal Advisory Committee. http://oregonstate.edu/~hixonm/index.htm

Steve Palumbi is a Professor at Hopkins Marine Station of Stanford University. He has conducted research on genetics, evolution, population biology, and systematics of a diverse array of marine organisms. His major focus is genetics of marine populations in the context of marine protected areas for conservation and fisheries enhancement. Palumbi also investigates the use of molecular genetic techniques for the identification of whale and dolphin products available in commercial markets, and mechanisms of reproductive isolation and their influence on patterns of speciation and degree of genetic structure in marine systems. http://www-marine.stanford.edu/HMSweb/palumbi.html

Andy Rosenberg is a professor in the department of Life Sciences and Agriculture at the University of New Hampshire. His research focus is on marine science, marine policy, and marine fisheries. Former deputy director of the National Marine Fisheries Service, Rosenberg was a key agency policymaker and liaison to Congress, the administration, resource management partners, and the public. Implemented protection plans for marine mammals such as harbor porpoise and right whales, and endangered species like Atlantic salmon. Prior head of delegation to the North Atlantic Salmon Conservation Organization and the Northwest Atlantic Fisheries Organization, and is a member of the U.S. Commission on Ocean Policy.

Vidar Wespestad is President of Resource Analyst International. He consults in area of global marine resource assessment and serves as Chief Fisheries Scientist for the Pacific Whiting Conservation Cooperative. From 1977 to 1997 he was a fishery research biologist with the U.S. National Marine Fisheries Service and led. the Bering Sea stock assessment group at the Alaska Fishery Science Center. He is a recipient of the American Fisheries Society's Distinguished Service Award for organizing and co-chairing the First World Fishery Congress and has received fellowships from the Fishery Research Council, the Norwegian Marshall Fund, and the Rockefeller Foundation. He received his Ph.D. in fisheries from the University of Washington.

Planning Committee

Bill Eichbaum (chair), World Wildlife Fund, Washington, D.C.

Loo Botsford, University of California, Davis, California

Mike Fogarty, NOAA Fisheries, NE Fisheries Science Center, Woods Hole, Massachusetts

Steve Gaines, University of California, Santa Barbara, California

Churchill Grimes, NOAA Fisheries, SW Fisheries Science Center, Santa Cruz, California

Ben Halpern, University of California, Marine Science Institute, Santa Barbara, California

Trevor Kenchington, Gadus Associates, Musquodoboit Harbour, Nova Scotia Canada

Ralph Larson, San Francisco State University, San Francisco, California

Mark Lundsten, Queen Anne Fisheries, Seattle, Washington

Rick Methot, NOAA Fisheries, Alaska Fisheries Science Center, Seattle, Washington

Mark Powell, The Ocean Conservancy, Bainbrige Island, Washington

Steve Scheiblauer, City of Monterey Harbormaster, Monterey, California

Priscilla Weeks, Houston Advanced Research Center, The Woodlands, Texas

James Wilen, University of California, Social Sciences and Humanities, Davis, California

Lead Organization

National Fisheries Conservation Center, Brock B. Bernstein, President

Supporting Organizations

Communication Partnership for Science and the Sea, Oregon State University
National Marine Fisheries Service
National Marine Protected Areas Center

Contributors

Aquarium of the Pacific
City of Monterey Harbor
City of Morro Bay Harbor
City of Santa Barbara Waterfront
David & Lucile Packard Foundation
The Curtis & Edith Munson Foundation
The Nature Conservancy
The Partnership for Interdisciplinary Studies of Coastal Oceans
The Port Liaison Project of Oregon Sea Grant
Port San Luis Harbor
The Surdna Foundation

Bibliography

Anderson, L. G. 2002. A bioeconomic analysis of marine reserves. Natural Resource Modeling 15:311-333.

Gerber, L. R., L. W. Botsford, A. Hastings, H. P. Possingham, S. D. Gaines, S. R. Palumbi, and S. Andelman. 2003. Population models for marine reserve design: a retrospective and prospective synthesis. Ecological Applications 13(Supplement):S47- S64.

Hilborn, R., K. Stokes, J. Maguire, T. Smith, L.W. Botsford, M. Mangel, J. Orensanz, A. Parma, J. Rice, J. Bell, K.L. Cochrane, S. Garcia, S.J. Hall, G.P. Kirkwood, K. Sainsbury, G. Stefansson, and C. Walters. In press. When can reserves improve fisheries management? Ocean and Coastal Management 47(2) available online in June 2004.

Hixon, M. A. 2002. Existing small marine reserves can indicate whether a larger network is feasible: case study from the west coast of the United States. MPA News 4(3):5. Followed by full report: Fishery effects of existing west coast marine reserves: the scientific evidence. Report submitted to the Oregon Ocean Policy Advisory Council and the California Fish and Game Commission.

Holland, D. S. 2002. Integrating marine protected areas into models for fishery assessment and management. Natural Resource Modeling 15:369-386.

Pacific Fishery Management Council (PFMC). 2001. Scientific and Statistical Committee Report on Status of Marine Reserves Proposals for Channel Islands National Marine Sanctuary (CINMS).

Pomeroy, C. 2002. Effectiveness of marine reserves: Socio-economic considerations. In: Starr, R. M., M. H. Carr, J. Caselle, J. A. Estes, C. Pomeroy, C. Syms, D. A. VenTresca, M. M. Yoklavich. A Review of the Ecological Effectiveness of Subtidal Marine Reserves in Central California. Report to the Monterey Bay National Marine Sanctuary. Part I: Synopsis of Scientific Investigations, pp. 73-87.

Smith, M. D. and J. E. Wilen. 2004. Marine reserves with endogenous ports: empirical bioeconomics of the California sea urchin fishery. Marine Resource Economics 18:85-112.

Wallace, R. K. and K. M. Fletcher. 2001. Understanding fisheries management: A manual for understanding the federal fisheries management process including analysis of the 1996 Sustainable Fisheries Act. 2nd edition. Mississippi-Alabama Sea Grant Consortium, Publication 00-005.

Ward, T. J., D. Heinemann, and N. Evans. 2001. Table 4: Potential fishery benefits of marine fisheries sanctuaries that are not restricted to areas inside or outside a sanctuary. In: The role of marine reserves as fishery management tools: a review of concepts, evidence, and international experience. Bureau of Royal Sciences, Canberra, Australia. 192 pp.

National Fisheries Conservation Center
308 Raymond Street
Ojai, California 93023
805 646-8369
http://www.nfcc-fisheries.org

nfcc national fisheries conservation center

Ecological Applications, 8(1) Supplement, 1998, pp. S72–S78

IMPLEMENTING THE PRECAUTIONARY PRINCIPLE IN FISHERIES MANAGEMENT THROUGH MARINE RESERVES

TIM LAUCK,[1] COLIN W. CLARK,[1,4] MARC MANGEL,[2] AND GORDON R. MUNRO[3]

[1]*Department of Mathematics, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z2*
[2]*Environmental Studies Board, University of California, Santa Cruz, California 95064 USA*
[3]*Department of Economics, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z1*

Abstract. Overexploitation of marine fisheries remains a serious problem worldwide, even for many fisheries that have been intensively managed by coastal nations. Many factors have contributed to these system failures. Here we discuss the implications of persistent, irreducible scientific uncertainty pertaining to marine ecosystems. When combined with typical levels of uncontrollability of catches and incidental mortality, this uncertainty probably implies that traditional approaches to fisheries management will be persistently unsuccessful. We propose the use of large-scale protected areas (marine reserves) as major components of future management programs. Protected areas can serve as a hedge against inevitable management limitations, thus greatly enhancing the long-term sustainable exploitation of fishery resources. Marine reserves would also provide an escape from the need of ever more detailed and expensive stock assessments and would be invaluable in the rehabilitation of depleted stocks.

Key words: bet hedging; controlling overexploitation; diversification; fisheries; irreducible scientific uncertainty; marine protected areas; marine reserves; precautionary principle in fisheries; risk aversion.

INTRODUCTION

In 1982, the United Nations (U.N.) Third Conference on the Law of the Sea closed and formally ushered in a new era in world fisheries management through the Law of the Sea Convention (United Nations 1982). Under the Convention, coastal states throughout the world were enabled to extend their management jurisdiction over fishery resources from 12 to 200 (22.2 to 370.4 km) nautical miles. It was estimated that 90% of the harvests of marine fishery resources would be accounted for by resources encompassed by the coastal state 200-mile (370.4-km) zones—Exclusive Economic Zones (EEZs; Kaitala and Munro 1995). The objective in establishing the EEZ regimes was to enhance the conservation and economic management of world marine fishery resources. In 1980, a Food and Agricultural Organization of the United Nations (FAO) publication, in anticipation of the EEZ regime, stated that: "the opportunity exists, as never before, for the rational exploitation of marine fisheries. . . . The 1980s provide the threshold for a new era in the enjoyment of the ocean's wealth in fisheries" (cited in United Nations Food and Agriculture Organization 1992).

The hopes and expectations of the early 1980s have not been realized. The same FAO recently reported that "69% of the world's marine [fish] stocks . . . are either fully to heavily exploited, overexploited, depleted . . . and therefore are in need of urgent conservation and management measures" (United Nations Food and Agriculture Organization 1995). Coastal state fishery management programs have proven, in far too many instances, to be seriously deficient.

One of the most dramatic and depressing examples of fishery management failure under the EEZ regime is provided by the large and extremely productive groundfish resources on the famous Grand Banks of Newfoundland, which constituted Canada's main bonanza under the EEZ regime. These resources had been overexploited while international common property. Under conservative Canadian management, it was hoped that fish stocks would be rebuilt, to the benefit of the Canadian fishing industry. The single most important of these resources, a cod stock complex extending from southern Labrador to southeastern Newfoundland, popularly known as Northern cod (*Gadus morhua*), was expected to yield sustainable annual harvests of 4×10^8 kg by the late 1980s (Canada 1983).

These sustainable harvests were not achieved. In the late 1980s, the Canadian government introduced drastic cuts in the Northern cod total allowable catches (TACs). The drastic TAC cuts were not enough. In 1992, the Canadian authorities felt compelled to impose a temporary 2-yr harvest moratorium on Northern cod.

Manuscript received 20 February 1996; accepted 15 December 1996; final version received 13 February 1997. For reprints of this Special Issue, see footnote 1, p. S1.
[4] Address correspondence to this author.

The authorities were horrified to find that the resource continued to decline after the moratorium had been imposed. The harvest moratorium still remains in place (in 1996) and has ceased to be temporary. It is now indefinite. To compound the misery, the Canadian authorities have had to impose harvest moratoria on several neighboring groundfish stocks.

The causes of the fishery resource collapse off Atlantic Canada are now the subject of an intense debate (Myers et al. 1997). What is clear is that the collapse came as a stunning shock to the authorities. One commentator remarked that the resource collapse would have had no credibility as a worst-case scenario, even a few years prior to the imposition of the moratorium (Roy 1996). What is equally clear is that the management of even seemingly stable fishery resources, such as groundfish, is subject to a far greater degree of uncertainty than heretofore had been realized and appreciated (Gordon and Munro 1996).

Standard Prescriptions for Correcting Management Failures

Suggestions for improving the management of marine fisheries have not been in short supply. We will not review here the long history of discussion of the "problem of overfishing," but will concentrate instead on the implications of uncertainty in fisheries management.

We take as an underlying assumption that fishery declines and collapses result in large part from overfishing, that is to say, from a level of fishing intensity that is excessive in terms of maintaining a sustainable population and fishery. We nevertheless recognize that changes in the marine environment are also often involved in the decline or collapse of any particular fishery. Levels of catch that may be sustainable under normal or favorable environmental conditions may prove not to be sustainable under abnormal conditions. Many fish populations that have suddenly collapsed under intensive exploitation had presumably persisted for thousands of years in spite of fluctuations in the marine environment. The parsimonious assumption is, therefore, that fishing decreased the resilience of these populations, rendering them more vulnerable to environmental change. From our perspective, this still constitutes overfishing.

Environmental fluctuations are but one of many sources of major uncertainty in fisheries. It is now widely accepted that management must somehow allow for uncertainty and potential inaccuracy in projected sustainable catch levels. It is our contention in this paper, however, that the full implications of uncertainty have not been recognized in the design and implementation of fisheries management strategies. This shortcoming, we believe, has been a major factor in the decline and collapse of many fisheries.

It is often suggested that uncertainty could be reduced if more research were to be undertaken. For example, increased stock assessment activity should keep management informed as to the current population size and its changes over time. While no one can dispute the need for stock assessment, it must be recognized that it is often very costly and that the estimates of stock abundance are almost always subject to considerable uncertainty. Many fish populations have become severely depleted before clear signals have appeared in the stock estimates. Fish stock assessment is now a highly developed and sophisticated science, but it is doubtful whether the levels of uncertainty can be greatly reduced by further refinements of technique. Fisheries science can and doubtlessly will continue to improve, but management decisions must depend on currently available methodology.

Accepting the inevitability of errors in sustainable catch estimates, fishery biologists have recently adopted management criteria that presumably err on the side of caution, a common example being the so-called $F_{0.1}$ criterion widely used in Canada and elsewhere. ($F_{0.1}$ is defined as the level of fishing mortality F at which the slope of the yield-per-recruit curve equals 0.1 times the slope at $F = 0$.) This criterion is more conservative than the maximum sustained yield criterion formerly favored, and as such allows for some degree of error.

But is the $F_{0.1}$ criterion sufficiently conservative? Walters and Pearse (1995) calculated that the $F_{0.1}$ value used in the Northern cod fishery, namely $F_{0.1} = 0.2$, would have to be reduced by 50%, to $F = 0.1$, in order to incorporate even a moderate degree of risk aversion in that fishery. ($F = 0.1$ means that 10% of the stock would be taken each year.)

Recommendations of this kind are based on the principle of erring on the side of caution, whether by maintaining catch levels or fishing mortality below estimated Maximum Standard Yield (MSY) levels, or maintaining stocks above the estimated MSY level (Roughgarden and Smith 1996). In essence these prescriptions are equivalent. Provided that such objectives can be reliably achieved in practice over the long term, sustainable fisheries will result. The question then becomes one of method and degree: how great a safety margin should be allowed, and which methods of management are most likely to achieve the objective of sustainable fisheries? For example, suppose that in a certain fishery stock estimates are considered valid to within $\pm 30\%$, that annual productivity varies unpredictably over a range of $\pm 50\%$ from the mean, and that fishing plus incidental mortality varies within $\pm 25\%$ of the TAC. In the worst-case scenario, stocks are 30% below the mean estimate, productivity is 50% below the mean, and fishery-induced mortality is 25% greater than the TAC. To ensure sustainability, the TAC should then be set at 28% of the mean estimated value (this does not allow for any stock rehabilitation in the event that the stock is, in fact, below the mean estimate).

Such a safety margin may seem extreme. Indeed, the industry might argue in favor of the best-case scenario, with a TAC equal to 244% of the mean estimate. From this point of view, the original mean estimate TAC doesn't seem so bad, yet it is undeniably fraught with risk. This fanciful, but perhaps not quantitatively unrealistic illustration, raises several interesting issues. What levels of uncertainty exist in particular fisheries? How much can these uncertainties be reduced by additional research, or by tighter control of fishing operations? What is an appropriate safety margin? Will episodes of overfishing and underfishing balance out over the long run? Do estimation errors tend to be unbiased, in retrospect, or are worst cases more common than best cases? We know of no literature addressing such questions, which seem fundamental for the transition to sustainable fisheries when managed by traditional methods based on catch or effort quotas.

Uncertainty and Unknowability in Complex Systems

In this era of scientific wonders it is hard to avoid the "world view" of science as being ultimately capable of fully revealing and understanding the complexities of nature. This view is encountered frequently in fisheries in terms of recommendations for more scientific research into the functioning of marine ecosystems. Thus, we are repeatedly admonished to graduate from single-species fisheries models to multispecies or full-ecosystem models, presumably represented as computer code. That the data requirements needed to validate any such model are vastly beyond our current capacity is seen only as the result of insufficient research funding.

An alternative, and we believe much more realistic view, is that there are limitations, both practical and theoretical, to what science can accomplish (Mangel et al. 1996). Full understanding and predictability of anything as complex (and, we should add, as unobservable) as a marine ecosystem will forever remain a chimera. The implications seem obvious. Progress in fisheries management will now proceed most rapidly, not from vastly increased research effort in marine biology, but from research into ways to deal with this irreducible uncertainty, or as it might be called, unknowability. This is a topic that has hardly ever been studied in the fisheries literature, to our knowledge, so that progress might be quite rapid.

Fisheries managers (whether individuals or committees) are regularly faced with the problem of setting catch quotas on the basis of current information. They may be quite aware of the fact that this information is incomplete, so that sustainable catch levels cannot be determined with a high degree of certainty. But how are the managers to take this uncertainty into account? Should they simply ignore it and base quotas on the "best scientific estimates" currently available? Our perception is that most management decisions are made in this way—and with good reason. Any admission of uncertainty only encourages the fishing industry to demand quotas at the upper limit of the confidence interval, on the grounds that science has not "proved" that lower quotas are necessary.

This approach would perhaps be workable if the system were self correcting, in the sense that excessive quotas in one year would have immediately detectable effects on the fish population, leading to reduced quotas in the next year. The truth is that overfishing, unless it is extreme, often takes years to detect. Moderate overfishing may lower the resilience of the population, but the impending collapse cannot be predicted from the available data. Also, reductions in quotas are always politically difficult to achieve, especially given the all but universal tendency towards overcapitalization in commercial fisheries.

In addition to these biases, actual fishing mortality often greatly exceeds the targeted level, from a variety of causes including unreported catches, by-catches, discards of small fish, and incidental mortality. Moreover, the productivity of marine ecosystems may be disrupted to an unknown extent as the result of habitat damage by fishing gear, or from pollution, as well as from the capture of species that serve as food for other commercial species. Little if any of this incidental impact is quantifiable in any scientific sense.

Given all these sources of uncertainty, error, and bias, is it any wonder that valuable fish populations continue to disappear at an alarming rate? What, if anything, can be done to reverse the trend?

Biological and Economic Responses to Uncertainty: Bet Hedging

Both the world of biology and that of economics possess a variety of techniques for dealing with uncertainty. Of particular interest in the fisheries context is the use of "bet hedging" strategies in biology and economics.

Bet hedging is a form of diversification of activities, having the purpose of reducing risk through pooling or averaging of (at least partially) independent random events. In biology, various types of reproductive strategies are thought to constitute bet hedging in uncertain environments (Seger and Brockmann 1987, Yoshimura and Clark 1993). Examples include multiple episodes of reproduction (iteroparity), dispersal of progeny, and delayed germination of seeds. At the population level, metapopulation structures may increase the chances that a species will survive in spite of local extinctions (Pulliam 1988).

In the financial world, bet hedging can be observed in the common practice of portfolio diversification, and also in the purchase of accident and liability insurance. Both of these practices serve to reduce the risk of a severe loss of financial assets. Bet hedging is usually thought to involve a cost, or "premium," in terms of a decrease in expected benefits, which is accepted in order to achieve a reduction in risk.

Bet Hedging in Fisheries: Protected Marine Reserves

How can fisheries management strategies be redesigned so as to include a bet hedging component? The risk that is to be avoided, of course, is a collapse or severe decline in the fish population as a result of overfishing.

The current "world view" of fisheries management is that every commercially valuable stock should be exploited at the optimal level. Given the large uncertainties and biases of management, overfishing of every stock seems almost predetermined. This practice, clearly the opposite of bet hedging, suggests what a bet-hedging management strategy would consist of: different stocks, or substocks, would be managed in different ways.

The simplest way to diversify the management of a given fishery resource would be to exploit part of the resource while protecting the remainder. We therefore propose that Protected Marine Reserves (sometimes called Marine Protected Areas, or "no-take" areas; Shackell and Willison 1995) should become an integral component in the management of all marine fisheries. The actual design and implementation of marine reserves would depend on what is known about the biological characteristics of each particular species or species complex. For the purposes of discussion, we will here consider the case of a demersal species inhabiting a large area of the ocean floor. The design of marine reserves for highly migratory species will obviously involve additional complications.

Desirable features of a program of Protected Marine Reserves are:

1) The area included in the reserve should be large enough to protect the resource in the event of overfishing in the unprotected area. Several mathematical models (see Appendix) suggest that reserves need to include up to 50% of the original population in order to hedge successfully against overfishing.

2) The reserve area should serve as a "source" (in the sense of metapopulation theory: Pulliam 1988) capable of replenishing the exploited stock in the event of its depletion (Brown and Roughgarden 1995). In particular, reserves should protect spawning grounds and other areas critical to the viability of the population.

3) The reserve areas should be rigorously and completely protected. Typically, reserve areas will contain greater concentrations of fish than exploited areas, making them prime targets for poaching. As in terrestrial reserves, poaching must be treated as a criminal activity.

Protected marine reserves would provide benefits over and above protection of the resource. In general terms, reserves would preserve marine biodiversity by protecting intact marine ecosystems. They would also facilitate scientific research, in that the unexploited area would play the role of a control in the "experiment" of fishing (Lindeboom 1995).

Problems of Reserve Design

Many practical issues will arise in the design of marine reserves. How large should the reserve be and where should it be located? Should there be one large, or several small protected areas? Should the reserve be tailored for individual species, or for the protection of an entire marine ecosystem? Economic as well as biological aspects may influence reserve design. For example, a large reserve encompassing traditional fishing grounds may unfairly affect local fishing communities. Fragmented reserves may have fewer economic impacts, but may be less effective and more difficult to manage than one or two larger reserves. Reserves should be permanent, but this requirement will have to be balanced with the need for flexibility in reserve design. Because of the very uncertainties that underlie the need for reserves, the concept of an "optimal" reserve may be meaningless. As in other instances of bet hedging, adopting a diversified strategy is the important step; the exact allocation of total assets to different types of investment is then largely a matter of judgment.

Comparison of Protected Reserves with Other Strategies

Protected marine reserves are not at present a common component of fisheries management programs. Indeed, many fisheries biologists behave as if they consider reserves as unnecessary or unworkable. Others have asserted that reducing catch or effort levels would have the same effect as a reserve. This claim is erroneous and can only arise from a misunderstanding of the role of uncertainty and uncontrollability in fisheries management.

Opening the entire population to exploitation exposes it to the risk of depletion, even if inadvertent. While it is obviously true that this risk would be reduced with reduction of the allowable catch, the uncertainties and biases associated with setting quotas and determining actual fishing mortality imply that the fishery would probably remain vulnerable unless the quotas were set far below the "best point estimates." As noted, target fishing mortality in the Northern cod fishery should have been reduced from 0.2 to 0.1 if even a moderate degree of risk aversion were to be included. Given that actual fishing mortality often exceeded the targeted value by up to 200% (Myers et al. 1997), even this unheard-of reduction might not have been sufficient to save the cod fishery. In any event, achieving a given target fishing mortality, whether 0.2

or 0.1, has two critical prerequisites: first, stock assessments must be accurate and up-to-date, and second, all sources of fishing mortality must be accurately accounted for. As we have already noted, often neither of these prerequisites holds true.

Other management practices, such as mesh or other gear restrictions, may also reduce the risk of overfishing, but, like reductions in catch quotas, they do not amount to a diversification of management strategy, but only to a switch to an apparently more conservative strategy. The possibility of biases, errors, and excessive catch rates remains in effect under such restrictions.

An important aspect of bet hedging is that risk reduction can be achieved at minimal cost, and our models suggest that this may be true for reserves. For example, placing 50% of a population's natural marine habitat into a reserve does not necessarily imply a 50% reduction in long-term catches, particularly if the reserve is highly productive and operates as a source. Also, because of the safety aspect of the reserve, the exploited area probably can be fished somewhat more intensively than would be desirable in the absence of the reserve.

Maintenance and protection of marine reserves will incur certain costs. If successful, the reserve areas would contain higher concentrations than the exploited areas. In addition, fish inside the reserve would tend to be larger. Poaching would therefore be especially attractive in the short term. It might be argued that reserves would interfere with economic efficiency (Walters and Pearse 1995), but reducing the risk of collapse by maintaining an adequate reserve has to be weighed against the short-term gains of "creaming the top" off the reserved stocks. It is certainly clear that reserve areas would need to be rigorously policed to prevent poaching; present satellite technology would make it easy to accomplish the necessary monitoring.

A Model of Uncertain Harvests

It is probably not useful to attempt developing a general model of marine protected areas, given the great variety of marine ecosystems and conceivable management regimes. To illustrate our ideas, we model a single harvested stock that grows according to a discrete logistic (Ricker) equation. Thus, in the absence of harvest, the stock in year t, $N(t)$, and the stock in year $(t + 1)$, $N(t + 1)$ are related by:

$$N(t + 1) = N(t)\exp\left[r\left(1 - \frac{N(t)}{K}\right)\right] \qquad (1)$$

where r and K have the usual interpretations. In particular, K is carrying capacity, in the sense of a stable steady state, and e^r is maximum per capita growth rate of the population. The role of a reserve is to prevent part of the stock from being harvested. In particular, we assume that a fraction A of the area in which the stock exists is available for harvesting and that the

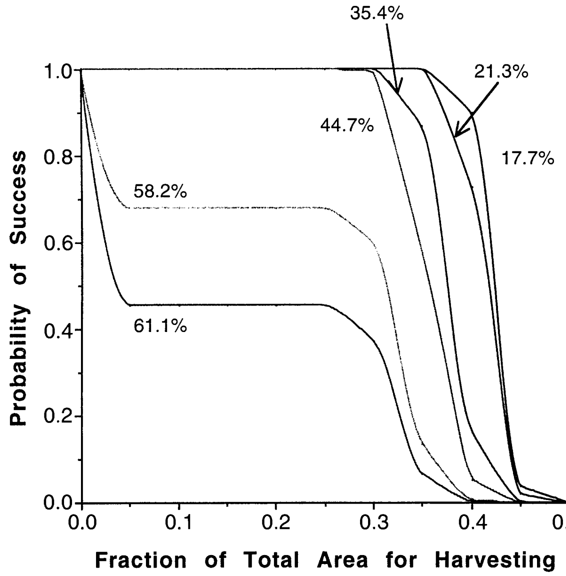


FIG. 1. The probability that the stock [$N(t)$] remains $>0.6K$ for a 20-yr time horizon, as a function of the fraction A of area available for harvesting, for six different coefficients of variation in the harvest distribution. The model assumes that $N(1) = K$ and uses beta distributions for the harvest, all with the same mean, 0.5.

harvest fraction in this area is targeted at u. However, we assume that the target harvest is uncontrollable. This lack of controllability is captured by assuming that the harvest fraction has a probability distribution. We further assume that the mean of the distribution is fixed at the target harvest fraction, but that the actual harvest varies about this mean.

As a criterion for successful management, we assume that the stock starts at carrying capacity and consider the probability that it remains >60% of carrying capacity over a time horizon of T yr. The notion of maintaining the stock $>0.6K$—which puts it in the so-called "Optimal Sustainable Population" region—appears in legislation such as the U.S. Marine Mammal Protection Act (MMPA) of 1972 (16 U.S. Code 1361 et seq., Publ. L. 92-522, as amended) and Magnuson Fishery Management and Conservation Act (16 U.S. Code 1801 et seq., amended 104 Congress, 'Sustainable Fisheries Act').

In the Appendix, we show how the probability of successfully achieving this goal can be computed. For computations, we used $r = 0.5$ (so that this is in the non-chaotic regime of the stock dynamics), $K = 80$, and $T = 20$. We used six different frequency (beta) distributions of catch, each with a mean of 0.5 (so that half of the animals in the harvested region are captured on average) and with coefficient of variation (CV = standard deviation of the harvest fraction/mean of the harvest fraction) ranging from ~18% to ~61%.

The results (Fig. 1) are striking. Even when the CV is moderate (say, <50%), the chance of success drops

TABLE 1. Fraction (A) of the fishing ground available for harvest to ensure a given level of protection for 40 yr, and the associated expected total catch (C) (see Appendix).

Mean harvest rate†	Level of stock protection 95%		99%	
	A	C	A	C
0.5	0.304	13.12	0.271	11.82
0.4	0.367	12.71	0.347	12.11
0.3	0.472	12.30	0.443	11.62
0.2	0.686	11.93	0.634	11.14

† CV = 50%.

rapidly from 1 once the fraction of the total area available for harvesting becomes greater than ~30%. When the CV is larger, the result is even more impressive: even at very low areas available for harvest (5%), the chance of success is <1. That is, a strategy that is very conservative on average is still likely to fail if it is too difficult to control.

We also experimented with unknowable carrying capacity. Interestingly, the results are not nearly as striking, as long as the carrying capacity is not too far off. Other models (J. Roughgarden, *personal communication*) have also shown this effect.

One conceivable alternative to a reserve is simply to lower the catch level. For example, if the mean catch is 10% of the stock, with a 50% CV, then there is >99% probability of keeping the stock $>0.6K$ for a 40-yr time horizon. The problem, of course, is that catch suffers. The methods described in the Appendix allow us to determine the size of reserve required to ensure a given level of stock protection and the catch associated with that reserve size. Typical results are shown in Table 1.

Two important points emerge from this table. First, a reserve can simultaneously lead to stock protection and a higher level of catch. For example, at a 95% level of stock protection over the 40-yr time horizon, a reserve of 70% of the potential fishing ground and a catch rate of 0.5 both protects the stock and gives an expected catch that is nearly 50% larger than the expected catch if the mean catch rate were reduced to 0.1 and the entire fishing ground fished. Second, it is possible to maximize catch while protecting the stock. For example, at a 99% level of protection, a mean catch rate of 0.4 provides slightly better expected catch than any of the alternatives.

We thus conclude that a system based on reserves may simultaneously provide protection of the stock and a higher long-term catch by allowing greater intensity of fishing in the fraction of the potential fishing ground in which fishing is allowed.

Finally, and not obvious from the figures or tables but consistent with our notions of fundamental uncertainties, the reserve provides insurance against errors in the model. That is, any real stock is managed with estimates of growth rates and carrying capacities. Furthermore, actual mean catches may exceed targeted values. A protected reserve provides a buffer against many of these uncertainties, without necessarily leading to great reductions in catch.

DISCUSSION

Widespread concern has been expressed over the failure to manage the world's ocean fisheries in a sustainable way, in spite of the opportunities provided by the 1982 Law of the Sea, and by EEZs. Recent conferences with titles such as "Re-inventing Fisheries Management" (held in Vancouver, British Columbia, Canada in February 1996) and "Ecosystem Management for Sustainable Marine Fisheries" (held in Monterey, California, USA, in 1996) attest to the desire for new approaches that would improve the dismal record. The most important component now needed is an operational admission of the limitations of science in comprehending and controlling as complex and unobservable a system as the marine environment.

Novaczek (1995) lists eight important advantages of Marine Protected Areas (MPAs). She says that MPAs can be used:

1) to protect biomass and population structure of commercial species,
2) to limit by-catch of juveniles,
3) to protect ocean biodiversity,
4) to protect essential life stages of commercial species,
5) to protect and enhance productivity,
6) to provide a location for marine research,
7) to protect artisanal and community fisheries, and
8) to enhance public education and encourage nondestructive enjoyment of the sea.

We would only add that MPAs can serve to hedge against inevitable uncertainties, errors, and biases in fisheries management. Marine Protected Areas (or as we have called them, simply, protected reserves) may well be the simplest and best approach to implementing the precautionary principle and achieving sustainability in marine fisheries.

LITERATURE CITED

Brown, G., and J. Roughgarden. 1995. An ecological economy: notes on harvest and growth. Pages 150–189 *in* C. Perrings, K.-G. Maler, C. Folke, C. S. Holling, and B.-O. Jansson, editors. Biodiversity loss: economic and ecological issues. Cambridge University Press, Cambridge, UK.

Canada. 1983. The Task Force on Atlantic Fisheries, Report. Supply and Services Canada, Catalogue Number CP32-43/1983. Ottawa, Ontario, Canada.

Gordon, D. V., and G. R. Munro, editors. 1996. Fisheries and uncertainty: a precautionary approach to resource management. University of Calgary Press, Calgary, Canada.

Kaitala, V., and G. Munro. 1995. The management of transboundary resources and property rights systems: the case of fisheries. Pages 69–84 *in* S. Hanna and M. Munasinghe, editors. Property rights and the environment. Beijer International Institute of Ecological Economics and the World Bank, Washington, D. C., USA.

Lindeboom, H. J. 1995. Protected areas in the North Sea: an absolute need for future marine research. Helgoländer Meeresunters **49**:591–602.

Mangel, M., et al. 1996. Principles for the conservation of wild living resources. Ecological Applications **6**:338–362.

Martz, H. F., and R. A. Waller. 1982. Bayesian Reliability Analysis. John Wiley and Sons, New York, New York, USA.

Myers, R. A., J. A. Hutchings, and N. J. Barrowman. 1997. Why do fish stocks collapse? The example of cod in Atlantic Canada. Ecological Applications **7**:91–106.

Novaczek, I. 1995. Possible roles for marine protected areas in establishing sustainable fisheries in Canada. Pages 31–36 *in* N. L. Shackell and J. H. M. Willison, editors. Marine protected areas and sustainable fisheries. Centre for Wildlife and Conservation Biology, Acadia University, Wolfville, Nova Scotia, Canada.

Pulliam, H. R. 1988. Sources, sinks and population regulation. American Naturalist **132**:652–661.

Roughgarden, J., and F. Smith. 1996. Why fisheries collapse and what to do about it. Proceedings National Academy of Sciences USA **93**:5078–5083.

Roy, N. 1996. What went wrong and what can we learn from it? Pages 15–26 *in* D. V. Gordon and G. R. Munro, editors. Fisheries and uncertainty: a precautionary approach to resource management. University of Calgary Press, Calgary, Canada.

Seger, J., and J. Brockmann. 1987. What is bet-hedging? Oxford Surveys in Evolutionary Biology **4**:182–411

Shackell, N. L., and J. H. M. Willison, editors. Marine protected areas and sustainable fisheries. Centre for Wildlife and Conservation Biology, Acadia University, Wolfville, Nova Scotia, Canada.

United Nations. 1982. Convention on the Law of the Sea. United Nations Document A/Conf.61/122.

United Nations Food and Agriculture Organization. 1992. Marine Fisheries and the Law of the Sea: a decade of change. U. N. Food and Agriculture Organization Fisheries Circular Number 853, Rome, Italy.

———. 1995. The state of world fisheries and aquaculture. Rome, Italy.

Walters, C. J., and P. H. Pearse. 1996. Stock information requirements for quota management systems in commercial fisheries. Reviews in Fish Biology and Fisheries **6**:21–42.

Yoshimura, J., and C. W. Clark, editors. 1993. Adaptation in stochastic environments. Lecture notes in biomathematics. Volume 98. Springer-Verlag, Berlin, Germany.

APPENDIX

In this appendix, we provide details for the computation of the success probability for the model of a stock growing according to the discrete logistic equation with unknowable harvest. We also clarify the assumptions used in the calculation.

Assume the size of the stock in the current year is $N(t)$. If the reserve fraction is $1 - A$, then the stock size on the reserve:

$$N_r(t) = (1 - A)N(t) \tag{A.1}$$

is untouched. The stock available for fishing is

$$N_f(t) = AN(t) \tag{A.2}$$

and a fraction u of this stock is harvested. Thus, the total stock remaining after fishing is

$$\begin{aligned} N_r(t) + (1 - u)N_f(t) &= (1 - A)N(t) + (1 - u)AN(t) \\ &= (1 - uA)N(t). \end{aligned} \tag{A.3}$$

We assume that this stock is well mixed over the combined reserve and fishing areas in order to determine the stock size in the next year. That is, the reserve boundaries are set for harvesting but the stock moves smoothly across the boundary and fills the entire fishing ground.

Define the probability of success by

$$p(n, t) = \Pr\{N(s) > n_c \text{ for } t < s \le T \,|\, N(t) = n\}. \tag{A.4}$$

Here, $n_c = 0.6K$ is the critical level and T is the length of time over which we focus protection.

This function can be evaluated by a dynamic iteration equation. At $t = T$,

$$p(n, T) = \begin{cases} 1 & \text{if } n > n_c \\ 0 & \text{otherwise.} \end{cases} \tag{A.5}$$

If the stock at the start of the fishing season in year t is n, then the size of the stock at the end of the fishing season is $n_u = (1 - uA)n$ and the stock at the start of the next season will be $n_u f(n_u)$, where $f(n_u) = \exp(r(1 - n_u/K))$. Consequently,

$$p(n, t) = E_u\{p(n_u f(n_u), t + 1)\} \tag{A.6}$$

where E_u denotes the expectation over the distribution on the harvest rate.

One can also compute the total catch this way by defining

$$c(n, t) = E_u\left\{\sum_{s=t}^{T-1} u(s)AN(s)\right\} \tag{A.7}$$

so that $c(n, T) = 0$ and

$$\begin{aligned} c(n, t) &= E_u\{Aun + c(n_u f(n_u), t + 1)\} \\ &= A\bar{u}n + E_u\{c(n_u f(n_u), t + 1)\}. \end{aligned} \tag{A.8}$$

We assume that the harvest fraction u follows the beta density (Martz and Waller 1982)

$$g(u) = c_n u^{\alpha - 1}(1 - u)^{\beta - 1} \tag{A.9}$$

where c_n is a normalization constant (which can be written in terms of gamma functions) and α and β are parameters. For the density of Eq. A.9, the mean and square of the coefficient of variation of u are:

$$\begin{aligned} \bar{u} &= \frac{\alpha}{\alpha + \beta} \\ \text{CV}^2 &= \frac{\beta}{\alpha(\alpha + \beta + 1)}. \end{aligned} \tag{A.10}$$

Thus, one can specify the mean and coefficient of variation of u and determine the values of α and β by solving Eq. 11.

Alolkoy

Marine Reserves in CINMS

The Publication of the Channel Islands Marine Sanctuary Foundation

Spring 2001

Volume 14 Number 1

Inside

From the Bridge

Marine Reserves

By Matthew Pickett, Sanctuary Manager

Over the past few years, the concept of marine reserves has gained attention as a viable tool in marine resource management. This issue of *Alolkoy* is focused on the benefits and challenges of marine reserves, and how the Channel Islands National Marine Sanctuary (CINMS) is moving towards effective implementation of marine reserves.

The Sanctuary, in partnership with the State of California, is engaged in a community-based process that has the potential to lead the nation in a new direction for marine resource protection. A recent consensus statement presented by over 160 marine scientists has added even more validation to the Sanctuary and State's efforts. Worldwide scientific studies support utilization of marine reserves as a method for protecting the ecosystem and sustaining marine economies.

CINMS brings unprecedented public involvement, the latest science and technological tools, strong economic analysis and community knowledge to the local process. This will be a year of important decisions. The establishment of marine reserves within CINMS will be a triumph for all who enjoy and utilize our offshore waters. The hard work necessary to establish marine reserves is sometimes challenging, but invaluable and of lasting benefit.

CINMS' rich underwater ecosystem would be protected by marine reserves.

Editor's Watch

Concept to Reality

By Cynthia Anderson, Alolkoy *Editor*

The concept of marine reserves in CINMS has captured considerable media attention. Never before have marine reserves been proposed for such a heavily populated coastal region of the United States.

The marine reserves process has brought together scientists, policy-makers, fishers and many others in a thorough exploration of the threats to the local marine environment and the viability of "no take" zones as a solution. This issue of the *Alolkoy* contains an overview of the process.

You'll find the Problem Statement adopted by MRWG on page 3, along with frequently asked questions. Patricia Wolf and Matthew Pickett detail the marine reserves process, while Sean Hastings provides an overview of existing state and federal legislation.

Bob Leeworthy and Peter Wiley cover the social economics of marine reserves. Matthew Cahn comments on the integration of science and policy. Satie Airame reviews the benefits of marine reserves, effective reserve size and the methodology of locating marine reserves.

Ben Waltenberger explains how a new GIS tool aids in the marine reserves process. See "Things to Do" for an update on upcoming MRWG meetings; the public is welcome.

Cover photo: An underwater photographer in CINMS explores a kelp forest. ©Mark Conlin

Alolkoy *is published quarterly through a contract between the Channel Islands National Marine Sanctuary and the Channel Islands Marine Sanctuary Foundation. Guest opinions expressed in* Alolkoy *do not necessarily reflect the official position of the Sanctuary or the Foundation.*

The Channel Islands National Marine Sanctuary is part of the National Marine Sanctuary System, established under Title III of the Marine Protection, Research, and Sanctuaries Act, as amended. For more information, contact: National Marine Sanctuary System, National Oceanic and Atmospheric Administration, U.S. Department of Commerce, 1305 East-West Highway, SSMC4, 11th Floor, Silver Spring, MD 20910.

Direct correspondence, submissions, and address changes to Editor, Alolkoy, *CINMS, 113 Harbor Way, Santa Barbara, CA 93109, 805/966-7107.*

Editor: Cynthia Anderson
Production: Rebecca Ditmore

"Alolkoy" is a Chumash word meaning dolphin. Printed with soy-based ink on recycled paper.

CHANNEL ISLANDS MARINE SANCTUARY FOUNDATION

CHANNEL ISLANDS
NATIONAL MARINE SANCTUARY

Marine Reserves: Frequently Asked Questions

What are marine reserves?
Marine reserves, or "no take" zones, are a specific type of Marine Protected Area (MPA) that prohibits all extraction or harvesting of marine resources. Marine reserves are not intended to limit access or anchoring.

Why are marine reserves being considered?
The answer to this question is found in the official Problem Statement adopted by consensus of the Marine Reserves Working Group (MRWG), the entity charged by the Sanctuary Advisory Council with developing a preliminary recommendation for marine reserves (see page 4):

"The urbanization of Southern California has significantly increased the number of people visiting the coastal zone and using its resources. This has increased human demands on the ocean, including commercial and recreational fishing, as well as wildlife viewing and other activities. A burgeoning coastal population has also greatly increased the use of our coastal waters as receiving areas for human, industrial and agricultural wastes. In addition, new technologies have increased the efficiency, effectiveness and yield of sport and commercial fisheries. Concurrently, there have been wide-scale natural phenomena such as El Niño weather patterns, oceanographic regime shifts and dramatic fluctuations in pinniped populations.

"In recognizing the scarcity of many marine organisms relative to past abundance, any of the above factors could play a role. Everyone concerned desires to better understand the effects of the individual factors and their interactions, to reverse or stop trends of resource decline and to restore the integrity and resilience of impaired ecosystems.

"To protect, maintain, restore and enhance living marine resources, it is necessary to develop new management strategies that encompass an ecosystem perspective and promote collaboration between competing interests. One strategy is to develop reserves where all harvest is prohibited. Reserves provide a precautionary measure against the possible impacts of an expanding human population and management uncertainties, offer education and research opportunities and provide reference areas to measure non-harvesting impacts."

Which species will marine reserves try to protect?
While marine reserves offer protection to the whole ecosystem, MRWG is also interested in protecting specific species. MRWG generated a list of over 100 species in CINMS to consider in designing reserves utilizing the following criteria: species that are economically or recreationally important; species that are candidates for, or listed as, endangered; species that have exhibited long-term or rapid declines in harvest; habitat-forming and dominant species; and species that are sensitive and/or important as prey. The species list includes marine plants, such as kelp; invertebrates, such as urchins; over 80 species of fish; marine birds, such as brown pelicans; and marine mammals, such as harbor seals.

Where are marine reserves being considered?
Marine reserves are being considered within the boundaries of CINMS, a federally designated MPA that encompasses 1,252 square nautical miles, from the shoreline out six nautical miles around San Miguel, Santa Rosa, Santa Cruz, Anacapa and Santa Barbara islands. Sanctuary waters overlap state waters (shoreline out three miles) and Channel Islands National Park (shoreline out one mile). Reserves are only being considered within the current boundaries of CINMS.

Marine Reserves Working Group Members

For additional information visit the Sanctuary website, **http://cinms.nos.noaa.gov/nmpreserves.html**.

Patricia Wolf, Co-Chair	California Department of Fish and Game
Greg Helms	Center for Marine Conservation
Dr. Michael McGinnis	UCSB, Ocean Coastal Policy Center
Steve Roberson	Channel Islands Marine Resource Restoration
Shawn Kelly	Surfrider Foundation, Ventura Chapter
Chris Miller	Lobster Trappers Association
Neil Guglielmo	Squid Seiner and Processor
Dale Glanz	ISP Alginates (Kelp Harvesting Company)
Tom Raftican	United Anglers
Marla Daily	Sanctuary Advisory Council
Dr. Craig Fusaro	Sanctuary Advisory Council
Gary Davis	National Park Service
Mark Helvey	National Marine Fisheries Service
Deborah McArdle	California Sea Grant
Locky Brown	Diving Interests
Robert Fletcher	Sportfishing Association of California
Matt Pickett, Co-Chair	Sanctuary Manager

The Marine Reserves Process

By Patricia Wolf and Matt Pickett

Marine reserves have been at the forefront of state and local politics for many years. A specific proposal for new reserves in the Channel Islands was made to the California Fish and Game Commission (FGC) in 1999 by a local conservation group of recreational fishermen. At the request of the FGC, and with the support of diverse interest groups, the Department of Fish and Game (DFG) and the Channel Islands National Marine Sanctuary (CINMS) developed a joint federal and state process to consider marine reserves.

©CINMS

A meeting of the Marine Reserves Working Group (MRWG).

At the core of this process is a panel of representatives formed by the Sanctuary Advisory Council (SAC). The panel is known as the Marine Reserves Working Group (MRWG) and represents many interest groups, experts and community members not represented on the SAC (See MRWG membership, page 3).

Two advisory panels support MRWG by providing additional expertise: a Science Advisory Panel and Socio-economic Advisory Panel (see related articles). These panels give advice and information to MRWG and analyze MRWG's proposals.

Goals for Marine Reserves

MRWG is designing marine reserves to achieve and balance the following goals:

Biodiversity: To protect representative and unique marine habitats, ecological processes and populations of interest.

Socio-economics: To maintain long-term socio-economic viability while minimizing short-term socio-economic losses to all users and dependent parties.

Sustainable Fisheries: To achieve sustainable fisheries by integrating marine reserves into fisheries management.

Natural and Cultural Heritage: To maintain areas for visitor, spiritual and recreational opportunities which include cultural and ecological features and their associated values.

Education: To foster awareness, promote stewardship and encourage responsible use of marine resources.

MRWG has already defined a problem statement, mission statement, and goals and objectives to guide the discussions. The mission statement gives the panel a clear direction: *Using the best ecological, socio-economic, and other available information, MRWG will collaborate to seek agreement on a recommendation to the Sanctuary Advisory Council regarding the potential establishment of marine reserves within the Channel Islands National Marine Sanctuary area.*

The MRWG recommendation will be consensus-based. The consensus approach requires that the legitimate concerns of all members be satisfactorily addressed before the group as a whole can reach agreement on a recommendation. The SAC will evaluate and forward this recommendation as formal advice to the Sanctuary Manager, who will then provide the recommendation to the FGC.

The power in the marine reserves process lies in the partnership among the agencies and the community. Through collective learning and communication, each panel member has become familiar not only with the problems at hand, but with the views and needs of other constituencies as well.

This multidisciplinary approach should lead to a recommendation that is more acceptable to all concerned parties. MRWG is using the best available science, socio-economics and local knowledge. The group forms a bridge linking ecology, economics and policy with the concerns of the marine community.

Because the recommendation will not be a majority vote and any member can stop the group from moving forward, everyone's needs must be met. This does not mean that a member can simply "veto" the recommendation. Concerns must be voiced along with constructive ways to meet them, without compromising the concerns of others.

The final recommendation will be stronger because it will represent the wide array of views and needs of the community-at-large. As MRWG nears the final steps in the negotiation, it is essential that we hear from all interested parties. You can track our progress and get involved by visiting the CINMS website: **http://cinms.nos.noaa.gov/nmpreserves.html**.

Patricia Wolf is Regional Manager of the Marine Region for the California Department of Fish and Game, the DFG Representative on the Sanctuary Advisory Council and Co-Chair of the Channel Islands marine reserves process. Matt Pickett, Sanctuary Manager, is also Co-Chair of the process.

Marine Reserves Legislation: A Review

By Sean Hastings

Marine protected areas and marine managed areas (MPAs and MMAs) are used increasingly by state and federal agencies as resource management tools. The purpose of MPAs and MMAs is to protect and/or enhance living marine resources, cultural heritage, water quality and recreational opportunities.

CINMS is an example of a federally designated MPA. When marine reserves are designated here, they will form a specific MPA within the Sanctuary. Taken together, MPAs and MMAs at the state and federal levels form a complex regulatory system. A key question is: how will Channel Islands marine reserves fit into this system?

This article attempts to answer this question by providing a brief outline of key legislation and agency activities at the state and federal levels since 1998.

State Legislation

State Interagency Marine Managed Areas Workgroup, 1998-2000

The Resources Agency of California established the State Interagency Marine Managed Areas Workgroup to evaluate MMA classifications and recommend improvements. The following agencies were involved: Coastal Commission, Department of Fish and Game (DFG), Department of Parks and Recreation, San Francisco Bay Conservation and Development Commission, State Lands Commission, State Water Resources Control Board and the University of California.

Marine Life Management Act (MLMA), 1998

The MLMA states that fishery management plans will form the primary basis for managing the state's sport and commercial fisheries. By September 2001, the DFG must prepare a status report on state-managed fisheries and a master plan for developing fishery management plans. The act stresses using the best available science and an adaptive approach to decision-making, including collaboration from a wide array of perspectives and expertise—as does the CINMS marine reserves process.

Marine Life Protection Act (MLPA), Assembly Bill 993, 2000

The MLPA sets goals for a comprehensive MPA program in California's marine waters; establishes criteria for selecting MPA sites, including fully protected marine reserves; requires development by 2002 of a statewide MPA master plan; and creates processes that require a sound scientific basis for the master plan and involvement by interested parties.

MMAs Improvement Act, Assembly Bill 2800, 2001

Based on the work of the State Interagency Work Group, this act establishes a new classification system for MMAs that consolidates over a dozen classifications into six and simplifies terminology. The act incorporates existing MMAs into the new system, without changing existing resource protection, in a manner consistent with the MLPA; eliminates the use of existing classifications by January 2002; and establishes a consistent designation process to be used by all state entities for MMAs.

The six new classifications are: State Marine Reserve, State Marine Park, State Marine Conservation Area, State Marine Cultural Preservation Area, State Marine Recreational Management Area and State Water Quality Protection Area. For more information, see: http://caselaw.lp.findlaw.com/cacodes/prc/36700-36900.html

Federal Legislation

President's Executive Order 13158 on Marine Protected Areas, 2000

President Clinton issued this Executive Order to develop, strengthen and expand a national system of marine protected areas. The order calls on federal agencies with an interest in MPAs to use their authorities to establish and recommend new MPAs, increase protection of existing MPAs and develop/share scientific information.

The order creates a National MPA Center in Santa Cruz, sponsored by NOAA and the Department of Interior, to provide scientific resources for establishing and managing MPAs. In California's ocean waters, the order particularly affects the activities of national marine sanctuaries, national parks, the Pacific Fisheries Management Council and the U.S. Environmental Protection Agency.

Pacific Fisheries Management Council (PFMC), 2000

The PFMC is one of eight regional fishery management councils established under the Magnuson-Stevens Fishery Conservation and Management Act. The PFMC recently adopted a technical report identifying options for using marine reserves as a management tool for species under its jurisdiction. Currently under way, Phase II of the PFMC reserve process will designate marine reserves for groundfish along the West Coast.

Bringing It All Together

The Channel Islands marine reserves process is a year ahead of other reserve designation processes under way at the state and federal level. Therefore, it will be crucial to integrate Channel Islands reserves into the larger framework of reserves in California.

CINMS and DFG staff, and local community representatives, participate in several of the state and federal processes listed above to ensure that the Channel Islands marine reserves process and eventual designation are consistent with the MMA Improvement Act, exceed MLPA requirements, satisfy the President's Executive Order and are nested in fisheries management plans required under the MLMA and the PFMC.

Ultimately, the California Fish and Game Commission, PFMC and NOAA will be responsible for integrating CINMS marine reserves into the existing marine resource management system.

Sean Hastings, CINMS Resource Protection Coordinator, is lead staff for the marine reserves process. The California Resources Agency contributed substantially to this article.

Social Economics of Marine Reserves

By Bob Leeworthy and Peter Wiley

Commercial and recreational uses of the Channel Islands National Marine Sanctuary generate $197.9 million of total income annually and support 5,491 jobs in the region. An effective marine reserve network will provide a sustainable resource base on which this economy can prosper over the long term.

A Socio-economic Advisory Panel was created to research the economic impacts of marine reserves and present a comprehensive analysis to the Marine Reserves Working Group (MRWG). Comprised of nine representatives from regulatory agencies, the research community and the community-at-large, the Socio-economic Advisory Panel mounted a vast data collection effort.

Given the lack of socio-economic data in CINMS when the analysis began two years ago, this analysis is arguably the most comprehensive to date. The panel's analysis focuses on consumptive uses such as private boat fishing/diving and commercial fishing/diving; and non-consumptive uses such as wildlife viewing, non-consumptive diving and kayaking. The analysis will assist in crafting a balanced marine reserve recommendation that maximizes ecological benefits while minimizing socio-economic impacts.

Recreation Industry

Researching the recreation industry involved collecting data from existing sources such as regional and county economic reports, identifying current activities and exploring patterns of recreational use. To perform a detailed and fine scale analysis, data were compiled at a 1 x 1 nautical mile resolution.

The team created a database of recreation charter/party boat operators for consumptive and non-consumptive activities. The data included geo-referenced data and business-related data of 18 operators.

Distribution of private boat activity was compiled from sources such as the Channel Islands National Park, The Nature Conservancy and yacht clubs/marinas.

Commercial Fishing Industry

Commercial fishing data were compiled from numerous sources. The California Department of Fish and Game (DFG) divides the ocean into 10 x 10 nautical mile blocks to record catch. Twenty-two DFG blocks encompass CINMS, and information was compiled for 1988-1999 by species caught and by each of the 22 blocks. Individual species, such as shrimp, shark and rockfish, were aggregated into 27 groups.

Information was collected on the distribution of catch at 1 x 1 nautical mile resolution for most of the 27 species groups. Thirteen species groups were mapped at 1 x 1 nautical mile resolution and placed in an Arc View geographic information system for analysis. These 13 groups account for 98.5 percent of the ex vessel value in CINMS, and include squid, urchin, spiny lobster and prawns. ("Ex vessel value" indicates the amount of money received by fishermen for their catch.) Nine maps for species groups that account for the other 1.5 percent were developed at 10 x 10 nautical mile resolution.

Socio-economic Advisory Panel Members

Dr. Vernon R. (Bob) Leeworthy, Chair, NOAA's National Ocean Service, Special Projects Office
Peter C. Wiley, NOAA's National Ocean Service, Special Projects Office
Dr. Cynthia Thomson, NOAA's National Marine Fisheries Service
Dr. James Lima, U.S. Department of Interior, Minerals Management Service
Marija Vojkovich, California Department of Fish and Game
Dr. Charles Kolstad, UC Santa Barbara
Dr. Craig Barilotti, Sea Foam Enterprises, San Diego
Dr. Caroline Pomeroy, UC Santa Cruz

Socio-economic Impacts

Economic models were constructed for both the recreation industry and commercial fishing industry to translate the mapped measurements into economic measures. The recreation industry model estimates the spending impacts of recreational users in CINMS. The commercial fishing model estimates the impacts on revenue (ex vessel value) of commercial fishing operations and translates this into total income and employment impacts. Socio-economic profiles of commercial fishermen show who might be impacted by marine reserves.

The socio-economic data and models will assist MRWG in designing boundary alternatives and allow the Socio-economic Advisory Panel to analyze their impacts. The models can estimate the "maximum potential loss" to users displaced from marine reserve areas. With the data distributions and models, and with local information on other factors, a complete socio-economic assessment will be produced for review by decision-makers and the general public.

Bob Leeworthy is Chief Economist of the National Ocean Service, Special Projects Office and the leader of the Socio-economic Advisory Panel. Peter Wiley is a staff economist of the National Ocean Service, Special Projects Office and the Panel's project lead for the recreation industry.

Integrating Science and Policy in Marine Reserves

By Matthew Cahn

CINMS is currently engaged in a fascinating decision-making process regarding the establishment of marine reserves, or no-take zones. As a federal agency, CINMS is required to solicit public input into any regulatory decision it makes. The marine reserves process, however, goes well beyond any required public participation. In fact, CINMS may be ahead of most other federal agencies in giving the public a seat at the table.

The challenge before the agency is significant. On one hand, CINMS must balance competing mandates established by the National Marine Sanctuaries Act in 1972: conservation of marine resources versus protection of public and commercial access to the Sanctuary. On the other hand, the agency takes its partnership with the public seriously.

There is a consensus among marine scientists that a network of marine reserves is a powerful tool for enhancing biodiversity and mitigating damage to marine ecosystems. Yet, marine reserves may seriously impact consumptive users of Sanctuary resources.

To meet this challenge, CINMS has constructed a unique stakeholder process for evaluating the marine reserve question. A stakeholder working group—the Marine Reserves Working Group (MRWG)—and two advisory panels (scientific and socio-economic) were convened to better review science and policy preferences. The Science Advisory Panel reviewed those aspects of the working group's discussion that relied upon science-based information. The Socio-economic Advisory Panel collected economic data and made those data available to MRWG.

The process represents the best ideal of civic science, where stakeholders are integrated into the scientific process of evaluation in areas including: a) framing the problem in partnership with scientists; b) defining goals and objectives, in consultation with scientists; c) and applying final ecological data to stakeholder reserve recommendations.

Scientists evaluated the best available information on marine reserves, assembled appropriate datasets and analyzed those data using theoretical modeling, case study analysis and computer-based annealing (see page 9).

Many observers have noted that the assumptions of science and policy are fundamentally different. Science is empirical; it assumes a high degree of training and expertise. There is a narrow protocol of acceptable methodologies, and outcomes are empirically justified according to these methodologies. By definition, access is limited.

In contrast, policy is normative, defining what we ought to do. Policy assumes multiple interests and stakeholders. There is no established protocol; instead, multiple methodologies are utilized. Policy outcomes are not empirically justifiable. And, policy access is, at best, unlimited. Stated another way, if science is rational and democracy is non-rational, there is bound to be conflict. It is no surprise, then, that bringing effective science into the policy process has been extremely challenging.

Integrating science into effective resource management has been attempted by federal agencies for many years. NOAA's national marine sanctuaries have developed an innovative approach that may provide a model across the nation. CINMS is at the forefront of this trend. The CINMS process is not yet complete; however, it is possible to make some preliminary assessments. It is clear that this evolving model is closer to resolving the paradigmatic conflicts that have long kept science and policy at arm's length.

When interest-based stakeholders and scientists are successful at linking their analytic approaches, a truly civic-science based rulemaking process will emerge. Although practical issues may limit its application, the CINMS process is a model of a policy-science partnership.

Dr. Matthew Cahn is a Professor of Public Policy at California State University Northridge and a Visiting Professor of Public Policy at the Bren School of Environmental Science and Management.

Science Advisory Panel Members

Dr. Matthew Cahn, Chair, CSU Northridge
Dr. Mark Carr, UC Santa Cruz
Dr. Ed Dever, Scripps Institute
Dr. Steve Gaines, UC Santa Barbara, Marine Science Institute
Peter Haaker, California Department of Fish and Game
Dr. Bruce Kendall, UC Santa Barbara
Dr. Steve Murray, CSU Fullerton
Dr. Daniel Reed, UC Santa Barbara, Marine Science Institute
Dan Richards, Channel Islands National Park
Dr. Joan Roughgarden, Stanford University
Dr. Steve Schroeter, UC Santa Barbara
Dr. Dave Siegel, UC Santa Barbara, ICESS
Dr. Allan Stewart-Oaten, UC Santa Barbara
Dr. Robert Warner, UC Santa Barbara
Dr. Libe Washburn, UC Santa Barbara, ICESS
Dr. Russ Vetter, National Marine Fisheries Service

Designing Marine Reserves for Conservation

By Satie Airame

Marine reserves are important tools for marine conservation and fisheries management, with the potential to protect ecosystems, improve fisheries yields and enhance recreational opportunities. Non-consumptive users, such as recreational divers and photographers, enjoy increased diversity and abundance of animals in and around reserves. Sport fishermen and divers may benefit from spillover of sport fish from reserves into non-reserve areas. Commercial fishermen may benefit from larval export of economically important species from reserves into non-reserve areas. All users benefit from sustainable use of resources over the long term.

There is substantial evidence that protecting areas from fishing leads to rapid increases in abundance, size, biomass and diversity of animals. Halpern (in press) reviewed 76 studies of reserves that were protected from at least one form of fishing. Across all reserves, abundance approximately doubled, biomass increased 2.5 times that in fished areas, average body size increased by approximately one third and the number of species present per sample increased by one third.

Marine scientists and state and federal agencies that manage fisheries have recognized the potential role of marine reserves in conservation and fisheries management. In 2000, the Pacific Fisheries Management Council specified a process to consider marine reserves as part of an integrated scheme to sustain a healthy ecosystem and more effectively manage the West Coast groundfish. In 2001, the National Research Council released an evaluation of marine reserves, identifying reserves as a tool for conservation and fisheries management where conventional approaches to management have failed to sustain fisheries. A consensus statement strongly favoring marine reserves, signed by 161 top marine scientists from the United States and 10 other countries, was released at the 2001 annual meeting of the American Association of the Advancement of Science.

Agencies and scientists agree that marine reserves should be implemented around the world for long-term fishery and conservation benefits.

Effective Reserve Size

One of the most important questions in conservation and fisheries management is how large reserves must be to provide specific benefits. Reserve size depends on goals for marine reserves and the level of fishing intensity in a particular region.

For example, Ballantine (1997) recommends a minimum size of 10 percent of representative marine habitats to meet humankind's ethical obligation to protect natural areas. DeMartini (1993) cautions that small reserves (e.g., 10 percent) may protect species with rapid growth, high reproduction and low dispersal, but larger reserves (e.g., 30 percent or more) may be necessary to protect species with slow growth and lower reproduction (such as rockfish). Sladek-Nowlis and Roberts (1997) recommend reserve sizes of 75-80 percent of the geographical distribution of populations to sustain species that suffer from extremely high fishing mortality.

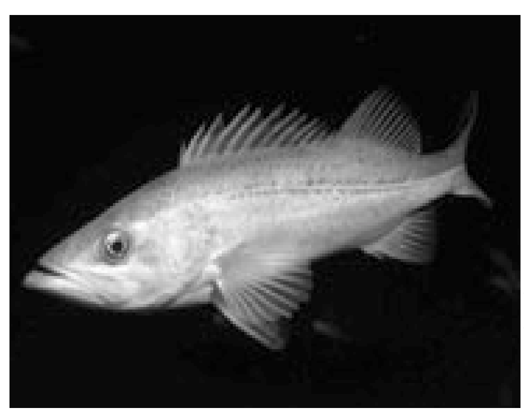
In general, the benefit of a reserve for conservation increases with size. Larger reserves protect more habitats and populations, providing a buffer against losses from environmental fluctuations and other natural factors that may increase death rates or reduce population growth rates.

For fisheries management, the benefit of a reserve does not increase directly with size. The maximum benefit of no-take reserves for fisheries, in terms of sustainability and yield, occurs when the reserve is large enough to export sufficient larvae and adults, and small enough to minimize the initial economic impact to fisheries.

The Science Advisory Panel evaluated the status of fishery resources around the Channel Islands and goals established by the Marine Reserves Working Group for conservation and fisheries management. One of the goals for marine reserves is to protect representative and unique marine habitats. Another goal is to achieve sustainable fisheries by integrating marine reserves into fisheries management.

The Science Advisory Panel determined that setting aside no less than 30 percent, and possibly 50 percent, of CINMS for marine reserves would achieve some measure of protection for both conservation and fisheries goals.

©Gregpry Ochocki



©Donna Schroeder

Marine reserves would help currently depleted populations of canary rockfish (left), and bocaccio (right) to recover.

and Fisheries Management

Locating Marine Reserves

CINMS is located in a region of tremendous biological and physical complexity. The Science Advisory Panel divided the study area (CINMS) into three bioregions (the Oregonian Bioregion, the Californian Bioregion and the transition zone between the two) based on species distributions and physical characteristics. Each of the regions exhibits distinct oceanographic patterns that influence species composition.

For planning purposes, the regions were subdivided into "planning units" of 1 x 1 minute (approximately 1 x 1 square nautical mile). Each planning unit was assigned a set of values based on habitat and species diversity. For example, scientists described the depth and the percentage cover of soft sediments (mud, sand, gravel) and hard sediments (rock, boulder, bedrock) in each planning unit. Submerged rocky features, such as pinnacles, seamounts and submarine canyons, were located using bathymetric maps, and the percent cover of each feature was estimated in each planning unit.

The areas covered by dominant algae and plant species, such as giant kelp, eelgrass and surfgrass, were identified from aerial photographs and habitat maps of the Channel Islands region. In addition, each planning unit was scored for the presence of bird colonies (16 species) and pinniped haul-outs (5 species).

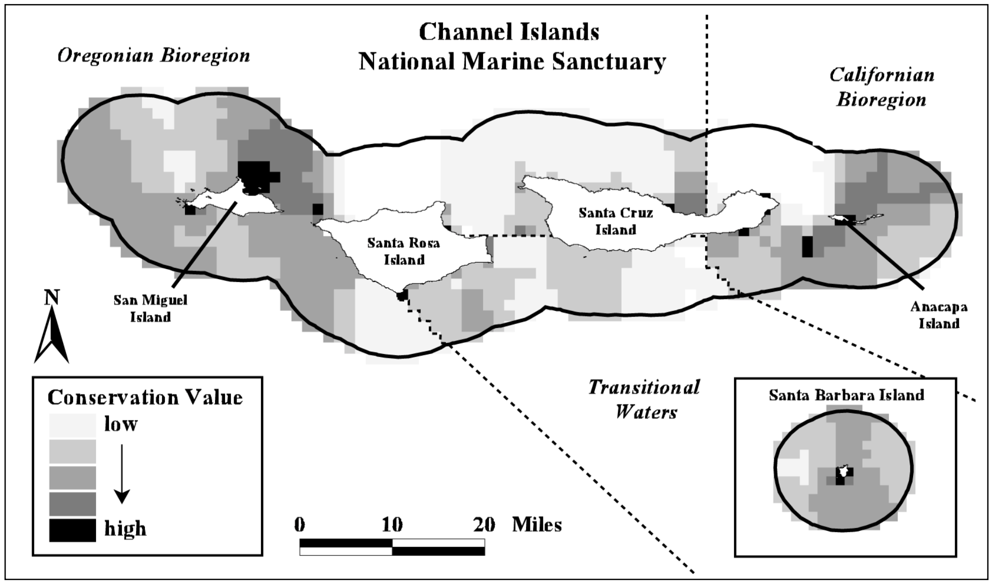


Figure 1. Conservation priority areas in the Channel Islands National Marine Sanctuary. Darker colors indicate areas of high conservation value in terms of a variety of habitats and species of interest.

Computer Analysis

Conservation priority areas were located using "Sites v. 1." This computer program was developed to help The Nature Conservancy locate potential reserve areas on land, and the program was modified to help conservation planners evaluate marine environments.

The program randomly generates an initial reserve system that includes the target percentage of each habitat and feature. The program then calculates the conservation value of the reserve system (based on the goals of the reserve system) and the cost of the reserve system (in this study, based on the boundary length of each planning unit).

After evaluating the initial reserve system, the program randomly selects a planning unit that might or might not already be included. The program evaluates the change to the value (and cost) that would occur if this planning unit were added or removed. At each step, the new solution is compared to the previous solution, and the best one is accepted. In this study, the program evaluated 1 million iterations during a single run, and over 300 runs for each analysis.

A large number of good solutions may satisfy a single set of goals. The Science Advisory Panel provided a map demonstrating the number of times each planning unit was selected for a final solution out of the total number of runs (Figure 1). This map was used to locate a set of core conservation areas. The Science Advisory Panel also selected five solutions that meet all ecological goals at targets of both 30 percent and 50 percent set-aside (for a total of 10 possible solutions). These solutions were chosen because of their high conservation value and because they were distinctly different from one another, allowing flexibility on the part of the conservation planners.

Flexibility to explore alternative solutions is critically important for conservation planners because optimal solutions may not be possible given practical problems. This approach provides resource managers with the tools necessary to develop acceptable and effective solutions to complex, multi-objective conservation problems.

Dr. Satie Airame is Scientific Advisor at CINMS. She currently works with the Science Advisory Panel and the Marine Reserves Working Group on conservation and fisheries management issues in the California Channel Islands.

References

Ballantine W. J. 1997. In *The Design and Monitoring of Marine Reserves.* Fisheries Centre, University of British Columbia, Canada.

DeMartini, E. E. 1993. Fishery Bulletin 91:414-427.

Halpern, B. In press. Ecological Applications.

Roberts, C. M. and J. P. Hawkins. 1997. Coral Reefs 16:150.

Sladek-Nowlis, J. J., and C. M. Roberts. 1999. Fisheries Bulletin US 67:604-616.

Spatial Technology in the Marine Reserves Process

By Ben Waltenberger

An important part of the marine reserves siting process is efficiently conveying relevant information to the Marine Reserves Working Group (MRWG) and to the public. Much of the scientific and socio-economic information gathered is complex, and in its native format not easily interpreted by someone who is not an expert in a particular field.

Also, because information is linked to specific "places in space" (i.e., potential marine reserve sites), complex datasets must be "anchored" to geographic locations. One of the best tools for doing this is a Geographic Information System (GIS). A GIS allows users not only to intuitively visualize potential reserve sites relative to themselves and external landmarks, but also to "mine" them for scientific and socio-economic data related to their locations.

CINMS has partnered with NOAA's Coastal Services Center to create an enhanced GIS interface called the Channel Islands Spatial Support and Analysis Tool (CI-SSAT). CI-SSAT is more than a GIS; it is a "decision support system," a term linked to the new and growing field of Public Participation GIS.

The idea behind Public Participation GIS is to create computer interfaces that allow stakeholders to query data contained in the GIS, and to "weight" those data relative to their importance to a particular stakeholder or group. This allows stakeholders to view and understand how community processes may affect them and gives them an informed voice in those processes.

To illustrate this idea, let's walk through a simple example of using CI-SSAT in a marine reserve siting process. The first screen in CI-SSAT is the criteria screen, where users can weight criteria (i.e., assign relative importance of one criterion to another) within an area they wish to analyze as a potential site.

In the Channel Islands marine reserves process, for instance, MRWG has two criteria: ecological and socio-economic. A fisherman would probably decide that the socio-economic criterion has a higher degree of relative importance than the ecological criterion (a reserve in Area X may curtail or end a particular type of fishing activity). An environmentalist concerned with protecting a rare species that only occurs in Area X would probably give the ecological criterion a higher relative weight.

Once weights are assigned, CI-SSAT analyzes the criteria comparatively using a simple suitability algorithm. It then creates a map with the chosen analysis area in color shades going from dark to light. The darker the shade, the more likely the area meets a stakeholder's goals based on the weights they chose. The lighter the area, the less likely it will meet their goals.

Once this "results" map is made, users can dig into the data associated with it. For instance, users can perform a socio-economic analysis that shows dollar amounts of particular fish species taken out of the area and the percentage of commercial use in that area relative to the entire CINMS. Users can analyze the data for ecological resources (e.g., percentage of kelp, percentage of rocky shoreline, number of bird species) that are found in the area. Users can also query and display ancillary datasets that show information such as historical use patterns, bathymetry (water depth) and geology, to name a few.

The ability to analyze and compare all these data in an intuitive map environment is a powerful tool to help citizens become informed and involved in the marine reserves process.

©CINMS

A custom-designed GIS tool, the Channel Islands Spatial Support and Analysis Tool (CI-SSAT), helps stakeholders query data regarding the marine reserves process.

Ben Waltenberger is Spatial Data Analyst for the Channel Islands National Marine Sanctuary.

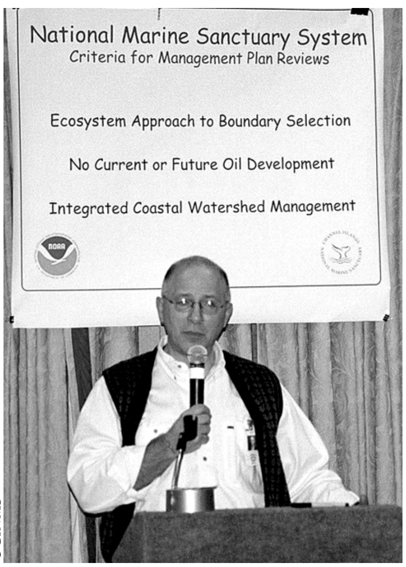
Sanctuary Waves

Management Plan Revision Update

On February 9, 2001 Dan Basta, Director of NOAA's Office of National Marine Sanctuaries, met with the Sanctuary Advisory Council to discuss CINMS boundary options. The SAC and the community advised Mr. Basta and CINMS staff on a wide range of concerns and ideas, and this information has been taken into consideration to help guide an agency decision on this challenging issue.

Late this spring or early summer, look for public release of the Draft Environmental Impact Statement (DEIS) and Draft Management Plan (DMP). These documents will compare a series of boundary options, identify the agency's preferred alternative and present a suite of management programs proposed for the next five years.

Following the DEIS/DMP release, public hearings will be scheduled, and CINMS will welcome and respond to public comments. Later in the year, watch for release of the Final Environmental Impact Statement and Final Management Plan.



©CINMS

Dan Basta, Director of NOAA's Office of National Marine Sanctuaries.

For ongoing updates on the management plan process, access the CINMS website at: **www.cinms.nos.noaa.gov/nmpintro.html** or contact Anne Walton at (805) 884-1470.

Cultural Resources Program Highlights

Conference presentations, a series of public lectures, an Internet chat and an online curriculum have been the focus of the CINMS cultural resources program.

Robert Schwemmer, CINMS Cultural Resources Coordinator, presented a paper at the Society for Historical Archaeology meeting in January 2001 that discussed the educational aspects of the cultural resources program. Deborah Marx of East Carolina University presented her survey work at the CINMS shipwreck site *Winfield Scott*, a California Gold Rush-era passenger steamer. Members of CMAR (Coastal Maritime Archaeology Resources), an avocational archaeological organization, presented papers on their partnership role in recording shipwreck sites in CINMS and Channel Islands National Park.

©CINMS

Robert Schwemmer, CINMS Cultural Resources Coordinator, spoke to audiences at the Maritime Museum's Munger Theater on Sanctuary shipwrecks.

Lectures on shipwrecks of the Channel Islands were presented at the Santa Barbara Maritime Museum's Munger Theater to audiences that included the general public and community schools. Robert Schwemmer and Laura Francis, CINMS Educational Coordinator, participated in a two-hour Internet chat hosted by Rain Camp that reached students and teachers throughout Southern California.

In December 2000, BRIDGE, an online Ocean Science Teacher Resources Center, provided teachers and students with a lesson plan featuring historic shipwrecks of the five West Coast sanctuaries. The curriculum is available on the CINMS website at **www.cinms.nos.noaa.gov**.

CINMS Foundation Initiates Collaborative Marine Research

The Channel Islands Marine Sanctuary Foundation has created a program to involve stakeholders in cooperative research, resource assessment and protection. The program is based on a partnership (facilitated by CINMS) of local marine researchers, commercial fishers and resource management agencies (National Marine Fisheries Service and California Department of Fish and Game).

This partnership will investigate resource management questions with commercial fishers in a variety of roles, including as participants in project selection and planning and as paid research assistants. The program is designed to collect resource management information in a cost-effective manner and build positive relations between marine stakeholders.

The program's pilot project will be "Movement Patterns of Nearshore Marine Fishes in the Channel Islands National Marine Sanctuary." Led by Dr. Jennifer Caselle of UC Santa Barbara, this project will investigate patterns of fish movement and stock structure of reef fishes (including California sheephead, rockfish, cabezon and kelp bass) associated with the premium/live finfish fishery. The project will involve trapping and tagging fish, combined with recapture and resighting surveys, in order to:

- Determine stock structure and population differences among sites for targeted and non-targeted species caught in live traps.
- Determine movement patterns and mobility scales for several stages and sexes (e.g. juveniles, adults, males and females) of species caught in live traps.
- Determine the catch composition of live traps in CINMS boundaries.
- Develop methods for efficient and effective fisher-scientist collaboration.

U. S. Department of Commerce
National Oceanic and Atmospheric Administration
Channel Islands National Marine Sanctuary
113 Harbor Way, Suite 150
Santa Barbara, CA 93109

Address Correction Requested

Alolkoy

Need more information? Contact:

Channel Islands National Marine Sanctuary
Santa Barbara Harbor
113 Harbor Way, Suite 150
Santa Barbara, CA 93109
805/966-7107

Channel Islands Harbor
3600 South Harbor Blvd., Suite 217
Oxnard, CA 93035
805/382-6141
805/382-6151

Email:
channelislands@nms.noaa.gov
Website:
www.cinms.nos.noaa.gov

Channel Islands National Park
1901 Spinnaker Drive
Ventura, CA 93001
805/658-5700
Website: www.nps.gov/chis/

Channel Islands Marine Sanctuary Foundation
Kelly Darnell
113 Harbor Way, Suite 150
Santa Barbara, CA 93109
805/687-0324

Things to Do, Places to Go

Marine Reserve Working Group (MRWG) Meetings

MRWG meetings are open to the public and all are encouraged to attend. On May 23, the Sanctuary Advisory Council will meet to receive the MRWG recommendation. There will also be a public forum in May, date to be announced.

On **June 19** at Chase Palm Park Center, there will be a Sanctuary Advisory Council meeting to discuss the MRWG recommendation. For more information, contact Sean Hastings at (805) 884-1472.

Whale Watch Trips

Join the Sanctuary Naturalist Corps for educational whale watch trips departing from Santa Barbara Harbor, Ventura Harbor and Channel Islands Harbor. SNC volunteers will be available for blue and humpback whale watch trips. For more information, visit the CINMS website or call Shauna Bingham at (805) 382-6151.

Dive into Fish Counting

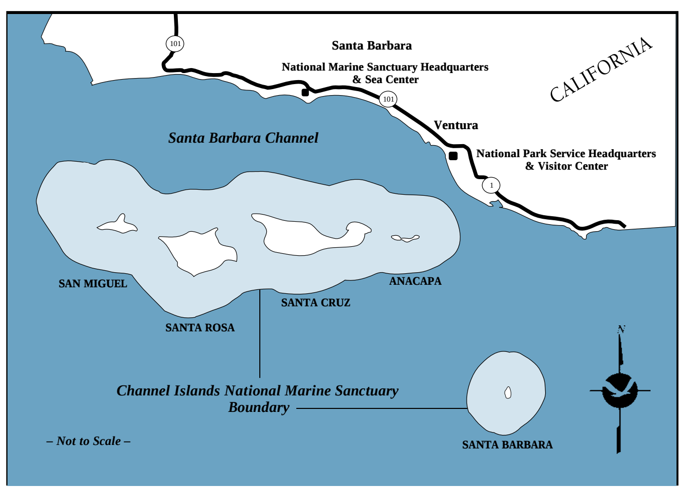
If you would like to participate in the Great American Fish Count this July, plan to attend a free Fish Identification Seminar. Reserve your place by contacting Laura Francis at **laura.francis@noaa.gov** or (805) 884-1463. **June 12, 2001**, 7 p.m.-9 p.m. Channel Islands National Park Visitor Center, 1901 Spinnaker Dr., Ventura; **June 19, 2001**, 7 p.m.-9 p.m. Munger Theater, Santa Barbara Maritime Museum, Santa Barbara Harbor; **July 7, 2001**, 7 p.m.-9 p.m. Waterfront Classroom, 125 Harbor Way (2nd floor), Santa Barbara Harbor.

Geographic Information Systems (GIS) Workshops

CINMS will host two GIS workshops for teachers this summer, one at UCSB from **June 16-19** and one at Ventura College from **August 8-11**. The $75 fee includes all curriculum materials and a field trip. Contact Laura Francis at **laura.francis@noaa.gov** or (805) 884-1463.

Fish Survey Trip

Join CINMS and REEF for a fish survey trip aboard the Truth Aquatics boat *Conception* on **July 8-9**. The fee is $175. Contact Shauna Bingham at **shauna.bingham@noaa.gov** or (805) 382-6151.



Appendix F. Outline of Information Required for Marine Protected Area Proposals

The Marine Life Protection Act (MLPA) requires the development and evaluation of alternative proposals for marine protected areas (MPAs) in each biogeographical region. There are several sources of guidance regarding the contents and evaluation of MPA proposals:

- The MLPA
- Discussions of the Master Plan Team established under the MLPA
- Criteria developed by the State Interagency Coordinating Committee for Marine Managed Areas pursuant to the Marine Managed Areas Improvement Act
- Experience with establishing MPAs in California and elsewhere.

Distillation of this guidance will assist in developing and evaluating MPA proposals by identifying early in the process the required or desirable information, synthesis, analysis, and evaluation. The current limited capacity of state agencies to carry out all of these functions argues for encouraging the private sector to take on more of these activities. The more the information and analytical requirements of the MLPA are met by MPA proposals from the private sector, the more likely it will be that responsible agencies can carry out due diligence review of these proposals.

The proposed outline of information required for MPA proposals is based on the guidance identified above. Definition of key terms will require further discussion as part of the broader MLPA Initiative. Whether prepared by a public agency or by a private organization, a proposal should aim at addressing most, if not all, of the requirements listed below.

The outline is organized in four sections:
- A summary
- The setting
- The proposal
- Individual MPAs within the proposal

Summary
- Objectives of proposal
- How the proposal addresses the requirements of the MLPA and other relevant law

The Setting
- Description of region
    - Legal description of the boundaries of study area
        - Rationale for boundaries
    - Species or groups of species likely to benefit from MPAs [FGC §2856(a)(2)(B)] (See list of species at www.dfg.ca.gov/mrd/mlpa/guidelines.html and www.dfg.ca.gov/mrd/mlpa/table_inv.html.)
        - Distribution of these species in the region and beyond
        - Status of these species in the region and beyond
    - Representative or unique marine ecosystems in the region [FGC §2853(b)(1)]
        - Distribution of these ecosystems
        - Status of these ecosystems (principally “function” and “integrity”)

- Distribution of representative and unique habitats in the region generally, and specifically for species likely to benefit:
    - Rocky reefs
    - Intertidal zones
    - Sandy or soft ocean bottoms
    - Submerged pinnacles
    - Kelp forests
    - Submarine canyons
    - Seagrass beds
- Distribution of oceanic features that may influence target species, including currents and upwelling zones (FGC §2856[a]2[B])
- Current and anticipated distribution of human uses
    - Aquatic
        - Commercial fishing
        - Recreational fishing
        - Diving
        - Etc.
    - Terrestrial
        - Discharges
        - Recreation
        - Aesthetics
        - Other
- Current management of human activities affecting target species, ecosystems, and habitats
- Evaluation of current management of human activities affecting target species, ecosystems, and habitats in relations to the goals and objectives of the MLPA

The Proposal

- Process used to develop the proposal
    - Participants and their roles
    - Sources of information

- Gap analysis
    - Description of existing MPAs
    - Adequacy of existing management plans and funding
    - Target habitats and ecosystems entirely unrepresented or insufficiently protected by existing MPAs and other management activities
    - Target habitats and ecosystems insufficiently protected by existing MPAs and other management activities, without replicates in the region or with replicates too widely spaced

- Framework for regional MPA proposal

- Regional goals and objectives for a MPA proposal
    - Relation of goals and objectives to the MLPA generally and to resource problems and opportunities in the region specifically

- General description of preferred proposal (and alternatives)
  - Spacing of MPAs and overall level of protection
  - Proposed management measures
  - Proposed monitoring for evaluating the effectiveness of the site in achieving its goals
  - Proposed research programs
  - Proposed education programs
  - Enforcement needs and means of meeting those needs
  - Funding requirements and sources
  - Proposed mechanisms for coordinating existing regulatory and management authority
  - Opportunities for cooperative state, federal, and local management,
  - Name

- Evaluation of the proposal:
  - How does the proposal emphasize:
    - areas where habitat quality does (or potentially can) support diverse and high-density populations
    - benthic habitats and non-pelagic species
    - hard bottom as opposed to soft bottom, because fishing activities within state waters have had the greatest impact on fishes associated with hard bottom, and because soft bottom habitat is interspersed within areas containing rocky habitat
    - habitats associated with those species that are officially designated as overfished, with threatened or endangered species, and productive habitats such as kelp forests and seagrass beds
  - How does the proposal include:
    - unique habitats
    - a variety of ocean conditions such as upwelling centers, upwelling shadows, bays, estuaries, and exposed and semi-protected coastlines
  - How does the proposal address existing MPAs?
  - How does the proposal include a variety of sizes and types of MPAs that:
    - Provide enough space within individual MPAs for the movement of juveniles and adults of many species
    - Achieve beneficial ratios of edge to area
    - Help to include a variety of habitats
    - Facilitate analysis of the effects of different-sized MPAs
    - Facilitate analysis of the effects of different types of MPAs
    - Provide for biological connectivity
    - Enable the use of MPAs as reference sites to evaluate the effects of climate change and other factors on marine ecosystems, without the effects of fishing
    - Enable the use of MPAs as reference sites for fisheries management,
    - Minimize the likelihood that catastrophic events will impact all replicate MPAs within a biogeographic region
    - If an MPA is less restrictive than a reserve, how do different uses and restrictions affect achieving the objectives immediately above?

- How does the proposal use simple and easily recognizable boundaries to facilitate identification and enforcement of MPA regulations?
- Where feasible, how does the proposal locate MPAs in areas where there is onsite presence to facilitate enforcement?
- How does the proposal consider non-extractive uses, cultural resources, and existing fisheries and fishing regulations?
- How does the proposal consider proximity to ports, safe anchorage sites, and points of access, to minimize negative impacts on people and increase benefits?
- How does the proposal facilitate monitoring of MPA effectiveness by including well-studied sites, both in MPAs and unprotected areas?
- How does the proposal consider positive and negative socioeconomic consequences?

- What are the socio-economic impacts of the proposal?
  - Current uses:
    - What are the current uses of sites within the proposal that are likely to be affected?
    - What are the likely impacts of MPAs upon these uses?
  - Future uses:
    - How are current uses expected to change in response to the sites within the proposal?
    - What are the socio-economic impacts of these changes?
  - Costs and benefits:
    - What uses are likely to benefit from sites within the proposal, and how?
    - What uses are likely to suffer from MPAs, and how?

- What is the improved marine reserve component of the proposal? (FGC §2857[c])
  - Which habitat types are represented in at least one marine reserve in this biogeographical region?
    - Do reserves include habitat types and communities across different depth ranges?
    - Do reserves include habitat types and communities across different environmental conditions?
    - Is each habitat type and community represented in at least one reserve in this region?

- Which species will benefit from the proposal and how?
  (See list of species at www.dfg.ca.gov/mrd/mlpa/guidelines.html and www.dfg.ca.gov/mrd/mlpa/table_inv.html.)

- How does this proposal meet the goals and guidelines of the MLPA (FGC § 2853[b]):
  - Protect the natural diversity and abundance of marine life, and the structure, function, and integrity of marine ecosystems;
  - Help sustain, conserve, and protect marine life populations, including those of economic value, and rebuild those that are depleted;

    - Improve recreational, educational, and study opportunities provided by marine ecosystems that are subject to minimal human disturbance, and to manage these uses in a manner consistent with protecting biodiversity;
    - Protect marine natural heritage, including protection of representative and unique marine life habitats in California waters for their intrinsic value;
    - Ensure that California's MPAs have clearly defined objectives, effective management measures, and adequate enforcement, and are based on sound scientific guidelines;
    - Ensure that the state's MPAs are designed and managed, to the extent possible, as a network.

- Information necessary for fulfilling required CEQA alternative analysis.

Individual MPAs within the Proposal

- What are the boundaries of this MPA?
- What is the total area of the MPA?
- What is the total shoreline length of the MPA?
- Does this MPA expand upon an existing MPA?
- What is the overall goal of this MPA?
- What are the objectives that serve this goal?
- What species, populations, habitats, or ecosystem functions are of most concern in this area?
    - What are the chief threats to these features?
        - Which of these threats are amenable to management?
    - What restrictions are proposed that address these threats?
    - What additional restrictions or designations (e.g. water quality protection areas) would help address these threats?
- Many of the general design issues identified for the network apply here as well.
- What features does the site display among those identified for different types of MPAs by the State Interagency Coordinating Committee for Marine Managed Areas? (See Attachment A.)

ATTACHMENT A TO APPENDIX F

Excerpted from California State Interagency Coordinating Committee for MMAs
CRITERIA FOR DESIGNATING MARINE MANAGED AREAS

Pursuant to statute, these designation criteria have been developed by the State Interagency Coordinating Committee for Marine Managed Areas to assist individuals or groups in developing site proposals. While the criteria are based on language in California law, it is not required that a site meet all of the criteria listed for a specific classification. Because different MMAs will have different goals and purposes, some of the criteria listed overlap or are mutually exclusive. All the criteria are presented here to help applicants prepare appropriate documentation. Site proposals need only address those criteria that apply to the specific site and classification being proposed (see item #6 on the application form).

[Note that the word "potential" has been added before each set of criteria in this attachment. This word has been added during development of the draft master plan framework for the MLPA Initiative and was not part of the original attachment as developed by the California State Interagency Coordinating Committee for MMAs.]

I. STATE MARINE RESERVE

A. Potential Biological Criteria

1. The proposed site will protect or restore rare, threatened, or endangered native species or habitats.

2. The proposed site will protect outstanding, representative, or imperiled marine species, communities, habitats, or ecosystems.

3. The proposed site will protect populations of one or more fish species that have been declared "overfished" by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

4. The proposed site will protect populations of harvested species that are of concern to state or federal fishery managers.

5. One or more habitats within the proposed site is/are designated as essential fish habitat (EFH) by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

6. The proposed site will protect habitat, or biological communities, populations, species or gene pools that are under-represented or not replicated in the existing network of state marine managed areas.

7. The proposed site will protect connections between geographic areas and/or habitat types, including estuarine and marine, wetland and intertidal, intertidal and subtidal, and deep and shallow water.

8. The proposed site is biologically highly productive.

9. The proposed site contains multiple habitat types.

10. The proposed site has historically received relatively heavy fishing effort, it is likely that some populations of fished species are locally depleted, and populations of fished species are expected to rebound if protected.

B. Potential Socio-Economic Criteria

1. The proposed site currently or potentially provides public access, consistent with resource protection goals.

2. The proposed site currently or potentially provides educational and interpretive activities for the public.

3. The proposed site has historically received relatively little fishing effort.

4. Designation of the proposed site is not likely to have a significant negative socio-economic impact on those who have traditionally used the area.

5. Designation of the proposed site is likely to have a positive socio-economic impact.

6. The proposed site is bordered by similar habitat in which spillover effects from protecting one or more species could benefit those fishing adjacent to the site.

C. Potential Management and Enforcement Criteria

1. The proposed site overlaps or is adjacent to an existing protected or managed area, thus facilitating enforcement.

2. The proposed site is adjacent to a populated area in which public stewardship would facilitate enforcement.

3. The proposed site has boundaries that are practical and enforceable.

4. Designating this site would lessen the impact of human uses on sensitive populations of marine or estuarine organisms.

5. The proposed site has little or no direct access from land, or the access is controlled.

6. The proposed site has or will have funding sources and/or in-kind resources for enforcement.

7. The proposed site has or will have funding sources and/or in-kind resources for management activities.

D. Potential Evaluation and Research Criteria

1. The proposed site will provide an opportunity for scientific research or monitoring in outstanding, representative, or imperiled marine habitats or ecosystems.

2. The proposed site has or will have funding for scientific research or monitoring.

3. The proposed site has been the site of previous scientific research or monitoring studies.

4. Seafloor habitat within the proposed site has been partially or totally mapped using side-scan sonar or equivalent technology.

II. STATE MARINE PARK

A. Potential Biological Criteria

1. The proposed site will protect a spacious natural system.

2. The proposed site will protect outstanding, representative, or imperiled marine species, communities, habitats, or ecosystems.

3. The proposed site will afford some protection to populations of harvested species that are of concern to state or federal fishery managers.

4. One or more habitats within the proposed site are designated as essential fish habitat (EFH) by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

5. The proposed site will protect habitat, or biological communities, populations or species that are under-represented or not replicated in the existing network of state marine managed areas.

6. The proposed site will protect connections between geographic areas and/or habitat types, including estuarine and marine, wetland and intertidal, intertidal and subtidal, and deep and shallow water.

7. The proposed site is biologically highly productive.

8. The proposed site contains multiple habitat types.

9. The proposed site has historically received relatively heavy fishing effort, it is likely that some populations of fished species are locally depleted, and populations of fished species are expected to increase if protected.

10. The proposed site will protect populations of one or more fish species that have been declared “overfished” by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

B. Potential Cultural Criteria

1. The proposed site has cultural objects or sites of historical, archaeological or scientific interest.

C. Potential Socio-Economic Criteria

2. The proposed site currently or potentially provides public access, consistent with resource protection goals.

3. The proposed site currently or potentially provides educational and interpretive activities for the public.

4. The proposed site will provide sustainable recreational opportunities in the absence of conflicting uses.

5. The proposed site will provide recreational opportunities to meet other than purely local needs.

6. The proposed site has historically received relatively little fishing effort.

7. Designation of the proposed site is not likely to have a significant negative socio-economic impact on those who have traditionally used the area.

8. Designation of the proposed site is likely to have a positive socio-economic impact.

9. The proposed site is bordered by similar habitat in which spillover effects from protecting one or more species could benefit those fishing adjacent to the area.

D. Potential Geological Criteria

1. The proposed site has outstanding or unique geological features that contribute to the biological productivity of the area.

2. The proposed site has geological features that are critical to the lifecycle of native marine or estuarine species.

E. Potential Management and Enforcement Criteria

1. The proposed site overlaps or is adjacent to an existing protected or managed area, thus facilitating enforcement.

2. The proposed site is adjacent to a populated area in which public stewardship would facilitate enforcement.

3. The proposed site has boundaries that are practical and enforceable.

4. Designating this site would lessen the impact of human activities on sensitive populations of marine or estuarine organisms.

5. The proposed site has or will have funding sources and/or in-kind resources for enforcement.

6. The proposed site has or will have funding sources and/or in-kind resources for management activities.

F. Potential Evaluation and Research Criteria

1. The proposed site will provide an opportunity for scientific research or monitoring in outstanding, representative, or imperiled marine habitats or ecosystems.

2. The proposed site has or will have funding for scientific research or monitoring.

3. The proposed site has been the site of previous scientific research or monitoring studies.

4. Seafloor habitat within the proposed site has been partially or totally mapped using side-scan sonar or equivalent technology.

III. STATE MARINE CONSERVATION AREA

A. Potential Biological Criteria

1. The proposed site will protect or restore rare, threatened, or endangered native species or habitats.

2. The proposed site will protect outstanding, representative, or imperiled marine species, communities, habitats, or ecosystems.

3. The proposed site will protect populations of one or more fish species that have been declared "overfished" by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

4. The proposed site will protect populations of harvested species that are of concern to state or federal fishery managers.

5. One or more habitats within the proposed site are designated as essential fish habitat (EFH) by the National Marine Fisheries Service. [see www.nmfs.noaa.gov for list]

6. The proposed site will protect habitat, or biological communities, populations, species or gene pools that are under-represented or not replicated in the existing network of state marine managed areas.

7. The proposed site will protect connections between geographic areas and/or habitat types, including estuarine and marine, wetland and intertidal, intertidal and subtidal, and deep and shallow water.

8. The proposed site is biologically highly productive.

9. The proposed site contains multiple habitat types.

10. The proposed site has historically received relatively heavy fishing effort, it is likely that some populations of fished species are locally depleted, and populations of fished species are expected to rebound significantly if protected.

B. Potential Socio-Economic Criteria

1. The proposed site currently or potentially provides public access, consistent with resource protection goals.

2. The proposed site currently or potentially provides educational and interpretive activities for the public.

3. The proposed site has historically received relatively little fishing effort.

4. Designation of the proposed site is not likely to have a significant negative socio-economic impact on those who have traditionally used the area.

5. Designation of the proposed site is likely to have a positive socio-economic impact.

6. The proposed site is bordered by similar habitat in which spillover effects from protecting one or more species could benefit those fishing adjacent to the area.

C. Potential Geological Criteria

1. The proposed site has outstanding or unique geological features that contribute to the biological productivity of the area.

2. The proposed site has geological features that are critical to the lifecycle of native marine or estuarine species.

D. Potential Management and Enforcement Criteria

1. The proposed site overlaps or is adjacent to an existing protected or managed area, thus facilitating enforcement.

2. The proposed site is adjacent to a populated area in which public stewardship would facilitate enforcement.

3. The proposed site has boundaries that are practical and enforceable.

4. Designating this site would lessen the impact of human activities on sensitive populations of marine or estuarine organisms.

5. The proposed site has living marine resources that if managed properly will allow for sustainable harvest.

6. The proposed site has or will have funding sources and/or in-kind resources for enforcement.

7. The proposed site has or will have funding sources and/or in-kind resources for management activities.

E. Potential Evaluation and Research Criteria

1. The proposed site will provide an opportunity for scientific research or monitoring in outstanding, representative, or imperiled marine habitats or ecosystems.

2. The proposed site has or will have funding for scientific research or monitoring.

3. The proposed site has been the site of previous scientific research or monitoring studies.

4. Seafloor habitat within the proposed site has been partially or totally mapped using side-scan sonar or equivalent technology.