QUESTIONS FOR THE SCIENCE ADVISORY PANEL

Is there a problem with current fisheries management in the Channel Islands National Marine Sanctuary?

What are the benefits of marine reserves for conservation and fisheries management?

Do reserves increase reproductive output and recruitment of fished species?

Can marine reserves enhance fisheries through spillover of adult fish into fished areas?

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Table 1. Examples of the effects of marine reserves on species diversity, biomass, abundance, and size (modified from Table 1 in Roberts and Hawkins 2000).

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Is there a problem with current fisheries management in the Channel Islands National Marine Sanctuary?

The following statement was developed by the Marine Reserves Working Group to describe the problems associated with conservation and fisheries management in the Channel Islands National Marine Sanctuary. The Working Group represents a variety of interests in the Santa Barbara and Ventura counties, including federal and state agencies, commercial and recreational fishermen and divers, and local community members.

"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 Nino 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."

What are the benefits of marine reserves for conservation and fisheries management?

Marine reserves are important tools for marine conservation and fisheries management, with the potential to provide ecosystem protection, improved fisheries yields, expanded understanding of marine environments, and improved non-consumptive opportunities. The degree to which a reserve will provide certain benefits or achieve specific goals will vary with the species, depending on life-history characteristics and various aspects of reserve design.

The number of documented successful examples of no-take marine reserves is increasing rapidly. There is now abundant evidence to show that protecting areas from fishing leads to rapid increases in abundance, size, biomass, and diversity of animals, regardless of where in the world reserves are sited. Halpern (in press) reviewed 76 studies of reserves that were protected from at least one form of fishing. He derived aggregate measures of reserve performance, by combining responses of all the organisms studied for each of four variables: abundance, total biomass, average body size, and species diversity. Across all reserves, abundance (measured as density) approximately doubled, biomass increased 2.5 times that in fished areas, average body size increased by approximately 1/3 (equivalent in many fish to an increase in egg output of 240% or more), and the number of species present per sample increased by 1/3. Table 1 summarizes examples of reserve effects from a range of different parts of the world and different habitats. Many other examples can be found in Roberts and Polunin (1991), Dugan and Davis (1993), Rowley (1994), Bohnsack (1996), and Fujita (1998).

Table 1. Examples of the effects of marine reserves on species diversity, biomass, abundance, and size (modified from Table 1 in Roberts and Hawkins 2000).

Reserve Name Location	Years of Protection	Habitat Type	Effects Reported
Leigh Marine Reserve, New Zealand	21	Warm-temperate rocky reef	The most common predatory fish *Pagrus auratus* was 6 times more common in the reserve than outside, while the spiny lobster *Jasus edwardsii* was 1.6 times more abundant and had a bigger carapace. In 18 years, sea urchin densities declined from 4.9 m2 to 1.4 m^2 in the reserve while urchin cover rose from 14% to 40% in unprotected areas (Babcock 1999).
Tawharanui Marine Park, New Zealand	14	Temperate rocky reef	The most common predator fish *pagnus auratus* was 9 times more common in the reserve than outside, while the spiny lobster *Jasus edwardsii* was 3.7 times more abundant, with a larger carapace (Babcock 1999).
Mayotte Island, Indian Ocean	3	Coral reef	Species richness did not differ between protected and unprotected areas, however, most large carnivores were more diverse and abundant in the reserve. The mean biomass of commercial species was 202 g/m^2 in the reserve compared to 79 g/m^2 outside (Letourneur 1996).
Looe Key, Florida, USA	2	Coral reef	15 species that were targets of spear fishers increased in abundance after spearfishing was banned; snappers by 95%, grunts by 439% (Clark et al. 1989).
Cousin Island, Seychelles	15+	Coral reef	Groupers, emperors, and snappers were more abundant and diverse within the reserve than in fished sites (Jennings 1998).
Sainte Anne, Seychelles	11	Coral reef	The diversity of target species and total fish biomass was higher in the reserve than in heavily fished areas (Jennings *et al.* 1995, 1996).
Merritt Island National Wildlife Refuge, Florida, USA	28	Sub-tropical estuary	Experiment catch per unit effort was 2.6 times greater in the reserve for all game fish combined; 2.4 time greater for spotted sea trout (*Cynoscion nebulosus*), 6.3 times for red drum (*Sciaenops ocellata*), 12.8 for black drum (*Pogonius cromis*), 5.3 for snook (*Centropomus undecimalis*) and 2.6 for striped mullet (*Mugil cephalus*). Fish in the refuge were larger and more abundant, and anglers were preferentially targeting the reserve boundary (Johnson *et al.* 1999).

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Reserve Name Location	Years of Protection	Habitat Type	Effects Reported
Kisite Marine National Park, Kenya	5	Coral reef	Groupers, emperors, and snappers were more abundant within the park and appear to be spilling over into fishing grounds. Protection did not affect species number (Watson *et al*. 1996).
Punta El Lacho, Chile	2	Temperate rocky intertidal	The commercially important marine snail, the loco (*Concholepas concholepas*), increased in density from 5 to 14 times and doubled in body size following protection (Castilla and Duran 1985).
Barbados Marine Reserve	11	Coral reef	Large fish were approximately twice as abundant in the protected area, and 18 of 24 species were bigger (Rakitin and Kramer 1996, Chapman and Kramer 1999).
Exuma Cays Land and Sea Park, Bahamas	36	Tropical seagrass meadow	The average density of adult queen conch (*Strombus gigas*) was 15 times higher in the reserve and late stage larval densities were 4-17 times higher (Stoner and Ray 1996).
Exuma Cays Land and Sea Park, Bahamas	10	Coral reef	The reproductive output of Nassau grouper (*Epinephelus striatus*) was 6 times greater in the reserve (Sluka et al. 1997).
Hawaii Marine Life Conservation Districts	Not reported	Coral reef	Fishes were 63% more abundant in areas protected from fishing (Grigg 1994).
De Hoop Marine Reserve, South Africa	2	Warm temperate rocky reef	Experiment catch per unit effort increased by up to 5-fold for 6 out of 10 of the most commercially important species (Bennett and Attwood 1991).
Saba Marine Park, Saba, Netherlands Antilles	4	Coral reef	In the no-take zone the biomass of target species was over twice that in fishing grounds (Polunin and Roberts 1993).
Hotel Chan Marine Reserve, Belize	4	Coral reef	Biomass of target species in the reserve was almost double that in fished areas, while in certain parts of the reserve it was ten times greater (Polunin and Roberts 1993, Roberts and Polunin 1994).
Anse Chastanet Reserve, Santa Lucia	2	Coral reef	Total biomass of commercially important species was more than double that in fished areas and the reserve contained 3 species found nowhere else (Roberts and Hawkins 1997).

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Ras Mohammed Marine Park, Egypt	15	Coral reef	Mean biomass of fish was 1.2 times greater on protected reefs, while differences for seven target species were much greater. Individuals of the lunartail grouper (*Variola louti*) were three times larger in the reserve (Roberts and Polunin 1993a, 1993b).
Kisite Marine National Park and Mpuguti Marine National Reserve, Kenya	Kisite 20 Mpuguti 0	Coral reef	Abundances of key commercial species (groupers, snappers, and emperors) were up to 10 times higher in the fully protected Kisite Marine National Park compared to the fished Mpunguti reserve. Keystone species such as triggerfish (a predator of urchins) were also more abundant in Kisite Park, while their urchin prey were much more abundant in Mpunguti (Watson and Ormond 1994).
Three Kenyan Marine Parks: Malindi, Watamu, Kisite	Malindi 24 Watamu 20 Kisite 19	Coral reef	Reserve helped support regional diversity by protecting species that were unable to persist in fished areas. Of the 110 species recorded in protected reefs, 52 were not found in fished areas (McClanahan 1994).
South Lagoon Marine Park, New Caledonia	5	Coral reef	Within protected areas, the species richness of fish populations increased by 67%, density by 160%, and biomass by 246% but the average size of most species did not increase (Wantiez et al. 1997).
Banyuls-Cerbere Marine Reserve, France	6	Warm-temperate rocky reef	18 target species were bigger in reserve (Bell 1983).
Shady Cove, San Juan Islands, Washington, USA	7	Temperate rocky reef	Lingcod (*Ophiodon elongatus*) were nearly three times more abundant in the reserve (Palsson and Pacunski 1995).
Edmonds Underwater Park, Washington, USA	27	Temperate rocky reef	The number of rockfish eggs and larvae originating in the park is 55 times greater than outside. For lingcod (*Ophiodon elongatus*), egg and larval production in the park is 20 times greater than outside (Palsson and Pacunski 1995).
Anacapa Island, Channel Islands, California, USA	20	Warm-temperate rocky reef	Densities of comercially exploited red sea urchin (*Strongylocentrotus franciscanus*) were 9 times higher in the reserve than in nearby fished areas (Fujita 1998).

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Reserve Name Location	Years of Protection	Habitat Type	Effects Reported
Tsitsikamma National Park, South Africa	22	Rocky reef	Of three species studied, one was 4 times more abundant in the reserve, and another was 13 times more. Bream (*Petrus rupestris*) were on average twice as large when protected (Buxton and Smale 1989).
Sumilon Island Reserve, The Philippines	10	Coral reef	Eighteen months after fishing resumed in the reserve, catch per unit effort fell by half, and the total yield of fish was 54% less, despite a greater area available for fishing (Alcala and Russ 1990).
Apo Island Reserve, The Philippines	6	Coral reef	The biomass of large predators increased 8-fold in the reserve. In fishing grounds, mean density and species richness of large predators also increased (Russ and Alcala 1996a,b).
Kyoto Precture Closure, Japan	4	Temperate sand and mud bottom	The proportion of large male snow crabs (*Chionoecetes opilio*) rose by 32% in the closed area (Yamasaki and Kuwahara 1990).
Maria Island Reserve, Tasmania	6	Temperate rocky reef	The densities of rock lobster (*Jas rubra*) and bastard trumpeter fish (*Latridopsis forsteri*) increased by 1 and 2 orders of magnitude respectively within the reserve (Edgar and Barrett 1999).

Do reserves increase reproductive output and recruitment of fished species?

Many studies demonstrate that marine reserves promote a rapid increase in biomass of commercially important fish species within their boundaries (Table 1). In most marine reserve areas, biomass will double after three to five years of protection, although some species, particularly those that have been exploited intensively, can increase in biomass by orders of magnitude. For any given area, increased biomass of a species should result in a greater reproductive output. For example, it has been estimated that the reproductive output of Nassau groupers (*Epinephelus striatus*) in a reserve in Exuma Cay in the Bahamas is 6 times greater than that in fishing grounds (Sluka *et al*. 1997). In Puget Sound off the north-west US coast, such differences are even greater. The reproductive output of lingcod (*Ophiodon elongatus*) in a reserve has been estimated at twenty times greater than it is in fished areas; the reproductive output of the copper rockfish (*Sebastes caurinus*) is 100 times greater in reserve than in fished areas (Palsson and Pacunski 1995).

Bohnsack (1992) modeled egg production by red snapper in the Gulf of Mexico with and without 20% network of reserve areas. He estimated that if 20% of the fishing grounds were closed, egg production would rise by 1200% due to the increased contribution from more older, larger fish which can produce many times more eggs per individual than smaller younger fish.

A model for scallops (*Placopecten magellanicus*) on the Grand Banks showed that egg production per female could increase by 15 times in protected reserves (McGarvey and Willison 1995). When two large reserve areas were established in 1994 on Georges Bank, stocks of scallops rebounded within four years and recruitment to adjacent fishing areas also increased (Murawski *et al*. 2000). In July 1998, total and harvestable scallop biomasses were 9 and 14 times denser, respectively, in closed than in adjacent open areas. Satellite tracking shows that scallop fisheries are now concentrated near reserves, and total landings are at 150% of 1994 levels.

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

Many questions about the effects of marine reserves on reproductive output and recruitment still remain unanswered. Part of the problem is that there are too few protected areas available for study and little research has been directed at the question of reproductive output and recruitment. Contributing to the problem, recruitment is an extremely variable process. Recruitment may vary by orders of magnitude from year to year making it extremely difficult to prove that any increases measured in fishing grounds are a result of nearby reserves.

Can marine reserves enhance fisheries through spillover of adult fish into fished areas?

Marine reserves can enhance and sustain fisheries through export of larval fish and spillover of adult fish into fished areas (Table 2). The distances over which spillover is significant depends on the mobility of the species involved. Numerous tagging studies, of fish and crustaceans in particular, demonstrate that these species have the potential to disperse sufficiently long distances to move out of reserves. For example, in South Africa, recreational game fish, the galjoen (*Dichistius capensis*), were tagged inside the De Hoop reserve and tag recoveries were monitored. Of 11,022 fish tagged, 1008 were recovered, and of these, 828 where recovered within 5 km of where they were released. The remaining 180 (18%) were recovered at least 25 km from where they were released, and the maximum distance that any fish traveled was 1040 km (Attwood and Bennett 1994).

Tagging studies in and around the Merritt Island National Wildlife Refuge in Florida, documented movements of red drum (*Sciaenops ocellatus*), spotted seatrout (*Cynoscion nebulosus*), black drum (*Pogonias cromis*), striped mullet (*Mugil cepalus*), common snook (*Centropomus undecimalis*), and sheepshead (*Archosargus probatocephalus*) from unfished to fished areas (Johnson et al. 1999).

If animals are moving out of reserves, then densities should be higher in areas close to reserve boundaries than far away. Ratikin and Kramer (1996) found this type of evidence for spillover in Barbados. In experimental trap fishing, they found highest catches and catch per unit effort inside the Barbados Marine Reserve. However, outside the reserve catches increased approaching the boundary from both the north and the south. Russ and Alcala (1996b) found a gradual increase in densities of fish outside Apo Island reserve in the Philippines, but very close to its boundary. This effect only became apparent after the reserve had been protected for 9 years, suggesting that this time was required for critical densities accumulated inside the reserve.

McClanahan and Kaunda-Arara (1996) found a 110% enhancement of catch per unit effort in fishing grounds close to the Mombasa Marine National Park in Kenya. This may have been due to a combination of spillover from the reserve and recruitment enhancement.

In Sumilon Island, Alcala and Russ (1990) found that catch per unit effort and total catches decreased by half after reserve protection broke down, despite a larger area of fishing grounds becoming available. This suggests that the reserve may have supported the fishery through a combination of spillover and recruitment enhancement.

Single-species closures provide further evidence of spillover. Spiny lobster (*Panulirus argus*) are protected from fishing in their nursery ground in the Biscayne Bay Spiny Lobster Sanctuary. As they grow, the lobsters move to fishing grounds in the Florida Keys where they may be harvested by commercial trappers (Davis and Dodrill 1980).

Closures for snow crab in Japan also led to higher catches nearby (Yamaski and Kuwahara 1990).

The most compelling evidence that spillover is significant can be found in changing patterns of fishing effort following reserve establishment. In places where there are well-respected reserves, “fishing the line” or fishing close the reserve boundaries, becomes increasingly prevalent. There are growing numbers of examples of fishing the line in different places in the world. Recreational anglers were frequently observed fishing the edge of the Merritt Island National Wildlife Refuge in Florida (Johnson *et al.* 1990). Several world record fish were caught near the Merritt Islands National Wildlife Refuge, including four red drum (*Sciaenops ocellatus*) and one black drum (*Pogonias cromis*), and three spotted seatrout (*Cynoscion nebulosus*). Conch and lobster fishers in Belize preferentially fish close to the edge of the Hol Chan marine reserve (Polunin and Roberts 1993). In Spain, fishers report 50-85% higher catches close to the Tabarca marine reserve after 6 years of protection (Ramos-Espla and McNeill 1994). Fishing patterns show that spillover does happen and it does benefit local fishers.