FOUR

What Marine Reserves Can Accomplish

> A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it does otherwise.
>
> —Aldo Leopold, 1949

Single-species management practices are like automobile maintenance: Action is only taken when a problem occurs or a part breaks. Ecosystem-based management however is likened to airplane maintenance, where the overall goal is to maintain the total system by preventing the failure of all important systems and components (Bohnsack 1998b). Because both ecosystem management and airplane maintenance share a common goal of avoiding crashes, both require (1) understanding how various systems operate, (2) building precautionary margins of safety into all operational systems, and (3) continuous monitoring of all critical elements. Marine reserves are often acclaimed as the marine ecosystem management tool par excellence, and their potential to provide a host of benefits has been repeatedly and positively reviewed (Box 4.1). What is the factual basis for these claims?

Despite their rising popularity, the application of marine reserves to marine conservation and fisheries management remains in its infancy. As the use of marine reserves continues to grow globally, our understanding of their effects on both exploited (i.e., those species that are targeted in commercial and recreational fisheries) and unexploited marine species as well as marine communities and ecosystems has grown rapidly and will continue to do so. Although we are far from understanding the full potential for marine reserves as a management tool, there is overwhelming direct scientific evidence for many beneficial reserve effects, strong and growing evidence for others, and strong indirect evidence, theoretical, and common sense support for still more.

4.1 Findings from Selected Scientific Reviews of Marine Reserve Efficacy

The scientific literature on marine reserve efficacy continues to expand rapidly. Over the last decade alone, hundreds of peer-reviewed scientific articles and more than a dozen reviews of that extensive literature have been published. The following excerpts from some of those reviews provide an indication of the high degree of scientific documentation and support for reserves to accomplish stated objectives:

- Marine reserves, regardless of their size, and with few exceptions, lead to increases in density, biomass, individual size, and diversity in all functional groups. The diversity of communities and the average size of the organisms within a reserve are between 20 and 30 percent higher relative to unprotected areas. The density of organisms is roughly double in reserves, while the biomass of organisms is nearly triple. These results are robust despite the many potential sources of error in the individual studies. (Halpern 2003, p. S129)
- Based on evidence from existing marine area closures (i.e., marine no-take reserves) in both temperate and tropical regions, marine reserves and protected areas will be effective tools for addressing conservation needs as part of integrated coastal and marine area management. (NRC 2001, p. 2)
- There is compelling, irrefutable evidence that protecting areas from fishing leads to rapid increases in abundance, average body size, and biomass of exploited species . . . increased diversity of species and recovery of habitats from fishing disturbance . . . in a wide range of habitats . . . ranging from tropical to cool temperate zones. . . . Marine reserves typically lead to at least a doubling in the biomass of exploited species after three to five years . . . [and] can increase [biomass and offspring production] by orders of magnitude over levels in fishing grounds. . . . Even relatively small reserves could produce regionally significant replenishment of exploited populations. (Roberts and Hawkins 2000, p. 16–17)
- Networks of no-take marine reserves can (1) help recover fishery populations; (2) eliminate mortality of nontargeted species within protected areas due to bycatch, discards, and ghost fishing; (3) protect reserve habitats from damage by fishing gear; and (4) increase the probability that rare and vulnerable habitats, species, and communities are able to persist. (Murray et al. 1999, p. 15)
- Reserves will be essential for conservation efforts because they can provide unique protection for critical areas, they can provide a spatial escape for intensely exploited species, and they can potentially act as buffers against some management miscalculations and unforeseen or unusual conditions. Reserve design and effectiveness can be dramatically improved by better use of existing scientific understanding. (Allison et al. 1998, p. S79)
- The benefits that can reasonably be expected from an appropriate system of marine reserves are extensive and substantial. Many have been repeatedly documented and conclusively established at a number of existing reserves in a variety of environments. (Sobel 1996, p. 16)
- There is overwhelming evidence from both temperate and tropical areas that exploited populations in protected areas will recover following cessation of fishing and that spawning stock biomass will be rebuilt. (Roberts et al. 1995, p. 5)
- Marine reserves commonly support higher densities and larger sizes of heavily fished species than are found outside reserves. (Rowley 1994, p. 233)
- Evidence from existing marine reserves indicates that increased abundance, individual size, reproductive output, and species diversity occurred in a variety of marine species in refuges of various sizes, shapes, and histories in communities ranging from tropical coral reefs to temperate kelp forests. (Dugan and Davis 1993a, p. 2029)

- Although there is overwhelming evidence of increases in the abundance, size, and biomass of exploited species in protected areas, many of the outcomes of diversity and species composition are not predicted. (Jones et al. 1992, p. 29)
- It has now been well established that the abundances of and average sizes of many larger carnivorous fishes increase within protected areas. Smaller fishes and species from different trophic levels show similar patterns where they are targeted by fishermen. (Roberts and Polunin 1991, p. 82)

Despite this substantial evidence, it will be a long time, if ever, before one can conclusively prove that marine reserves will improve fish catches overall to everyone's satisfaction. Scientific study of marine reserves is complicated by many factors, including:

- "control" and replication issues (both spatial and temporal),
- natural environmental and recruitment variability,
- the complicating effects of other management measures, and
- changes in fishing patterns or effort external to the reserves.

Even under these constraints, and considering how few and how small existing reserves generally are compared to the size of fished areas, science has made much progress in demonstrating reserves' potential to provide fishing and other benefits beyond their borders. As the evidence for reserve benefits continues to mount, peoples' comfort levels with reserves continue to grow. Furthermore, as reserve size, number, and design improve, the evidence for external fisheries benefits will also continue to grow. There is much more to reserve benefits than just fishery benefits, and they may not even be the most important, but clearly demonstrable fishery benefits would likely aid stakeholder acceptance.

THE SCIENTIFIC EVIDENCE

Among the more recent, comprehensive, and rigorous reviews of marine reserve impact, Halpern and Warner (2002) carefully analyzed published results from eighty-nine separate studies spanning the globe. They reviewed only studies that (1) involved strictly no-take marine reserves; (2) provided survey data from before and after reserve creation or from inside and outside the reserve, or both; (3) addressed one or more of four key biological measures (density, biomass, size, and diversity of organisms); and (4) focused on reserves where no known harvesting had occurred. The results provide clear, strong, and unequivocal evidence ($p < 0.001$) that marine no-take reserves generally produce positive changes or increases in overall density, size, and biomass of organisms, and increase biodiversity, as measured by species richness, within their boundaries. Despite the recognized limitations in available data and in their comparability, the qualitative and quantitative analyses performed leave little doubt regarding the positive impact of reserves on these biological parameters.

The Halpern and Warner study went further than prior work in estimating mean changes to these parameters at marine reserves and provides an indication of the magnitude of the changes one can expect within them. The study concludes that reserves appear on average to roughly double the density, triple the biomass, and increase organism size and diversity 20 to 30 percent compared to controls. A similar analysis restricted only to peer-reviewed studies demonstrated even greater increases (Fig. 4.1; PISCO 2003). Such averages are useful, but should be used with caution given variability among sites and species.

The burgeoning marine reserves literature identifies numerous proposed, potential, and documented benefits for reserves. Most potential benefits fall under one of four broad categories: (1) protect ecosystem structure, function, and integrity; (2) improve fisheries; (3) expand knowledge and understanding of marine systems; (4) enhance nonconsumptive opportunities. These categories should be considered overlapping rather than discrete. For example, protecting ecosystem structure, function, and integrity clearly contributes to and overlaps with all three of the other broad categories. Likewise, the enhanced understanding and knowledge of marine systems stemming from marine reserves and their study are essential to or contribute to each of the other broad categories. Box 4.2 provides a list of approximately fifty identified benefits, classified under these four broad headings. These benefits were identified by marine scientists and other reserve experts as ones that can be reasonably expected to result from an effective system of marine no-take reserves complemented by other management measures. In some cases, the degree of benefit may vary for individual species and be dependent on both their life histories and the reserve design (Bohnsack 1998a; Sobel 1996).

In the sections that follow, we review the experience with marine reserves and their efficacy for achieving specific benefits under these four broad goals as well as the mechanisms by which marine reserves produce these benefits.

PROTECTING ECOSYSTEM STRUCTURE, FUNCTION, AND INTEGRITY

As an integral component of ecosystem-based management, one of the most common goals of marine reserves and marine reserve networks is to preserve

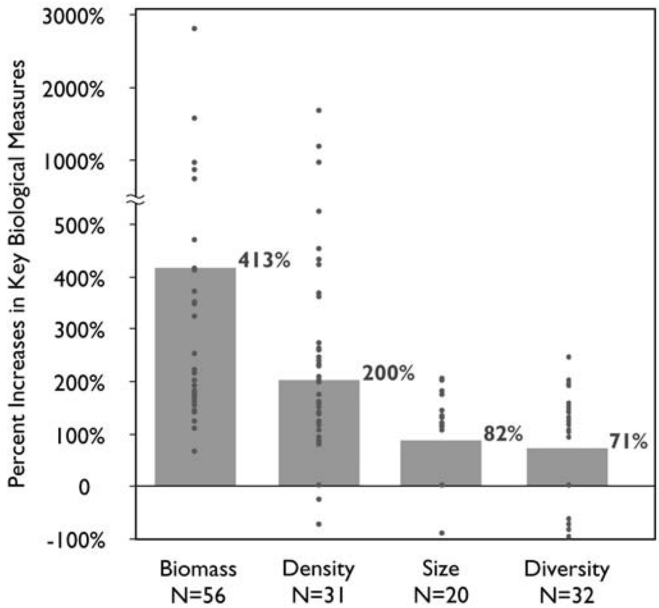

FIG. 4.1 Quantitative Analysis of Marine Reserve Impact on Key Biological Measures. Graph shows average percent increase in biomass (+413 percent), density (+200 percent), size (+82 percent), and diversity (+71 percent) within marine reserve borders based on analysis of results from peer-reviewed studies on marine reserves spanning the globe. Source: Adapted and reprinted with permission from PISCO 2003. Data courtesy of Halpern 2003 and Palumbi 2003.

ecosystem properties or characteristics and the processes that control or regulate them. This is true of both the ecosystems defined within the reserves and the larger ones of which they are a part. Within marine reserves, natural processes that preserve ecosystem structure have the opportunity to exercise their influence over the distribution and abundance of species, the interactions among species within an ecological community, and the pathways through which matter and energy flow.

Among the most commonly documented effects that reserves have on marine ecosystems are those in which the abundance, density, population structure, or composition of exploited species is changed within them. Because marine reserves prohibit all forms of fishing and other extractive activities within their boundaries, targeted species benefit the most from reserve protection. By eliminating fishing and other forms of exploitation from an area, a significant source of mortality is removed, and a greater number of target or exploited fish and invertebrates survive. Because extraterritorial marine reserve effects are contingent on changes occurring within the reserve it is also expected that these would be observed first.

4.2 Potential Benefits of Marine Reserves

Protect Ecosystem Structure, Function, and Integrity

- Protect physical habitat structure from fishing gear and other anthropogenic impacts
- Protect biodiversity at all levels
    - Prevent loss of vulnerable species
    - Restore population size and age structure
    - Restore community composition (species presence and abundance)
    - Protect genetic structure of populations from fisheries selection
- Protect ecological processes from the effects of exploitation
    - Maintain abundance of keystone species
    - Prevent second-order and cascading ecosystem effects
    - Prevent threshold effects
    - Maintain food web and trophic structure
    - Ensure system resilience to stress
    - Retain natural behaviors
- Maintain high-quality feeding areas for fish and wildlife
- Leave less room for irresponsible development
- Promote holistic approach to ecosystem management

Enhance Nonconsumptive Opportunities

- Enhance and diversify economic opportunities
- Enhance and diversify social activities
- Enhance personal satisfaction by
    - Improving peace of mind for naturalists, conservationists, and other passive users
    - Enhancing aesthetic experiences
    - Enhancing spiritual connection to natural resources
- Enhance nonconsumptive recreational activities
- Create opportunities for wilderness experiences
- Enhance educational opportunities
- Promote ecotourism
- Create public awareness about environment
- Build conservation ethic
- Increase sustainable employment opportunities
- Stabilize the economy

Improve Fisheries

- Increase abundance of overfished stocks
- Reduce fishing for vulnerable species
- Reduce bycatch and incidental fishing mortality
- Simplify enforcement and compliance
- Reduce conflicts between users
- Provide resource protection with little data and information needs
- Enhance reproduction
    - Increase spawning stock biomass
    - Increase spawner density
    - Provide undisturbed spawning sites
    - Increase spawning potential and stock fecundity
    - Provide export of eggs and larvae

- Enhance fisheries via spillover of juveniles and adults
- Provide insurance against management failure
- Accelerate recovery after stock collapse
- Support trophy fisheries
- Provide data for improved fisheries management
- Increase understanding of management
- Facilitate stakeholder involvement in management
- Protect population genetics and life history characteristics from selective fishing
- Enhance recruitment

Expand Knowledge and Understanding of Marine Systems

- Foster understanding of natural systems
- Provide long-term monitoring sites free of human impacts
- Provide continuity of knowledge in undisturbed sites
- Reduce risk to long-term experiments
- Provide experimental sites needing natural areas
- Provide focus for study
- Enhance synergies from cumulative studies at one site over time• Provide undisturbed natural references for studies of fisheries and other anthropogenic impacts
- Allow studies of natural behaviors
- Provide natural sites for education

Adapted from Sobel 1996 and Bohnsack 1998a.

Studies of marine reserves of all shapes and sizes, in a variety of temperate and tropical marine systems, have documented a greater relative abundance or density of exploited fish and invertebrate species within reserves than outside reserves in areas subject to fishing (Fig. 4.1 and 4.2). Although few individual studies of this sort can conclusively demonstrate that observed differences are due solely to the protection afforded by the reserve rather than to other factors that may differ between reserve and nonreserve areas (e.g., habitat quality), the large number of studies involving different species from different places that show the same pattern of higher densities in reserves provides strong evidence that reserve protection is responsible for observed differences (Dugan and Davis, 1993a; Halpern and Warner 2002; NRC 2001; Roberts and Hawkins 2000; Roberts et al. 1995; Ward et al. 2001).

Considerable evidence that marine reserves are capable of increasing the abundance or density of exploited species is also provided by studies that have examined the change in the abundance or density of exploited species in an area over time before and after a reserve has been created. These studies typically show an increase in the abundance of exploited species within the reserve area for several years following its designation. As with spatial comparisons of species abundance or density within versus outside reserves, comparisons of

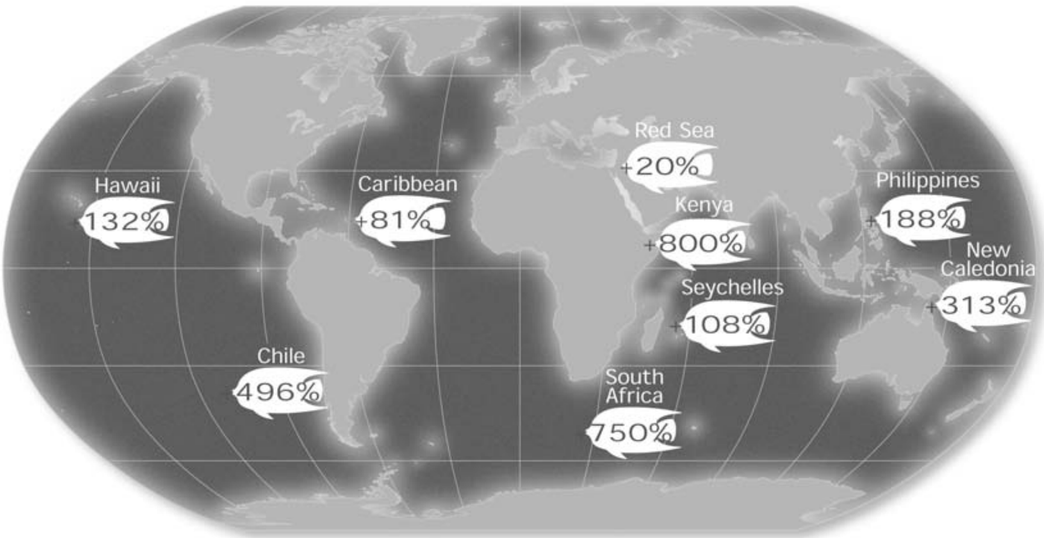

FIG. 4.2 Average Increase in Fish Biomass within Marine Reserve Borders by Location. Around the world, marine reserves have demonstrated the ability to increase fish biomass inside their boundaries. The numbers on this map show average increases of fish biomass inside marine reserves after the reserves were established for nine locations based on quantitative analysis of 32 peer-reviewed marine reserve studies. Source: Jerome N. Cookson based on data from Halpern and Warner (2002).

abundance or density before and after the implementation of reserve protection may be confounded by other factors. In this case, factors that vary over time in both reserve and nonreserve areas (e.g., recruitment or the arrival of new individuals to an area) may cause the observed changes in density, rather than the protection from exploitation within the reserve. Even with such limitations, the collective weight of evidence from the large number of studies demonstrating such increases is compelling (Dugan and Davis 1993a; Halpern and Warner 2002; NRC 2001; Roberts and Hawkins 2000; Roberts et al. 1995; Ward et al. 2001).

Studies in which density of an exploited species greatly increased over time within a reserve but did not increase substantially outside of the reserve support the case that the protection offered by the reserve is responsible for observed increases in density. For example, in a reserve that encompasses rocky intertidal habitats along the coast of Chile, the density of a harvested gastropod, the loco (*Concholepas concholepas*), increased steadily after an area was fenced off to create a marine reserve. The increase in this predatory gastropod led to a trophic cascade discussed later in this section that transformed the entire local community. In areas outside the reserve, however, there were virtually no increases in loco density (See later this section and chapter 11; Castilla et al. 1994; Durán and Castilla 1989).

Similarly, studies that show reversible changes in abundance following the creation of marine reserves and their subsequent reopening to fishing strengthen the case that observed changes in abundance are due to reserve protection. In the Philippines, this pattern is evident in the abundance of exploited fish over time following the creation of two marine reserves and the subsequent reopening and closing of one of the reserves to fishing (Fig. 4.3 and chapter 11). In the reserve that was continuously closed, there was a steady 12-fold increase in the density and a 17-fold increase in the biomass of large predators over a ten-year period, and increases appeared to be continuing at a steady rate (Russ and Alcala 1996, 1998, 1999, 2003). Clearly, such a shift in the predator guild would likely also have impacts on community structure, predation, competition, energy flow, and other ecosystem properties.

In addition to increasing the abundance or density of exploited species, marine reserves have often been shown to increase the average size of exploited species or to increase the proportion of large individuals in the population. For example, a study of spiny lobster (*Jasus edwardsii*) populations inside and outside a New Zealand marine reserve found that both density and mean size of lobsters increased within the marine reserve for several years, and that the largest lobsters and most lobsters beyond the legal size limit were found within the marine reserve. Female density and size continued to increase throughout the study, though male increases leveled off, probably due to migrations of large males outside of the reserve where they were subject to fishing (MacDiarmid and Breen 1992). Another study of spiny lobster in four New Zealand marine reserves compared populations within the reserves to similar sites nearby, and conservatively estimated increases in density of 3.9 percent per year and 9.5 percent per year in shallow and deep water sites, respectively, with a similar but somewhat higher rate of increase for biomass and egg production (Fig. 4.4; Babcock et al. 1999; Kelly et al. 2000).

Given the ecosystem-focused spiny lobster discussion in chapter 1, how did these changes impact the surrounding ecosystem? Babcock et al. (1999) studied this question and found that, in addition to the changes in the lobster population,

1. abundances of the most common demersal predatory fish, the New Zealand snapper (*Pagrus auratus*) (also discussed in chapter 3), large enough to feed on urchins were six to nine times more abundant within two of the marine reserves than outside;

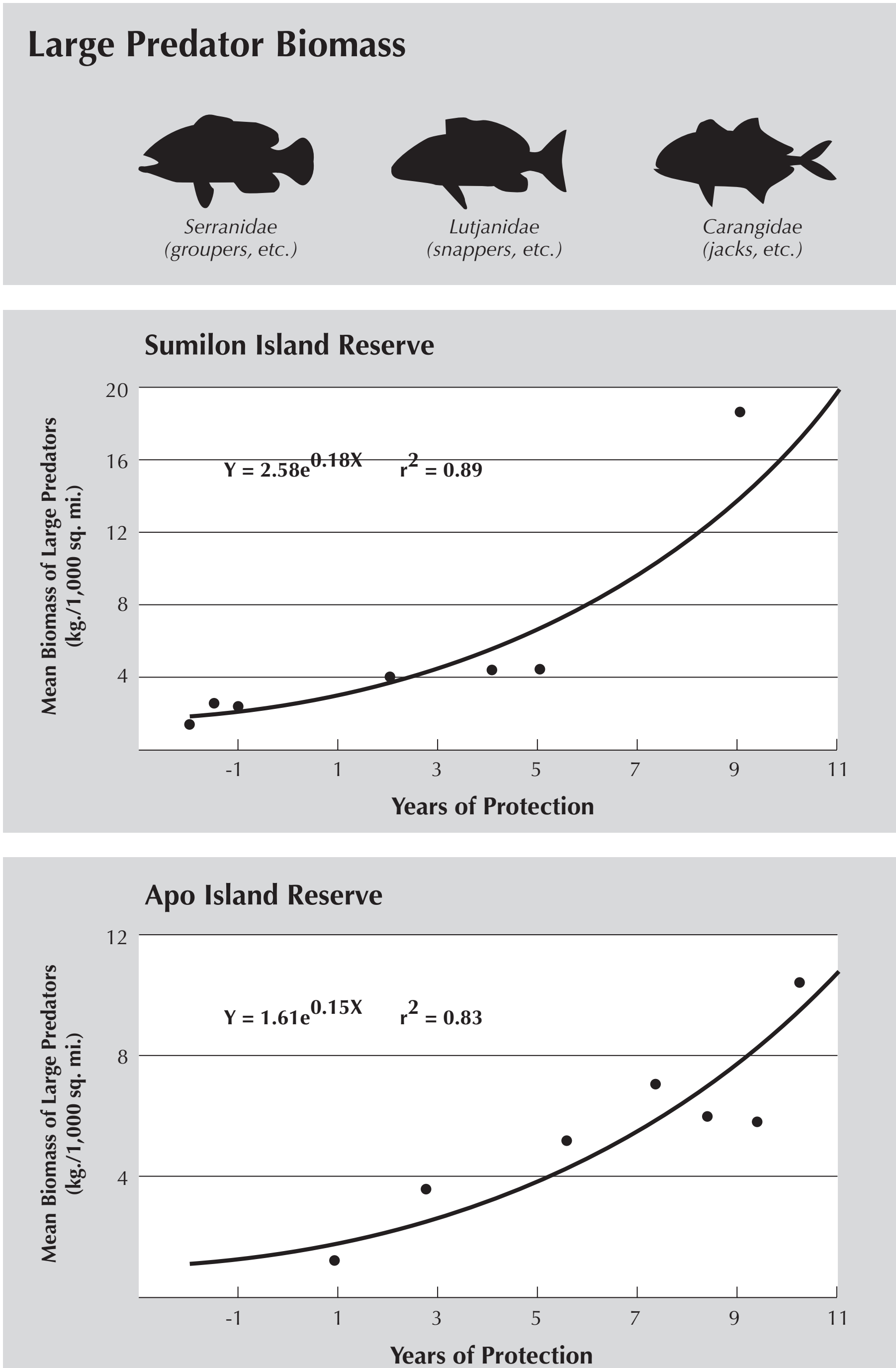

FIG. 4.3 Changes in Biomass of Large Predators within Two Philippine Marine Reserves (Sumilon Island and Apo Island Marine Reserves) Following Closures versus Length of Time Protected. Large predator biomass continues to increase exponentially in both reserves and had increased more then 17-fold at Apo following 18 years of protection. Source: Adapted with Permission from Russ and Alcala 2003.

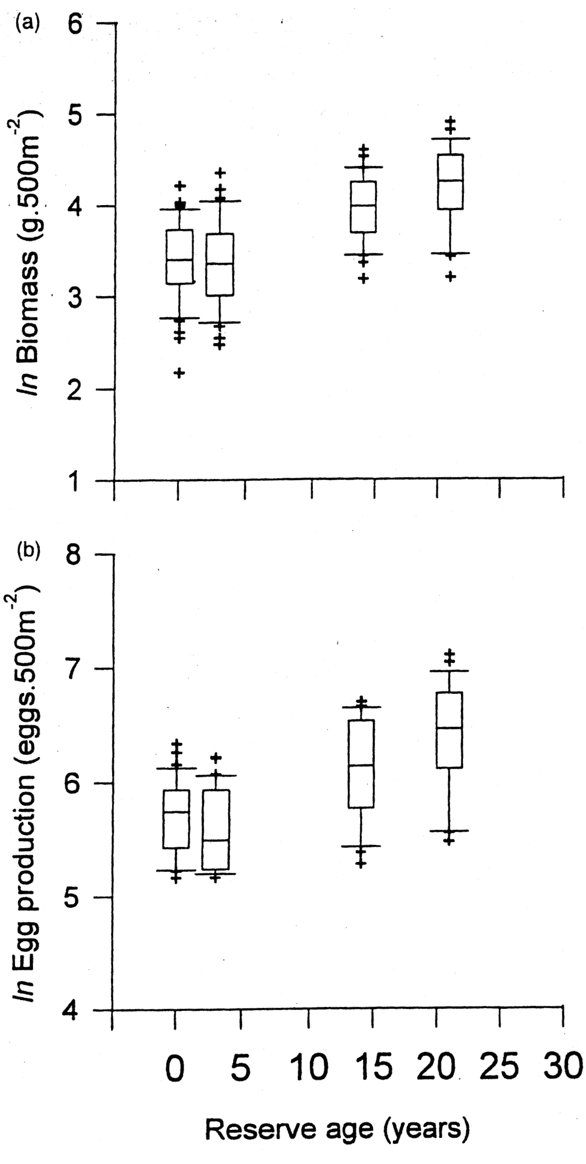

FIG. 4.4 Changes in Spiny Lobster Biomass and Egg Production in New Zealand Marine Reserves Following Protection. Boxplot using natural log of (A) biomass and of (B) egg production versus reserve age to compare marine reserves of different ages. Source: Kelly et al. 2000, reprinted with permission from *Biological Conservation.*

2. sea urchin (*Evechinus chloroticus*) abundance had declined in areas frequented by it in one of the reserves from 4.9 to 1.4/m^2 since its creation;
3. kelp forest cover had increased within the reserves since their creation;
4. urchin dominated barrens covered only 14 percent of available reef area in the reserve compared to 40 percent outside; and concluded that

5. these changes in community structure reflected increased primary and secondary production within the reserves as a result of protection; and conversely that
6. trends within the reserve indicated diminished production outside of the reserves due to fishing activity (see also chapter 11).

Restoration of otherwise heavily fished lobster and snapper populations within the reserves as a result of reserve protection appears to have triggered a trophic cascade and resulting transformation of the reserve ecosystem, shifting it back toward a possibly more natural one favoring kelp forest habitat. Given the widespread importance and impact of these fisheries in New Zealand (Hauser et al. 2002) and similar fisheries around the world, this provides insight into their impact, the causes of the ecosystem changes previously described, and the ability of reserves to help understand and reverse or mitigate such changes.

Increases in size have been reported for a variety of exploited fish and invertebrate species in marine reserves around the world. This effect on size results for two primary reasons. First, because fishing often targets larger individuals, larger individuals of exploited species are often rare in fished areas, and the mean size of animals is smaller than it would be under natural selective pressures (e.g., predation and competition), which often favor larger individuals. Because marine reserves prohibit the selective removal of large individuals by fishers, natural selective processes can determine the size structure of exploited species populations. The second reason why exploited species are often larger within marine reserves is because many marine species grow throughout their entire life. In marine reserves, the absence of high mortality rates resulting from fishing allows exploited species to survive to older ages and gives them more time to grow. Size differences between reserve and nonreserve areas are likely to occur in places where fishing pressure is high and strongly size selective outside of reserves, but effectively excluded from within the reserve (Chapman and Kramer 1999; Roberts and Polunin 1992). It is also important to note that a reserve's effect on size may take time to become noticeable because species within the reserve must outlive and consequently outgrow their conspecifics in nonreserve areas, and may be confounded by the effects of recruitment and emigration.

Although it is not surprising that the density and sizes of exploited species increase within reserves and are higher than in surrounding areas subject to fishing, these effects have important implications for the ability of reserves to provide specific benefits, including ones related to improving fisheries, protecting ecosystems, and conserving biodiversity. Reproductive output is often size dependent for many exploited fish and invertebrate species, with the number of eggs produced by a female often increasing as a third power function of her length. Red snapper (*Lutjanus campechanus*) provide a good example of this: a single 61 cm female produces the same number of eggs as 212 42 cm females (Figure 4.5; NMFS 1990). Consequently, if large individuals are more common inside a reserve, a relatively small number of such large individuals within a reserve can contribute a disproportionately large amount to reproduction, which may be essential to the viability and recovery of the species.

As discussed in chapter 1, exploitation has reduced the abundance of several species to levels where they are threatened or endangered with extinction. Some of these species are those that suffer from Allee effects, in which reproductive output declines greatly or ceases altogether below a particular density threshold. Many invertebrate species with limited mobility such as abalone, sea urchins, and conch, for example, exhibit Allee effects at low densities (e.g., Levitan et al. 1992; Stoner and Ray-Culp 2000; Tegner 1993). In fished areas, the densities of these species are often reduced below the level required for reproductive success or below some minimum viable population size, reducing their chance of recovery. Within reserves, however, densities of these species may be maintained at a high level, and reproduction within reserves may be essential for the short-term preservation and long-term recovery of the species.

Marine reserves can also preserve other natural aspects of the population structure, life history characteristics, and even genetic composition of populations that have been altered by selective fishing pressure. For example, in several exploited fish and invertebrate species, males and females may grow to different sizes. Because fishing often targets larger individuals, the sex ratio or ratio of males to females may be altered dramatically. For species in which females grow to larger sizes than males, the effect of fishing that removes larger individuals can greatly reduce the number of eggs produced by the population and limit its ability to replenish itself. The same problem occurs for species in which males grow to larger sizes than females and males are selectively removed from the population by fishing. In several important fisheries species fertilization success is directly related to sperm density and motility, both of which may be lower for smaller males. Moreover, smaller males may not be as successful in mating as large males. Thus severe changes in the ratio of males to females may result in a shortage of males and, subsequently, reduced reproductive success (Trippel et al. 1997).

For several exploited species in which males are larger than females, the females can actually change sex and become males as they get older and larger.

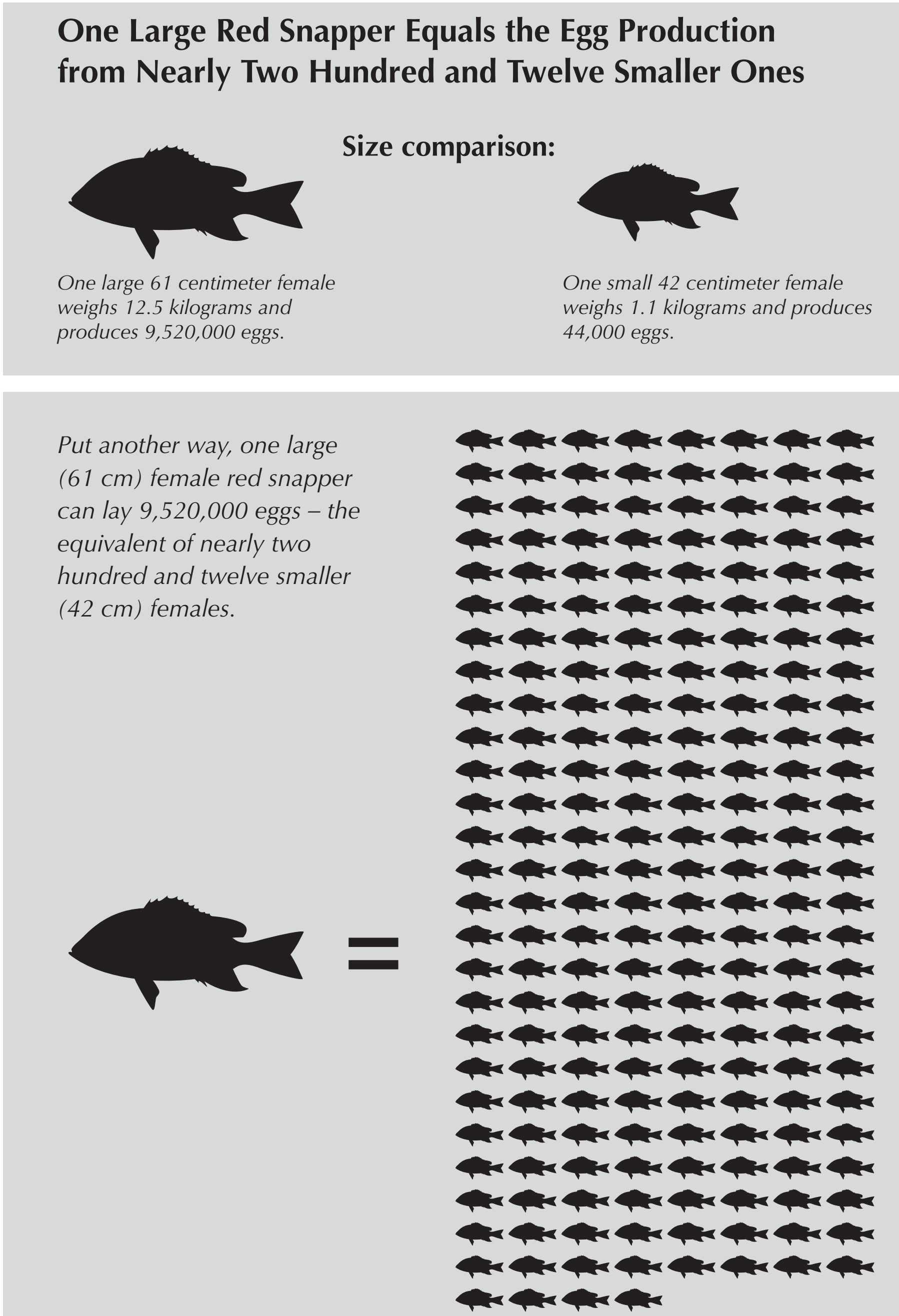

FIG. 4.5 All Fish Are Not the Same: The Importance of Large Individuals. A single large female red snapper (*Lutjanus campechanus*) produces as many eggs as 212 smaller ones. Large females of many other species are similarly important. For other species, including certain groupers and spiny lobster, large males can also be important for successful fertilization. Current research is also elucidating the importance of large individuals with respect to quality of eggs and larvae in addition to quantity. Source: Data from NMFS PDT (1990).

This is common for groupers and other reef fish. As fishing selectively removes larger males, females may begin changing to males at smaller sizes. This can severely reduce egg production as the average size of females is reduced, and may reduce the ability of males to fertilize eggs as the average size of males is reduced. Thus fishing that selectively removes larger males may reduce reproductive rates no matter how the population responds. Within reserves, however, protection from exploitation that allows exploited species to survive to larger sizes can maintain sex ratios at natural levels and allow changes in sex to occur at natural sizes. For example, a spawning aggregation of red hind (*Epinephelus guttatus*) was fished to such an extent that the more natural ratio of females to males, approximately 4:1 (which may also have been distorted due to earlier lower levels of fishing), was skewed to as many as 15:1. Closing the spawning area to fishing returned sex ratios to more natural levels after about seven years of protection (Beets and Friedlander 1999). Unfortunately, the more vulnerable Nassau grouper (*Epinephelus striatus*) once shared the same spawning site but has not yet made a similar comeback despite the closure of the area to fishing.

By increasing the abundance and size of exploited species and preserving natural characteristics of their population structure and life history, marine reserves can further protect these species from harmful human impacts. For example, if any characteristics that are altered by fishing are genetically based, changes in characteristics of the population may reflect changes in the genetic composition of the population or a reduction of the genetic variability of the population. Such reduced genetic variability may reduce the resistance or resilience of the species to changes in factors that influence the population. By maintaining natural population structure and life history characteristics, marine reserves may serve as a repository for natural genetic characteristics of the species and may be critical for maintaining the long-term viability of the population.

The galjoen (*Coracinus capensis*) endemic to southern Africa and among its most popular and exploited recreational fish species provides another documented example of human alteration to the genetics of a wild fish population, discovered via a marine reserve. Two separate populations of galjoen exist with apparently limited movement between them. Mark recapture studies conducted within and surrounding the Hoop Marine Reserve strongly suggest that observed dispersal behavior is best explained by genetic differences resulting alternatively in resident versus nomadic behavior. Further, the emigration estimated from the reserve suggests that the 50 km reserve is not only protecting the population's genetic characteristics but is also contributing to this recreational fishery by providing an unassailable source of mature fish to nearby and distant exploited areas (Attwood and Bennett 1994).

Even when the characteristics affected by fishing are not genetically based, the preservation of the natural characteristics of exploited species by marine reserves can still provide numerous benefits. Increases in abundance and size as well as preservation of sex ratios and life history characteristics within marine reserves may all contribute to preserving the reproductive capacity of these species and their ability to replenish their populations. Similarly, marine reserves may help to buffer exploited species against population fluctuations that, when coupled with high levels of exploitation, may threaten the species. Variable environmental conditions and other factors may make replenishment of exploited species infrequent. A single cohort or year-class may constitute the majority of a population, whose long-term viability may depend on reproductive output from this single year-class. In fished areas, strong year-classes may be rapidly reduced or even wiped out entirely as soon as they are large enough to be caught in the fishery, limiting or eliminating their contribution to the population's reproductive output. Within marine reserves, however, strong year-classes are preserved in the population's structure (e.g., Ferreira and Russ 1995; Russ et al. 1998), and can continue to replenish the population for a number of years until another strong year-class can also contribute to the population. Thus marine reserves can help to stabilize population fluctuations and ensure against population crashes that may occur in fished areas.

Marine reserves may also affect nonexploited species and the structure and function of ecological communities and entire ecosystems. For example, fish and invertebrate assemblages within marine reserves often have higher species richness or diversity than do fished areas (e.g., Jennings et al. 1996, 1995; McClanahan 1994; Wantiez et al. 1997). In the absence of fishing, processes such as predation and competition for limited resources can limit or regulate the distribution and abundance of species and the organization of species into ecological communities. In most areas of the sea, these processes may still operate, but their effects are often masked or overshadowed by the dominant effects of fishing, which removes certain species and alters the balance of marine ecosystems. Often, species selectively removed by fishing play an important role in structuring the ecosystem.

In marine reserves however, all components of the ecosystem are preserved, and natural processes are allowed to dominate how the ecosystem is structured. In the rocky intertidal zone of Chile, a predatory gastropod called the loco is commonly harvested for food. In most areas, where locos are fished, their abundances are low. As a result, their preferred prey, mussels, are able to cover up to 100 percent of the intertidal zone because they are competitively dominant over barnacles, kelp, and other organisms for the limited space available on the rocks. Within a marine reserve, however, loco abundance or density is much greater, which increases their impacts as predators and reduces populations of mussels. The reduction in mussels on the rocks opens up space that can be colonized by barnacles, kelp, and other inferior competitors. The resulting dramatic transformation of this rocky intertidal landscape provides a whole new and different vision of its natural condition. Thus the increase in abundance of an exploited species that serves as a keystone predator, in this case, the loco, directly and indirectly affects other species in the community at lower levels of the food chain. (See also chapter 11; Castilla et al. 1994; Durán and Castilla 1989).

Nonexploited or nontarget species that may benefit the most from protection within marine reserves are those species that are taken as bycatch outside reserves. Because fishing is prohibited in marine reserves, the incidental take of nontarget species or bycatch is also eliminated within them. For species that suffer greatly from being taken as bycatch, like the barndoor skate, marine reserves may be the only areas where viable populations still exist (Casey and Myers 1998).

Nonexploited and exploited species alike may also benefit from the ability of reserves to protect habitats from destructive fishing gear and other human impacts. As mentioned in the previous chapter, marine habitats face multiple human impacts, including threats from fishing. Because habitat characteristics often have an important influence on the distribution and abundance of fish and invertebrates, habitat preservation by reserves may affect both exploited and nonexploited species. In a marine reserve in New Caledonia, for example, the species richness of reef fish increased by 67 percent in marine reserves but did not increase in fished areas (Wantiez et al. 1997). As the distribution and abundance of species change in response to habitat protection, the composition and structure of the ecological community may change to a more natural state.

By protecting both exploited and nonexploited species from various human impacts, marine reserves provide numerous benefits for ecosystem conservation. By protecting all components of the ecosystem and removing the dominant effects of exploitation, marine reserves allow “natural” processes to determine community and ecosystem structure and function. Unlike the case of fishing where it may be profitable to harvest every last individual of a particular species, many of these natural processes are driven by the density of various species or components of the ecosystem (e.g., the density of predators, prey, or competitors) and operate through negative feedback loops. Thus they may help to stabilize the ecosystem, making it resistant and resilient to change. Allowing ecosystems to be self-regulating or function under their own natural controls is one of the fundamental principles of ecosystem-based management.

IMPROVING FISHERY YIELDS

Although effective fisheries management requires that ecosystem structure, function, and integrity are maintained to some extent, it also requires that marine resources be optimally utilized for long-term sustainability (Dayton et al. 1995). We have already indicated how marine reserves can maintain ecosystem structure, function, and integrity, but can marine reserves also contribute to the optimal use of marine resources? It may seem counterintuitive to some that closing an area to fishing and thereby reducing the proportion of fish available to the fishery can actually enhance landings and allow the optimal use of marine resources, but marine reserves can do this in several ways.

One of the guiding principles for optimizing the sustainable use of marine resources is that the harvest of marine stocks cannot go unchecked. Limits must be placed on catches so that they do not exceed the ability of a species to replenish itself. In chapter 3, we briefly discussed traditional fishery management approaches to ensure this, their shortcomings and poor track record, and the use of marine reserves as a supplementary tool. Marine reserves can help prevent overfishing by providing a spatial refuge from fishing mortality. Such protection from overfishing may result from reduced overall fishing effort, but it can also arise with no overall reduction in fishing effort. As the difference in spawning stock biomass within and outside the reserve grows, even the displacement of fishing effort from reserve to nonreserve areas reduces average fishing mortality (especially for older and larger fish residing disproportionately in the reserve areas), provides increased protection against overfishing, and can provide a net benefit to fisheries.

Most modern fisheries management plans have target levels for maintaining spawning stock biomass, usually at levels on the order of at least 20 to 30 percent of the estimated unexploited spawning stock biomass. Because marine reserves contain higher abundances and larger individuals than surrounding areas, they can contribute significantly to conserving spawning stock biomass and sound fishery management. However, the size required for a reserve or reserve network alone to protect adequate spawning stock biomass may be quite large—20 to 80 percent of an area (e.g., Dahlgren and Sobel 2000). In some cases, proper placement of reserves may enhance their contribution disproportionally to their size. Even so, the utility of reserves for protecting spawning stock biomass may be greatest as a complement to other management tools and as insurance against the failure of those tools to protect sufficient spawning stock biomass.

In addition to simply safeguarding biomass against exploitation, marine reserves can actually support or enhance fisheries landings in several ways. For this to happen, the increase in abundance or biomass of exploited species within the reserve must be accompanied by a net export of individuals from the reserve to areas where they can be caught in the fishery. Moreover, for reserves to actually enhance fisheries productivity, increases in target species biomass outside the reserve must be greater than the biomass that would have been available to the fishery in the reserve area if it were not protected.

Reserves may serve to boost productivity in nonreserve areas in two ways: the net movement of juvenile or adult animals from the reserve to fished areas, often referred to as spillover, increases recruitment of older juveniles and adults into the fishery; and the net export of larvae from reserves to nonreserve areas increases settlement and larval recruitment initially, and recruitment into the fishery later. The terms *spillover* or *leakage* are often used synonymously to describe movement of older juvenile and adult fish and invertebrates out of a reserve and into fished areas, but it may be more appropriate to use the second of these terms to differentiate between how such animals move out of a reserve into the fishery.

Spillover is expected to result from the effects that reserves have on exploited species, such as the increase in density, size, or biomass within the reserve. For example, individuals may move or spill over from the reserve if their increase in abundance or biomass within the reserve results in a decrease in the per capita availability of resources, such as food or refuges. In this case, as the carrying capacity of a particular species is approached within the reserve, animals respond to crowding and the subsequent decrease in resource availability by moving to areas with lower abundance or biomass. Thus they may leave the reserve and enter the fishery. In addition to increases in density within reserves, increases in body size of exploited species within reserves can lead to increases in movement rates or home range size that can cause spillover. Because spillover results directly from the positive effects of marine reserves on the density, biomass, or size of exploited species, such movement from the reserve is expected to result in enhanced landings in fished areas adjacent to the reserve.

Furthermore, the reserve is also expected to produce numerous other benefits, such as preserving natural ecological community structure and protecting spawning stock biomass of exploited species.

In contrast, the term *leakage* can be used to refer to the case where movement out of the reserve is independent of reserve effects on abundance, size, or biomass. Ontogenetic habitat shifts, periodic migrations, home ranges that overlap with reserve boundaries, or other types of movements that may occur independently of the density or size of individuals may cause leakage from the reserve into the fishery. Because leakage refers to movement that is largely independent of any effects produced by marine reserves and animals "leaked" by the reserve may be caught in the fishery, it can prevent populations from approaching their maximum biomass, so it may limit other reserve benefits. Just like a leaky container doesn't fill with water, a leaky reserve may not accumulate biomass of exploited species. Although the overall benefits produced by leaky reserves may be limited, leakage may still allow some increases in biomass of exploited species within the reserve and the export of that biomass to fished areas. Thus landings adjacent to the reserve may be somewhat elevated, but not to the extent that a reserve with high spillover rates would. Similarly, even small increases in size and abundance within a reserve may provide some additional benefits to protecting ecosystem structure, function, and integrity. Although both spillover and leakage may be present to some degree for any species in any reserve, the different mechanisms underlying these movements may have implications on the effects or benefits of this movement.

Indirect evidence that reserves can support fisheries outside their borders via emigration comes from studies of the movement rates and distribution patterns of important fishery species. For example, mark and recapture experiments in reserves and adjacent exploited areas show that marked fish released within reserves were frequently caught outside the reserves (Attwood and Bennett 1994; Johnson et al. 1999; Munro 1998; Roberts et al. 2001). Although this movement by itself does not demonstrate that fisheries outside reserves were enhanced by reserves, it suggests that, as abundance and biomass of fishery species increase within reserves, emigration from reserves has the potential to enhance fisheries.

Examination of population distribution patterns provides further indirect evidence that juveniles and adults from reserves may support fisheries in exploited areas outside of reserves. Fish and invertebrates with home ranges in the center of a reserve are less likely to emigrate from the reserve and be captured in the fishery than those at the edge of the reserve. Therefore, population distribution characterized by decreasing density with increasing distance from the center of the reserve may indicate emigration from the reserve to exploited areas, which supports local fisheries, especially if such decreasing density continues outside of the reserve boundaries (Kramer and Chapman 1999; Rakitin and Kramer 1996). However, a decreasing trend only within the reserve itself could also be confounded by a poaching gradient.

Nassau grouper (*Epinephelus striatus*) within and outside of the Exuma Cays Land and Sea Park, a large Bahamian marine reserve, show a peak at the center of the reserve and decreasing density as distance from the center increases, including a continuing decline within fished areas outside the reserve (Fig. 4.6; Sluka et al. 1996; see also chapter 9, Bahamas case study). Such a pattern is consistent with spillover or leakage from the park into adjacent fished waters, but not with a poaching gradient alone. A poaching gradient could explain such a decrease within the park, but not beyond its borders.

Identifying direct and indirect evidence of emigration from reserves is an important step in testing hypotheses related to the potential of marine reserves to provide spillover benefits to fisheries but does not directly test whether this movement enhances fisheries. Net emigration out of the reserve is indicative of spillover and a prerequisite for such benefits. Resulting increased landings or catch per unit effort (CPUE) attributable to such movements are better evidence of fishery enhancement. Correlating such movement with the occurrence of increased landings near a reserve, provides even stronger evidence that movement out of the reserve is actually enhancing fisheries.

In lagoonal marine reserve zones within Florida's Merritt Island National Wildlife Refuge, originally protected for security reasons due to its proximity to the Cape Kennedy Space Center, increased abundance and mean size of recreationally targeted fish species inside the reserve, movement of tagged individuals out of the reserve and their capture in the fishery, and a proliferation of world record fish caught in adjacent areas, suggest that the reserve is supporting an important recreational trophy fishery in surrounding waters. (Fig. 4.7; Johnson et al. 1999; Roberts et al. 2001).

Further evidence of fishery enhancement by emigration from a marine reserve comes from the Sumilon Island Marine Reserve example discussed earlier and its adjacent reef fish fishery in the Philippines. In this case, a reserve was established for a number of years before it was opened to fishing. Catch per unit effort of local fishers was high when 25 percent of a reef was protected within a marine reserve, and decreased dramatically shortly after the entire reef was open to fishing (Alcala 1988; Alcala and Russ 1990; Russ and Alcala 1996).

The authors believed this was the result of spillover effects, but could also not rule out larval export as a factor. In Kenya, a large reserve encompassing over 60 percent of fishing grounds dramatically increased catch per unit effort in nearby fisheries (McClanahan and Kuanda-Arara 1996). Similarly, artisanal fisher catches adjacent to a network of five small reserves in St. Lucia increased from 46 to 90 percent, depending on gear type, within five years of their creation (Roberts et al. 2001). These three examples from St. Lucia, the Philippines, and Kenya demonstrate that emigration from reserves to fished areas can be important in supporting local fisheries; in fact landings actually increased when a significant portion of the fishing grounds was closed to fishing.

Whether or not emigration from a reserve can support or enhance fisheries, however, may depend on the underlying mechanism or process driving the movement. Although movement out of the reserve may provide a mechanism for transferring the increase in biomass (size and/or abundance) of exploited species from the reserve to the fishery, frequent movement out of the reserve and into the fishery may result in high capture rates of animals from the reserve and prevent biomass increases from occurring within the reserve.

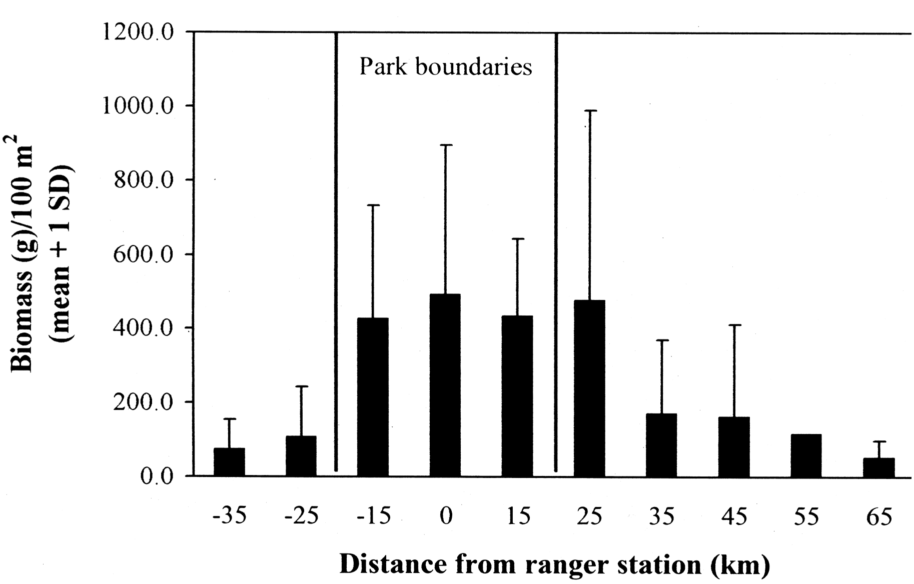

FIG. 4.6 Nassau Grouper Density Distribution within and outside Bahamian Marine Reserve. Graph shows relative density (biomass/area) of Nassau grouper versus distance from the ranger station located near the center of the Exuma Cays Land and Sea Park. Densities are much higher within the park and taper off away as you move away from it, consistent with emigration and net export out of it. Source: Adapted from Sluka, et al. 1997. Data provided by Mark Chiappone.

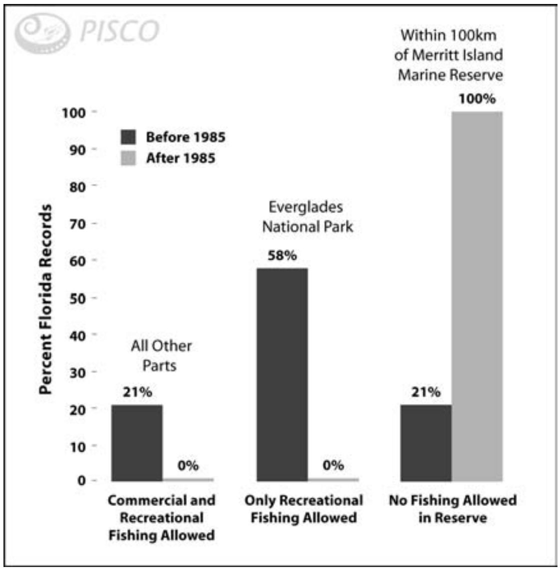

FIG. 4.7 Merritt Island Florida Marine Reserve and Adjacent World Record Catches. This graph compares the percent of Florida's world record catches coming from waters adjacent to the Merritt Island reserve to that of Everglades National Park and to all other parts of the state, both before and after 1985, when the reserve was established. Prior to 1985, Everglades National Park, where only recreational fishing is allowed produced most of the records. Since then, waters adjacent to Merritt Island reserve have produced nearly all of them. Source: Adapted and reproduced with permission from PISCO 2003.

Even though spillover, and to a lesser extent leakage, from marine reserves can enhance fisheries on local scales, marine reserves may provide more important benefits to fisheries on even greater spatial scales via larval export or replenishment. Unfortunately, it is much more difficult to demonstrate the fisheries enhancement benefits of marine reserves via enhanced larval supply because it is difficult to directly link the production of larvae within a marine reserve to enhanced landings elsewhere. Nevertheless, there are several lines of evidence suggesting that the export of larvae from marine reserves can support or enhance fisheries. In addition, developing techniques and technology are enhancing our capacity to directly link within-reserve production to landings outside (see chapter 7).

Most fisheries management tools operate on the premise that preserving a certain amount of spawning stock biomass in the sea is necessary for populations of exploited species to produce enough larvae to replenish themselves and support fisheries. Because the spawning stock biomass of exploited species is often higher in marine reserves than in fished areas, and larval production is correlated with the spawning stock biomass, marine reserves may contribute a disproportionately high amount of larvae to the regional population and support surrounding fisheries.

Marine reserves have additional advantages over other fishery management tools. Earlier in this chapter, we presented evidence that marine reserves often harbor greater spawning biomass of exploited species than surrounding fished areas due to both greater densities and larger sizes within reserves and discussed the likely greater reproductive output per area within the reserves than outside them. The simple fact that spawning stock biomass within reserves is often greater than in fished areas on a per unit area basis suggests that reserves make a disproportionately large contribution of larvae to the regional population. More and larger spawners can translate into greater reproductive output for most species, but this reserve effect can be even greater for those species that experience Allee effects. Such species can benefit tremendously from increased density within marine reserves, especially when heavily fished or depleted outside. Similarly, by permitting exploited species to grow to larger sizes than in fished areas where other management tools are used, other aspects of the natural population structure (e.g., male to female ratio) of exploited species are preserved, which can increase reproduction success. For any increase in reproductive output from reserves to enhance fisheries, the increased output must be transported to areas where larvae can settle and grow until they enter the fishery.

Although transport mechanisms can retain larvae locally within a reserve, currents are likely to advect or diffuse the majority of larvae for most marine species out of the reserve and replenish exploited stocks downstream unless the reserve is large. Because many reserves are only a few kilometers long, even if larvae only travel or mix over tens of kilometers before the settle from the plankton, it is likely that they will be transported out of the reserve and into areas where they may grow to enter the fishery.

Even when present, documenting fisheries enhancement by marine reserves through either spillover or larval replenishment may be difficult in practice. Russ (2002) and Jones et al. (1992) provide good overviews of the inherent difficulties of demonstrating such reserve effects. Consequently, various mathematical models have been used to predict the effect of marine reserves on fisheries. For example, a model developed by Hastings and Botsford (1999) found that marine reserves can produce yields similar to other fisheries management tools that are more commonly used. Similarly, several models suggest that larval export from marine reserves can support or enhance fisheries, particularly for species that are heavily exploited outside of reserves (Holland and Brazee 1996; Sladek Nowlis and

Roberts 1997, 1999; Sladek Nowlis and Yoklavich 1998). In addition, other models indicate that larval dispersal from reserves can reduce variability or uncertainty in fisheries management (Guenette et al. 2000; Lauck et al. 1998), or maintain genetic variability that may be reduced by fishing (Trexler and Travis 2000).

In addition to mathematical models indicating that the advection of larvae from a reserve can support or enhance fisheries, there is some direct evidence that increased larval production within a reserve can enhance recruitment of larvae in areas that are accessible to fishers. An example of this comes from the Bahamas, where the queen conch (*Strombus gigas*) is an important fishery species. The density of queen conch within a marine reserve there is several times higher than nearby areas that are fished. As a result, the density of early stage queen conch larvae was measured to be about ten times higher within and around a marine reserve than in fished areas further away. Late stage larvae (several weeks old), however, were not concentrated around the marine reserve but were dispersed throughout the region and concentrated in areas where hydrographic features retained them. Thus larval production within the park is likely to contribute substantially to supporting the conch fishery throughout the region (Stoner et al. 1998; Stoner and Ray 1996). As we gain a better understanding of larval transport and develop new techniques for determining where larvae and recruits were spawned, we will be able to further investigate this important benefit of marine reserves.

Marine reserves can also contribute to improved fisheries management and fisheries yields in other pragmatic ways. Enforcing other fishery management tools is often difficult since enforcement of these tools requires complex inspection and tracking systems. Management tools that limit catch or landings in the fishery require that all landings be inspected and tracked, often on the basis of an individual fisher. Management tools that limit or restrict fishing effort require tracking fishing effort in terms of the number of fishers, boats, or boat days fished, and/or the number and type of fishing gear used. In either case, to determine if a fisher or fishing vessel is operating illegally, enforcement officers must often board the vessel and inspect the fishing gear or catch to see if there are any violations. Within marine reserves, however, enforcement is simplified; because no fishing is allowed within marine reserves, all enforcement officers must do is determine whether a boat within a marine reserve is fishing or not. This benefit of marine reserves is very attractive in areas where there is limited capacity for fisheries enforcement.

At the cusp of improving fisheries and expanding our knowledge and understanding of marine ecosystems, marine reserves can play a critically important and frequently overlooked role in providing reliable stock assessment and other information necessary for sustainable fisheries and other purposes. Schroeter et al. (2001) used information gleaned from a long-term fisheries independent monitoring program that included reserve and nonreserve sites to assess a new dive fishery for warty sea cucumbers (*Parastichopus parvimensis*) in California's Channel Islands. The long-term data showed a decrease in abundance throughout the Channel Islands within three to six years after the onset of the fishery. Using before–after, control–impact (BACI) analyses, they implicated fishing mortality as responsible for a 33 to 83 percent decline in stocks. By contrast, traditional CPUE data showed no declines and even an increase for one island.

EXPAND KNOWLEDGE AND UNDERSTANDING OF MARINE ECOSYSTEMS

Several marine reserves have been created in areas near marine laboratories for scientific reasons (e.g., Leigh Marine Reserve [Ballantine 1994] and Hopkins Marine Reserve [Paddack and Estes 2000]). Marine reserves can enhance scientific research and education in several ways. The simple fact that marine reserves may be used to separate different uses of marine resources contributes to this benefit of marine reserves. It is difficult for scientists to conduct controlled experiments in a marine environment when components of their experiments are being captured and eaten or otherwise disrupted by human impacts. By setting aside areas of the sea that are free from many human impacts, scientists may be able to conduct more effective experiments and learn more about the marine environment. The understanding gained from such experiments is essential for the effective management of marine environments.

Similarly, by setting aside areas of the sea that are free from fishing and other human impacts, scientists have "control" areas to study, compare, and contrast with areas that are subject to fishing and other human impacts. This allows scientists to examine what effects exploitation has on living marine resources and marine ecosystems. In chapter 1 and previous sections of this chapter, we discussed how fishing alters marine ecosystems and how populations of marine species and ecological communities are often structured differently in areas that are subject to exploitation when compared to areas in which natural processes dominate. Because human impacts have spread throughout the global marine environment, such studies are impossible without the creation of marine reserves, as McClanahan (1990) has eloquently stated (see chapter 1).

Studies of species interactions and ecological processes within reserves can provide critical insights to determine how marine ecosystems are regulated by natural processes and how they respond to various natural and human induced stresses. Comparisons between populations, communities, and ecological processes operating in marine reserves and nonreserve areas allows scientists not only to determine the impact of exploitation and other impacts but also to evaluate the efficacy of other management tools and strategies. As the idea of ecosystem-based management of marine environments is increasingly put into practice, use of marine reserves as a baseline reference or guide will allow managers to more effectively manage the marine environment and adapt management measures as necessary to meet the goals of maximizing sustainable productivity of fishery resources while preserving ecosystem integrity.

Earlier in this chapter, we recognized that the four broad categories of marine reserve benefits should be considered overlapping rather than discrete. Several of the examples discussed earlier under protecting ecosystems and improving fisheries also clearly demonstrate how reserves can provide critical insights about the ocean that might otherwise remain hidden and are worth mentioning here. The Chilean reserve example involving the loco, its recovery, and its role in transforming its rocky intertidal community greatly expanded our knowledge and understanding of this ecosystem, how it functions, and what is natural (Castilla et al. 1994). The Kenyan reserve example provided similar information regarding Kenyan coral reefs; the ecological roles and relationships involving predatory fish, herbivorous urchins, coral, and algae; and their roles in the stability and resilience of this ecosystem (McClanahan et al. 1999). Likewise, the examples from reserves in Tasmania and New Zealand both provided valuable insights into the functioning of kelp forest ecosystems, the roles of fish and lobster in them, and their response to fishing activities (Ballantine 1994; Edgar and Barrett 1999). The Channel Islands warty sea cucumber fishery example clearly demonstrates how reserves expand our knowledge about fishing impacts by detecting trends that might otherwise go unnoticed (Schroeter et al. 2001).

The list of examples documenting the role of reserves in expanding our knowledge and understanding of the ocean realm is a long one, but two more from the North Pacific are worth mentioning here. The first is discussed in more detail later in this book and involves the use of reserves and de facto reserves in British Columbia to study large adult pinto abalone (*Haliotis kamtschatkana*), which were nearly impossible to find elsewhere (Wallace 1999), and lingcod (*Ophiodon elongatus*) mating behavior and related movements that were difficult to unravel in fished waters. On a much grander scale, a U.S. National Research Council panel recently recommended that the U.S. government run a decade-long test involving the creation of two large marine reserves and two control areas off Alaska to help unravel the mystery surrounding the thirty-year decline of Stellar sea lions (*Eumetopius jubatus*), determine the role of fishing in it, and settle a high-stakes dispute concerning regulations for one of the world's most valuable fisheries. The panel concluded that the experiment "is the only approach that directly tests the role of fishing in the decline" and controls for other factors including climate change (Malakoff 2002).

Finally, marine reserves provide a natural classroom for marine education. Just as terrestrial parks and wildlife refuges serve as a center for people to visit in order to appreciate and learn about the natural environment, marine reserves serve as such centers, simply due to the fact that they are protected. This is perhaps one of the most important aspects of marine reserves because it helps to foster an understanding of marine environments—wild ecosystems with their full diversity and abundance of marine life—and a conservation ethic across a wide range of people.

ENHANCE NONCONSUMPTIVE OPPORTUNITIES

Although they function by preserving natural marine ecosystems and permit ecological processes to operate in the absence of human impacts, marine reserves are created to meet human social, economic, and cultural needs. Earlier in this chapter, we saw examples of how marine reserves enhance fisheries through emigration from reserves and larval replenishment. But their economic benefits are not limited to enhancing consumptive uses of marine resources. Enhancing scientific research and marine education are among the many nonconsumptive opportunities enhanced by marine reserves. There are a number of other ways that marine reserves enhance nonconsumptive opportunities that provide economic, social, and cultural benefits. We discuss some of these benefits here and also later in this book.

Tourism is now the world's leading industry. As with terrestrial parks, marine reserves are often areas people visit to experience nature. In many cases, the simple designation of an area as a marine park or reserve has caused an increase in visitation (Ballantine 1991). Although heavy visitation of these areas may be incompatible with reserve protection intended to minimize human impacts, some degree of visitation is desirable to promote marine conservation education and to provide economic benefits to communities around the reserve in the form of ecotourism. Ecotourism has proven to be a viable economic activity in a number of marine settings. Tourism based on scuba diving, sea kayaking, whale watching, and other recreational activities may cause minimal impact to the marine environment but provide a source of income to local communities. The creation of marine reserves may enhance opportunities for these nonconsumptive uses of the sea. In the Florida Keys, the socioeconomics of these and related activities have been extensively documented in connection with marine protected area (MPA) and reserve development (Johns et al. 2001), and small marine reserves created around several popular dive sites have been promoted as "extra strength" dive sites because of their protected status and the likely increase in fish biomass that will develop there (Fig. 4.8).

Ecotourism can be particularly important to communities surrounding marine reserves both as a local economic benefit and as an alternative source of income for fishermen if the creation of the reserve is intended to reduce overall fishing effort on a regional scale. Ecotourism and other economic opportunities that result from marine reserves may not only be a more lucrative opportunity than fishing but may also be a more dependable source of income than fishing. Such tourism, however, must be monitored and if necessary regulated to ensure that these human impacts do not degrade the marine environment in the manner of more consumptive uses. Rudd and Tupper (2002) conducted a preliminary quantitative assessment of the impact of Nassau grouper size and abundance on scuba diver site selection and marine reserve economics in the Turks and Caicos Islands. They concluded that Nassau groupers provide nonextractive economic value to divers. This value would increase under reserve management as the size and number of fish increased, and it could affect the economic viability of such reserves.

There are also many social benefits to marine reserves. The simple fact that they can support the livelihood of fishermen and provide alternative sources of income is of great social benefit. In many places where fisheries have crashed, fishermen have lost their jobs, and capital invested in the fishery has either been wasted or financed by the government. Society therefore must pay a heavy price to support fishermen who can no longer fish and may not have alternative sources of income available to them. Although they are by no means the entire solution to this problem, marine reserves may contribute toward avoiding this costly situation.

Marine reserves may also provide some important cultural benefits. By supporting fisheries, marine reserves can support traditional ways of life that may be lost forever if fisheries crash. Many cultural values may be associated with

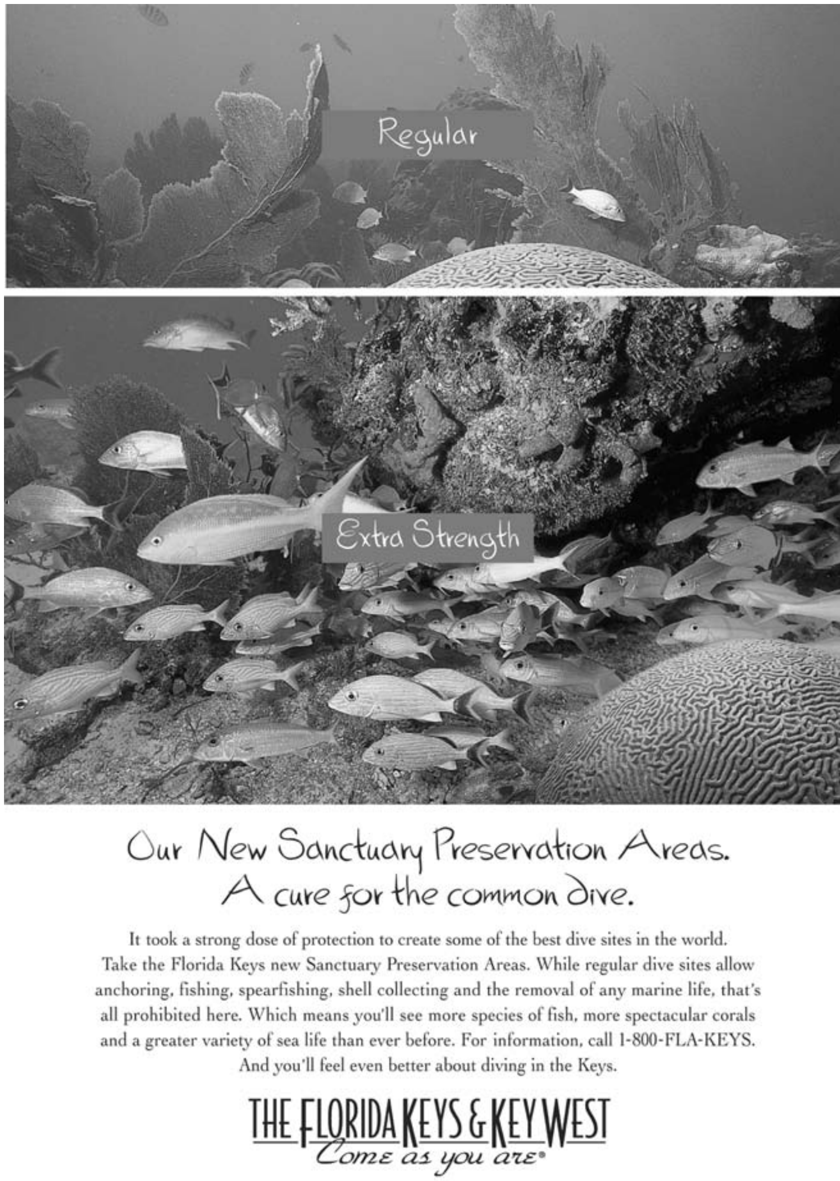

FIG. 4.8 Florida Keys Tourism Promotion Featuring "Extra Strength" Marine Reserve. Photo and ad courtesy of photographer Stephen Frink.

these traditions and may be lost with them. By preserving marine resources, marine reserves can contribute to preserving these cultural values and traditions. Similarly, in parts of the world where there is a conservation ethic, even among a minority of the population, marine reserves can provide peace of mind to those who are concerned about the health of the marine environment. The social and cultural dimensions of marine reserves are discussed in more detail in chapter 6.

WHAT MARINE RESERVES CAN'T DO

Marine reserves may be thought of as an essential vaccine, insurance, and wellness program for the oceans, not a panacea for their growing ills. Even among the strongest reserve proponents, few consider them to be a silver bullet. Most supporters consider them to be a vital tool and necessary part of a comprehensive ocean protection and management approach, but not adequate by themselves. Some reserve opponents have tried to frame the debate as a choice between marine reserves and sound resource management, but this is a false dichotomy. Effective ocean resource management increasingly requires the development of effective marine reserves and marine reserve networks among its most important tools.

Sound public policy requires meeting and balancing multiple societal goals and values (see also chapter 6). Most coastal communities, societies, and nations want to both protect the oceans and utilize them for multiple purposes, including recreation and food production. Treating the entire ocean as a marine reserve might go a long way to achieving ocean protection, but would clearly not meet all other goals. Size and boundary considerations, political realities, and other societal needs and desires require that marine reserves be used in conjunction with other tools to achieve all of their and society's other goals and to maximize reserve benefits.

Both protecting the oceans generally and maximizing the effectiveness of individual reserves and reserve networks of any size also requires addressing threats and impacts generated from activities external to reserves. Reserve design and regulations can mitigate such impacts and sometimes provide a limited degree of protection against some of them, but frequently they operate outside of reserve jurisdiction or on a scale where they are best dealt with using additional approaches. Pollution, coastal development, and other threats to water quality are among the most critical of these. Global change, operating on an even larger scale, is another. Even fishing-related impacts, given likely societal choices, will best be addressed through a combination of marine reserves and other management tools. The following passage summarizes these points well:

> Reserves will be essential for conservation efforts because they can provide unique protection for critical areas, they can provide a spatial escape for intensely exploited species, and they can potentially act as buffers against some management miscalculations and unforeseen or unusual conditions. . . . Reserves are insufficient protection alone, however, because they are not isolated from all critical impacts . . . with-

out adequate protection of species and ecosystems outside of reserves, effectiveness of reserves will be severely compromised. (Allison et al. 1998)

CONCLUSION

Despite scientific evidence that marine reserves provide and are capable of providing a multitude of benefits and can make significant contributions to marine conservation and fisheries production, many still ask, "Just because a reserve works there, will it work here?" when a reserve is proposed in a new area. Although a particular reserve may not produce all of the benefits that reserves are capable of, and it is often difficult to predict what benefits are likely for a particular reserve, the large number of studies showing similar reserve effects from a variety of diverse systems suggests that the response of marine populations and communities to reserve protection is fairly robust to unique features of individual reserves. Many of the reserve effects and benefits discussed in this chapter are supported by examples from around the globe in a variety of marine systems. Thus we can expect reserves to achieve many of their proposed goals much of the time. To answer the simple question, Do reserves work? the answer is yes. The efficacy for a particular reserve to achieve specific management objectives, however, may depend on a variety of factors, including the species that the reserve is intended to protect, public compliance with reserve protection, and design characteristics of the reserve.

However, this evidence is not always ironclad or accepted for all potential benefits in the context of a dispute over designation of a particular reserve. Here one must ask, Can anyone provide similarly conclusive, empirical evidence, using similar standards, that other (nonmarine reserve) fishery management tools have been directly responsible for improving long-term fishery yields in a tropical reef or other system? Have other tools been proven to prevent the collapse, extirpation, and extinction of the more vulnerable fish populations? Can they prevent degradation of reefs and maintain natural diversity and intact systems? The point is not to question whether these other tools can be effective. Many are widely accepted. But it is clear that, by these criteria, marine reserves can provide benefits likely unavailable via traditional management tools.

People often view the marine environment as being invulnerable or at least resilient to human impacts. This may be reinforced by the fact that most people, although they may be reliant on the sea in many ways, do not have an appreciation for the sea and the diversity of life that inhabits marine environments. Because changes in the marine environment may often occur over generations, even fishers and others who make their living from the sea may not realize the changes that result from human impacts until these impacts cause severe disruptions to their livelihood. By having marine reserves as a reference, people may better appreciate how different the marine environment is in surrounding areas where human impacts dominate. This understanding may help to dispel the myth that the sea is too vast to be affected by humans, and instill the notion that conservation and effective management of marine systems are necessary to preserve them.

The strong track record of marine reserves to date combined with their sound theoretical underpinnings provides compelling arguments to greatly expand their use in order to address the problems discussed in chapters 1 through 3, reverse related trends, restore natural baselines and the abundance and diversity of marine life, and protect the oceans' vitality and integrity. A preponderance of evidence strongly supports the expectation that an appropriate system or network of reserves can provide a full suite of benefits falling under the four general categories of protecting ecosystems, improving fishery yields, expanding our knowledge and understanding of the oceans, and enhancing nonconsumptive opportunities.

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