BULLETIN OF MARINE SCIENCE, 66(3): 875–888, 2000 MOTE SYMPOSIUM INVITED PAPER

INFORMATION NEEDS FOR MARINE PROTECTED AREAS: SCIENTIFIC AND SOCIETAL

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ABSTRACT

Marine protected areas are increasingly being used to protect biologically rich habitats, resolve user conflicts, and help restore overexploited stocks and degraded areas. The upsurge in the use of the tool has arisen in part because fisheries managers are now looking to reserves to complement conventional fisheries management techniques. In the United States, the legislative requirement to identify and protect essential fish habitat for managed fisheries species has contributed to the debate over and use of marine protected areas in all their various forms. Information needed to design and implement effective marine protected areas is usually drawn from the fields of fish population dynamics, oceanography, community ecology, and organismal biology, but because the placement, design, and management of marine protected areas are all related to the intended goals, the most crucial information is that about the specific objectives the protected area is designed to achieve. This information is ultimately societal, not scientific. After the specific objectives are elaborated, conservation biology and other sciences can be harnessed to help identify what needs to be protected and in what manner, leading to optimally effective marine protected areas.

Marine Protected Areas

The designation 'marine protected area' encompasses everything from small marine parks established to protect an endangered or threatened species, a unique habitat, or a site of historical or cultural interest to vast reserves intended to achieve a range of conservation, economic, and social objectives and encompassing different types of protection. The use of marine protected areas has enjoyed a sudden upsurge in popularity as marine reserves are being invoked to complement and strengthen traditional fisheries management. In the United States, this trend has been aided by both the establishment of the 200-mi Exclusive Economic Zone (EEZ) that established national jurisdiction over coastal habitats (Agardy, 1998) and the recent revision of the Magnuson-Stevens Fisheries Conservation and Management Act that now requires fisheries managers to identify and protect essential fish habitat. Paralleling this new push for the use of protected areas in fisheries management regimes has been an upsurge in multiple-objective protected areas. Many of the newest marine protected areas are more ambitious than conventional ones, resulting in multiple-use reserves that try to accommodate many different users groups, each with its own needs and objectives. Administrators are finding different uses can indeed be fostered without adverse impacts on ecosystem function, as long as planning is based on ecological realities, relies on specific objectives from the outset, and balances established objectives. These protected areas can provide a footing for integrated coastal management and better ocean governance overall. Whatever the scope of protected area, the science of conservation biology has contributed important theories, perspectives, and tools, many of which await critical testing (Allison et al., 1998).

The terms marine protected area, marine reserve, closed area, harvest refugium, marine park, and sanctuary may cause semantic difficulty because they are often used interchangeably and without definition. The spectrum in size, design, and management objectives is vast, ranging from the small and focused refugium (a place where exploitation of one or more species, usually of fish or shellfish, is restricted) to the large and ambitious sanctuary. Closed area and harvest refugium are sometimes synonymous, but closed areas can also be closed to entry in general or can be used to restrict extraction of nonliving resources, such as oil and gas. Reserve is the term most nearly synonymous with marine protected area in some countries, although 'reserve' can refer to a particular type of protected area such as a biosphere reserve or, as in Britain, to an area closed to all fishing (in other words, a harvest refugium; Gubbay, 1995). Last, there is that problematic term 'marine park', which outlived its usefulness when protected areas shifted away from being places of recreation. The term 'marine protected area', and only that term, encompasses all of the other terms and is therefore the term used herein.

Marine protected areas are fundamentally different from terrestrial protected areas, although whether in kind or degree is debatable. An important factor underlying the difference is the nebulous nature of boundaries in the fluid environment of the sea (Steele, 1974, 1998), which make it difficult to attach boundary conditions to marine ecological processes and threats to those processes (see Table 1). Even inland freshwater ecosystems usually have distinct horizontal layers and more discernable outer bounds. As on land but to a far greater extent, it is impossible to 'fence in' living marine resources or the critical ecological processes that support them, just as it is impossible to 'fence out' the degradation of ocean environments caused by land-based sources of pollution, changes in hydrology, or ecological disruptions occurring in areas adjacent or linked to a protected area. Long-distance dispersal and the vastness of linkages between critical habitats in coastal and marine ecosystems requires comprehensive management of all their parts (Caddy and Sharp, 1986; Costanza et al., 1993; Mooney 1998).

Coastal and ocean areas range in openness from relatively fixed and 'land-like' systems to highly dynamic and complex systems. The organisms in coral-reef ecosystems, for example, are largely confined to the specific habitats of reef, surrounding soft or hard benthos, and coastal wetlands (Roberts, 1995b). The structural framework for reef systems is fixed in place and can be mapped, much as a tropical forest provides a relatively fixed framework for the interactions of the forest community. The functional links between the water column in reef areas and the benthos are strong, so one can treat the ocean space together with reef structures themselves. In contrast, temperate open-ocean systems such as estuary/gulf/banks complexes are highly dynamic and in no way 'fixed'. There, living marine resources move in space and time according to physically dominated, largely nondeterministic patterns (de Groot, 1992). The ecology of the water column is not strongly linked to that of the benthos, and physical reference points for the system cannot easily be mapped. This wide array of system types thus presents a challenge to conservationists and resource managers, requiring that protected-area measures be appropriate to the system in question (Agardy, 1997). The random application of terrestrial models to the marine environment may not succeed in protecting resources and the underlying ecology that gives rise to them. New paradigms are needed, and the newest generation of marine protected areas reflects this new way of thinking.

Modern marine protected areas serve a wide variety of functions, but no single 'model' marine protected area exists. The size, shape, and means of implementation in any single marine protected area will be a function of the primary objectives that it sets out to achieve. If the goal is, for example, the protection of a single vulnerable habitat type from a spe-

Table 1. Differences between marine and terrestrial systems.

Marine	Terrestrial
nebulous boundaries	relatively clearer boundaries
large spatial scales	small spatial scales
fine temporal scales	coarse temporal scales
three-dimensional living space	relatively two-dimensional living space
relatively unstructured food webs	relatively structured food webs
nonlinear systems dynamics	relatively linear systems dynamics
not well studied	relatively well studied

cific type of use (e.g., protection of a fringing reef system from prospective shipping accidents), the resulting protected area can be simple in both design and management. If, however, the conservation goal is to protect a wide range of habitats or resources, the protected area will necessarily have to be more complex. Where a functional approach is adopted—in other words, where the object of conservation is not a single stock of resources or a single species but the ecosystem and its processes—marine protected areas will tend to be large and encompass many types of linked habitats (Lauck et al., 1998). These large multiple-use protected areas can be thought of as demonstrating the concept of ecosystem-based management, where the limits of protection in a geographical sense are based on the extent of movements of organisms and physically linked processes (Hatcher et al., 1989; Dayton et al., 1995). The underlying ecology thus defines the outer boundaries for the area of protection or management unit. In recognizing these linkages, marine protected area planners can work toward conserving ecosystem function, not just individual resources or ecosystem structure.

What is the minimum information necessary to establish effective marine protected areas? First, information must be compiled to provide a rationale for site selection of reserves in the broadest geographic sense. Strategic means for designing networks of marine protected areas fall under three approaches: (1) preservation of ocean or coastal 'wilderness' areas that remain relatively pristine and are usually chosen for their high diversity, (2) resolution of conflicts among users (current or future), or (3) restoration of degraded or overexploited areas. One might view these three categories according to the nature of the intervention by which they get established: (1) the first category is proactive, in that the protection strategy is adopted before degradation occurs; (2) the second is interactive, as the protection strategy aims to resolve conflicts between users; and (3) the third is reactive, in that the protection strategy is designed to avert continued degradation.

Most existing national marine protected area networks follow the first strategy. For example, Parks Canada is currently designing a network of Marine National Conservation Areas to represent each of the 29 distinct ecoregions (based on large-scale biophysical units) of Canada's Atlantic, Great Lakes, Pacific, and Arctic coasts. The long-term goal of this program is to establish a protected area in each region. Similarly, the federal government of Australia is developing a strategy for establishing a National Representative System within Australian Coastal and Marine Environments. In the design of such a system, site selection is guided by representativeness, opportunity, and redundancy (meaning that the government's policy is to designate more than one protected area per representative habitat type) (Commonwealth of Australia, 1998). Other national efforts are currently under way. In fact, the 1995 publication of the Great Barrier Reef Marine Park Authority, the World Bank, and the International Union for the Conservation of Nature, which is the most comprehensive overview of existing marine protected areas and gaps in coverage, strongly urges all countries to establish such representative networks (Kelleher et al., 1995).

Conflict resolution is the other major driving force behind the establishment of networks or systems of reserves or protected areas. Virtually all the world's coasts and nearshore areas are characterized by conflict between and among user groups or jurisdictional agencies, or at a minimum a serious lack of communication between these factions. Shipping and mineral extraction, for example, often conflict with recreational use of coastal areas. Fishing, both commercial and subsistence, conflicts with skin and scuba diving and nature-based tourism. In such cases, zoning can be used to accommodate a wide variety of user groups in relative harmony and can be a tool for dispute resolution where conflicting uses clash (Reynard, 1994; Valdez-Pizzini, 1995).

The human element in marine protected areas must not be understated. The success of any protected area is closely related to how well user groups and stakeholders are identified and brought into the planning and management processes. Marine protected areas cannot afford to be elitist, that is, to cater only to the interests of those who can buy access for recreational usage, again underscoring the difference between terrestrial and marine protected areas. Common property ownership of coastal habitats means that wide-ranging rights of access and use must be considered in the protection of these areas. Humans and their needs—including the needs of future generations—are the driving force for marine protected area work, and humans stand most to benefit from their effective implementation. The designation of a marine protected area can provide local communities, decision-makers, and other stakeholders with a defined arena in which to promote effective management—a sense of place, as it were.

Finally, a third approach is to look at threats to ecosystems and degree of degradation of areas and to establish a system of marine protected areas to allow restoration of sites (and replenishment of resources) as quickly as possible. Although few systematic attempts to identify coastal and marine areas in need of restoration exist, the ongoing restoration program for southern Florida (including the Everglades area, Florida Bay, and the Florida Keys) is a good example of an analytical approach to establishing a network of protected areas for restoration purposes. In some marine protected area examples, the restoration effort is aimed at a single species or stock, as in the restoration of a historically overexploited fishery. Such protected areas include closed areas and often become a starting point for more comprehensive and effective protected area management later on.

Closed Areas and No-Take Fisheries Reserves

Marine protected areas serve a wide range of functions, including protection of commercially or locally valuable fisheries resources (Gubbay, 1995). Although fisheries restrictions in one form or another contribute to the management regime of virtually all marine protected areas worldwide, fisheries management has rarely been the primary objective of any but the smallest. This pattern is largely a function of history, because marine protected areas were originally used to protect landscapes/seascapes for recreation, and such broader protection included but was not limited to fisheries management. In the last decade, however, marine protected areas have departed from tradition and are increasingly being employed to stem degradation of habitat and prevent overexploitation of living resources.

Fishing pressure undoubtedly affects the population dynamics of the target stock as well as those species that interact with the target stock directly (Borisov, 1979; Goeden, 1982; Caddy and Sharp, 1986; Holt, 1990; Fogarty et al., 1991). Exploitation can quickly become overexploitation, particularly with sessile organisms or those species that are naturally rare, have low reproductive rates, or are slow-growing (Jamieson, 1993; Pauly, 1995; Tegner et al., 1996). It is also clear, however, that fisheries exploitation affects food webs and entire ecosystems (Goeden, 1982; Dayton et al., 1995), especially as large-scale commercial exploitation has changed the inefficient hunting mode of the last century to the extremely efficient mining mode of today, made possible by modern technological advances in boats, fishing gear, navigation, and fish-finding instruments (Jennings and Kaiser, 1998). Even quite small-scale fisheries can cause dramatic changes to community ecology and ecosystem productivity when destructive methods of fishing are employed (Saila et al., 1993; R. Steneck, unpubl. data). These impacts and those brought about by large-scale, long-term fisheries exploitation are often large in scale themselves—and sometimes result in what appear to be permanent changes to the ecosystem (Russ and Alcala, 1989; Dayton et al., 1995; Roberts, 1995b; Auster, 1998; Jennings and Kaiser, 1998). The ecological and economic cost of such changes, however, is only now being calculated, and even where such costs have been found to be high, scaling back commercial fisheries exploitation has proven difficult. The open-access nature of marine fisheries has resulted in two problems that are difficult to solve: (1) the attitude of fishing interests who consider marine resources common property and their access to such property an inalienable right and (2) the overcapitalization of fisheries, which makes it nearly impossible for those with investments in fisheries to reduce effort. Given that open access is the root cause for much of the difficulty (Beddington, 1995), area closures seem a logical solution (Polacheck, 1990; Roberts and Polunin, 1991; Bohnsack, 1992; Agardy, 1994b; Ballantine, 1994; Dayton et al., 1995).

Because of the prevalence of such fishing-induced ecosystem impacts, a search is under way to identify new tools to complement traditional, and thus far largely ineffective, means of fisheries management (Holt, 1998). Area (and in some cases seasonal) closures are one such tool, but all forms of protected area can be harnessed to aid in fisheries management. The large marine sanctuary that aims to reduce user conflicts by zoning different areas for different uses may contribute to conserving fish species even if additional fisheries regulations are not part of the management plan. Similarly, a biosphere reserve that brings users into the planning and management process can help conserve fish habitats and fish stocks even if that is not the driving objective of the protected area.

The use of closed areas in fisheries, also known as harvest refugia, presents an effective way to conserve stocks and habitats threatened by overexploitation, destructive fishing, and indirect degradation caused by pollution or the trickle-down effects of poor resource management in the vicinity. Such area closures may be established as a fisheries management tool or may be a component of a wider array of spatially defined management measures such as exist in a multiple-use protected area, a biosphere reserve, or a coastal management plan (Done and Reichelt, 1998). Among the benefits that accrue are conservation of stocks and species, maintenance of genetic diversity, protection of spawning-stock biomass, reduction of growth overfishing, simplicity in being able to explain the management measure, relative ease of enforcement, provision of a baseline for monitoring of condition of stocks and the productivity or health of the ecosystem, and insurance against management failure (Lauck et al., 1998). By providing a means to address differential pressures applied to different stocks and different age groups, the closed area designation comes closest to approximating ecosystem-based, comprehensive management (Agardy, 1994a). However, the possibly high costs of excluding certain users, the mechanics of boundary delineation, scientific uncertainties in identification of ecologically critical areas, lost opportunity, and the spillover of potentially increasing fishing pressure outside the limits of the closed area all compel managers to evaluate costs and benefits carefully before using closed areas to complement other forms of fisheries management.

Closed area designations of some form or another have probably been used since mankind first began harvesting the sea's bounty, making this one of the oldest forms of marine management. Area closures, whether formally designated or informally agreed to, have emerged as a way of settling user conflicts, conserving resources, and laying claim to territory. Today, closed-area designations can be classified into at least four groups: (1) 'traditional use' or 'taboo' closed areas, (2) core areas within reserves or multiple-use coastal plans, (3) harvest refugia for fisheries management, and (4) de facto area closures where exploitation is difficult or impossible because of physical constraints or poor resource availability. Closed areas that form one class of core areas within a multiple-use protected area are also a means for protecting especially critical or sensitive areas. When core-area designations are established to protect productivity and biodiversity, they protect important ecological processes (Agardy, 1995). Such processes can be physical, geochemical, or biological and include such things as upwelling, longshore and tidal fronts, warm and cold core rings, surface currents, freshwater mixing zones, nutrient loading, atmospheric exchange, population recruitment, keystone species, symbiotic associations, nursery areas, and predator-prey linkages (Agardy, 1997). The scientific basis for identifying such critical core areas exists, although harnessing that science to make it useful for management purposes requires synthesizing information across many disciplines and over a broad geographic scope.

Area closures that are designated specifically to protect 'seed banks' or sources of recruits are becoming more and more common (Roberts, 1995a; Russ and Alcala, 1996). The link between certain coastal areas and maintenance of marine fisheries resources has been clearly established (see, e.g., Odum, 1984). The important biological processes that support fisheries productivity include spawning, migratory pathways, feeding, settlement, and concentrated feeding (de Groot, 1992). Such ecologically critical processes in nearshore ecosystems are often concentrated in areas that can be easily identified by physical parameters such as reef formations, extensive shallow water areas, certain types of coastal wetlands, continental shelf breaks, and frontal systems (Caddy and Sharp, 1986). Refugia focused on these critical areas are being designated in the context of multiple-use protected areas, coastal management plans, or independent fisheries-management tool.

Closed areas and harvest refugia are increasingly being selected from the portfolio of options available to marine resource managers, largely because conventional measures for managing fisheries and conserving marine ecosystems have repeatedly failed. This failure entered the realm of public consciousness as the signs of mismanagement began to affect consumers as well as fishermen (The Economist, 1988). Limiting fisheries management to controls on quantity of effort or catch ignores the potentially significant impact that fisheries activities have on ecosystems and their function. The use of spatial and temporal regulations, as made possible by area closures, ensures that the benefits of management are extended beyond just the target stock to wider segments of ecosystems themselves (Davis, 1989). Thus closed areas, when used in conjunction with other forms of regulation, can move fisheries management away from largely ineffective species-by-species fisheries management to more ecosystem-based conservation.

Certain systems are better suited than others for the use of refugia. In general, the less dynamic the system, in terms of spatial and temporal variability, the more suitable (Quinn et al., 1993). Coral reefs, for example, are relatively static systems for which the precise location of certain features and resources at any given point in time is known (Hatcher et al., 1989). In contrast, highly dynamic ecosystems like those of temperate continental shelves have components that move about in often unpredictable ways. Therefore, for reasons related to identification of critical areas, required scale of protected area public education, and enforcement feasibility, designation of closed areas may be easier in relatively 'fixed' ecosystems (Jennings and Polunin, 1996). That is not to say, however, that closed areas in temperate and boreal systems are unfeasible, nor should it suggest that potential benefits of such protected areas are fewer in nontropical systems (Auster and Malatesta, 1995).

From a fisheries-management perspective, one of the most critical scientific considerations in the identification of closed areas is where recruits come from and what affects their success. Recruitment dynamics are often complex and seemingly unpredictable (Holt, 1990; Fogarty et al., 1991), but sources and sinks for recruits can be readily identified in some ecosystems (see, e.g., Gaines and Bertness, 1992). When scientific uncertainty is high or systems exhibit chaotic behavior, the use of a network of closed areas or reserves allows fisheries managers to hedge bets and increase the probability that productivity will be maintained.

Where open-access regimes for high-value sedentary resources or highly territorial species leads to stock depletion, rotating harvest schemes can act as a modified closed-area system (Caddy, 1992). If growth rates are low and longevity high, only small proportions of the stock should be harvested annually. Rotating harvest schemes rest on the ability to divide the stock range into blocks or cells, each of which can be harvested in sequence and assume that adequate quota levels can be estimated, quotas are enforceable, and quotas accurately equal the biomass of the resource divided by the number of cells. The period of harvest can be modified to allow one, or very few, year classes of optimal economic size to dominate the catch. This procedure has been widely used for other resources, in particular forestry and agriculture (Caddy, 1992). As long as harvesting allows for residual spawners (or, more likely, that the stock in adjacent areas replenishes the population) the cell is given time to 'rest' for a period of years or months. This system may have both economic and ecological advantages.

Although the usefulness of closed areas and harvest refugia is being increasingly documented as resource managers turn to this management option, some constraints on their broad applicability are undeniable (Allison et al., 1998; Russ and Alcala, 1998). Limited scientific knowledge of population replacement rates, dynamics, recruitment patterns, and impacts of fishing pressure on ecosystem function have all been used as excuses hindering establishment of no-take reserves. The stochastic nature of many marine systems also undermines the usefulness of this approach, particularly if closed areas are treated as static and immutable entities rather than as flexible management measures. Social constraints may limit the applicability of closed areas as well. The notorious difficulty of regulating the fishing industry precludes the acceptance of many new, potentially effective management tools. Closures having a scientific basis can be viewed by the fishing community as exclusionary practices that are somehow rooted in social discrimination. This perception predisposes user groups to reject the idea of area closures even before they have the chance to discover exactly why and how these would be beneficial to them.

Financial or logistical constraints that limit enforcement capability also limit the potential effectiveness of closed areas, although their enforcement can be more cost-effective than that of quota limits, tow times, gear restrictions, etc. One important constraint is the physical demarcation of the closed area, so that its status is clear to users and prospective transgressors (Gubbay, 1995). The use of buoys can complement traditional latitude/longitude designations, but several researchers have raised the possibility that visibly marked areas may in fact become a lure to poachers. Without due consideration of compliance, even the best-designed closed areas may be doomed to fail, and each such failure can further alienate fishing communities and other users.

If carefully planned and grounded in good scientific understanding of ecosystem dynamics, closed-area designations can be an effective tool to complement other fisheries regulation. The prospect of increased management and enforcement will be a hard one to swallow for many members of the fishing community, but only until the effectiveness of such areas in maintaining and even increasing catch is demonstrated. Managers using this technique will have to be responsive to changes in scientific information, the status of the resources, and management needs in order to make refugia optimally effective. If they can do so, by adopting management techniques that require refinement based on periodic reassessment of zone boundaries, regulations, and overall extent of the protected area, everyone stands to benefit from the use of this management measure.

Information Needs For Designing And Implementing Marine Protected Areas

We now know that marine protected areas can be designed to help make fisheries and coastal management more effective. In the last 5 yrs, new, rigorous, and defensible evidence has emerged to show that marine protected areas do indeed improve fish yields while conserving biological diversity more generally (Jennings and Polunin, 1996; Jennings and Kaiser, 1998). These benefits have included increased fish stock size inside the reserve as well as spillover effects in which fish populations have also increased outside the reserve (Roberts, 1995c). One of the most cited examples of this spillover effect has been the work of Russ and Alcala (1996, 1997) in the Philippines, where a small protected area at Apo Island was shown to increase fish yields well outside the boundaries of the reserve less than a decade after its establishment. Other apparently successful marine protected areas include Kenyan refuges (McClanahan and Shafir, 1990; McClanahan and Kaunda-Arara, 1996), New Zealand fishery reserves (McCormick and Choat, 1987; Ballantine, 1991, 1994), several Mediterranean reserves (Dugan and Davis, 1993), invertebrate reserves in Chile (Castilla and Duran, 1985), coral-reef reserves throughout the Caribbean (Roberts and Polunin, 1991; Reynard, 1994; Rakitin and Kramer, 1996), Red Sea reserves (Roberts and Polunin, 1992), and fisheries zones in Florida (Bohnsack, 1996a,b), among others. The ideal situation seems to be the establishment of harvest refugia within the context of a larger multiple-use protected area such as a coastal biosphere reserve, marine sanctuary, or other large-scale marine protected area.

On the assumption that marine protected areas can be used to protect essential fish habitat, ecologically critical areas, and coastal systems more broadly, certain basic information is needed for the process of designing, implementing, and maintaining marine protected areas. These data and resulting information must guide (1) geographical placement, at the ecoregion scale, of multiple-use marine reserves and networks of reserves; (2) design of marine protected areas and location of specific sites within them that should be protected as core, no-take areas; (3) establishment of regulations and effective management of the protected area that will meet objectives; and (4) monitoring and evaluation of whether goals are being met, including benefit valuation. Scientific information on biomass, dispersal patterns, recruitment dynamics, trophic interactions, and critical habitat are often used to determine the size, shape, and management of marine protected areas, but the foremost need, often overlooked when the process of establishing a marine protected area is initiated, is information on the intended goal of the protected area. This goal-setting or objective elaboration is critical to determination of expectations, effective design of the reserve, and establishment of targets and benchmarks against which progress toward the objectives can be measured. The most crucial information for protected areas is therefore inherently societal rather than scientific.

The primary use of closed areas is as a tool to complement other forms of resource management in the maintenance or, in some cases, increase of fisheries productivity through replenishment and spillover effects (Florida Institute of Oceanography, 1997; Roberts, 1997b). Closed areas are often established to protect against stock collapse, but if implemented too late, they rarely meet even this limited objective. These apparent failures often overshadow the very real potential benefits, such as ease of management and reduced data collection needs, supplemental stocking (Russ and Alcala, 1989), maintenance of 'control areas' for scientific research and monitoring, and potentially enhanced nonconsumptive uses (Plan Development Team, 1990). More specifically, no-take reserves can (1) limit harvest of specific life stages (usually those critical to production or those especially vulnerable to direct and indirect effects of fishing activity), (2) prevent overexploitation of threatened stocks or species beyond replacement rates or prevent growth overfishing, (3) protect sources of recruits or sinks for settlement, (4) maintain the genetic composition and/or age structure of a stock or population, or (5) protect habitat and maintain structural diversity, and (6) buffer against management mistakes caused by scientific uncertainty or difficulties in executing management measures. Given these diverse objectives, design and management of reserves is likely to vary as well. Table 2 shows how reserve design and management can correspond to the specific objectives that the protected area is designed to meet.

Once objectives are determined, science can be harnessed to design effective protected areas (Agardy, 1993), but the science of marine protected areas is still in its infancy, and relatively little of a technical nature has been written about design criteria. That gospel of marine protected area managers, Salm and Clark's (1989) *Marine Protected Areas: A Handbook for Managers*, provides general advice on protected area design, but the book is a decade and a half old and therefore largely out of date. More recent work is now available (Gubbay, 1995), but many publications refer to design of protected-area networks, as opposed to individual protected areas (Roberts, 1997a; Sladek Nowlis and Roberts, 1997). Although some of the same principles apply, networks are usually designed to conserve overall biological diversity, whereas individual marine protected areas are usually intended to protect individual species and the habitat that supports them (Bakus, 1982). Very recent symposia have, however, resulted in synopses of information on what

Table 2. Relationship between marine protected area objectives, size and design complexity. CZM = coastal zone management.

Objective	Relative size	Complexity
Protecting an endangered species	Small to medium	Simple
Protecting a migratory species	Large (or network)	Simple to complex
Protecting habitat from single threat	Medium	Simple
Protecting habitat from multiple threats	Medium to Large	Complex
Preventing overfishing	Small	Simple
Enhancing stocks	Small to medium	Simple
Protecting an area of historic or cultural interest	Small	Simple
Providing a CZM model or empowering local people	Small to medium	Somewhat complex
Promoting marine ecotourism	Small	Simple
Providing site(s) for scientific research	Small	Simple
Conserving biodiversity	Large (or network)	Simple to complex

we have learned about protected-area design (e.g., Roberts et al., 1995a,b; Florida Institute of Oceanography, 1997).

A central question in the design of a protected area is that of optimal size. As some scientists have impatiently proclaimed, bigger is obviously better, but bigger is not always possible—and given that establishment of protected areas does incur economic and social costs, one must look at size carefully (Agardy, 1993). New studies have shown that even very small refugia can have significant positive impact on marine biodiversity and productivity (Roberts and Hawkins, 1997), and small marine protected areas that are linked in a systematic network that protects a large proportion of critical habitats or particularly important sources of recruits in a region provide even more benefits (Rowley, 1994; Dias, 1996; Roberts, 1997a; Sladek Nowlis and Roberts, 1997).

Considerations beyond individual reserve size and area coverage of networks include whether, all other things being equal, more can be accomplished through establishment of one large reserve or through establishment of a network. Sladek Nowlis and Roberts (1997) have begun in address this classic ecological question (known as the SLOSS—'single large or several small'—debate in terrestrial ecology), and others are following suit. Shape is another consideration, as is whether a system of seasonal or rotating closures is optimal in some (especially temperate) situations (Rijnsdorp et al., 1991; Caddy 1992; Carr and Reed, 1993; Auster and Malatesta, 1995; Hutchings 1995; Auster, 1996). As more manipulative experiments are undertaken and time series data are gathered, technical guidance on design will be more readily available.

It is important to note that the implementation of a reserve or protected area marks the beginning of information gathering and management, not the end point as many would believe. Some of the initial and subsequent information will be derived through experimental biology, oceanography, and natural history, and some will have to derived from traditional knowledge accrued by users of the resource (Johannes, 1984; Ruddle, 1996). Once such traditional knowledge is identified, science can be used to 'ground-truth' the information to give it the necessary rigor.

For marine protected areas serving marine conservation generally, several essential steps will increase the likelihood of success (Agardy, 1997):

1. Clearly define specific objectives for the marine protected area at the onset.
2. Design zoning to maximize protection for ecologically critical areas and processes.

3. Design boundaries so that they reflect ecological reality and be prepared to alter the design as more ecosystem information is derived.

4. Design the marine protected area and develop its management plan with feasibility in mind.

5. Make the planning process truly participatory.

6. Develop monitoring and evaluation methods that are appropriate to the specific objectives of the protected area.

7. Use the marine protected area to raise awareness.

8. Form an independent, nonpartisan or multi-user-group body to manage the marine protected area.

9. Undertake valuation exercises periodically to ensure that the full value of the protected area is being realized.

10. Use individual marine protected areas as a starting point for more effective marine policies overall.

Fishers, nations, and indeed the entire biosphere can benefit from the establishment of marine protected areas at all scales and in all coastal environments. As noted above, the rationale for marine protected area establishment is no longer lacking, but the courage to go forward is often hard to summon. Despite incomplete knowledge and imprecise science, steps must be taken to establish protected areas now, and to use the additional information we gain as time goes on to alter these reserves, remove superfluous ones, and add new ones. By clearly defining objectives and using science to design the best possible plans for meeting those objectives, we can improve our management of marine activities before the health of the seas is compromised and with it the ability of marine systems to provide us with the resources and services upon which we increasingly depend.

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