Ecological Goals for Marine Fishery Reserve Design: Workshop Summary

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INTRODUCTION

The use of "no-take" Marine Fishery Reserves (MFRs), as a management tool has gained acceptance in recent years. In 1995, two seminal workshops were conducted concerning MFRs, which have direct relevance to the Caribbean region. The first was sponsored by the Center for Marine Conservation and the Caribbean Marine Research Center and identified the many potential fishery and non-fishery benefits of MFRs (Table 1). Many of these benefits are not readily achievable through current stock management approaches based on population dynamics. The second workshop, sponsored by the U.S. South Atlantic Fishery Management Council, concluded that, indeed, MFRs could achieve many management goals, and when combined with other management measures can be an effective tool for managing reef fish resources if the biological, economic and social objectives are clearly identified (Roberts *et al.*, 1995). Ballantine (1996) outlined the necessary principles (Table 2) guiding the use of MFRs, and his methodological approach (Ballantine, 1997) is a null basis for MFR design, that is, an approach that can be used in the absence of detailed information (Table 3). The question follows, then, as to what approaches exist that might enhance or facilitate the design of MFRs beyond Ballantine's basic approach.

The purpose of the present workshop was to consider and, if possible, define the biological objectives of a marine reserve, and given the objectives, identify what ecological characteristics would be desired such that design criteria could be specified to achieve these goals. These were viewed specifically within the context of Caribbean reef fisheries.

OBJECTIVE OF MARINE FISHERY RESERVES

The principle biological objective of any MFR is to protect the structure, integrity and stability of the ecosystem. In this sense, the basic objective of any MFR is no different from the conservation function of any area closed to exploitation. Arguments for the adoption of MFRs should not be conditioned on only one or two points (Table 1). In particular, there are four management goals specifically addressed by MFRs that render their inclusion as necessary management tools a new paradigm: maintenance of ecosystem function including fish production, maintenance of biological diversity (species, genetics, behavior, etc.), providing insurance against management failure outside reserve areas, and providing control areas against which to assess the effects of fishing.

Discussion of the biological objectives of marine fishery reserves is often couched in terms of dichotomies, e.g., conservation versus fisheries enhancement, or reserves to maintain "natural areas" versus those serving fisheries issues. This approach is unfortunate and misleading, and may result from difficulties in either comprehending or communicating the potential benefits of MFRs. Difficulties may also arise when emphasis is unduly placed on only one potential MFR benefit (e.g., export of large fishes through emigration for fishery enhancement). Ballantine (in Pitcher, 1997) succinctly summarized the overall objective of MFRs in stating that there was only one definition of a dead reef, so any management action that moves the system in the opposite direction is beneficial. In the Caribbean, as elsewhere, the extent and impacts of overfishing reef systems are obvious. That marine reserves can function to reverse those effects is evident (e.g., top carnivores/large fish are only found in protected areas), even when mechanistic functions have not been scientifically explained. From a management prospective, the biological validity of marine reserves must rest on general principles and be viewed in light of ecological and economic risk, not solely in terms of strict, scientific demonstration of cause and effect in all cases.

The maintenance of ecosystem function is a necessary prerequisite for achieving the potential benefits that MFRs offer; as such, any closed area offers advantages to fisheries. Still, closure of any area will have the immediate impact of shifting effort and concentrating it areas still open. This will result in a lower catch-per-effort as the resource in the area outside the reserve is reduced prior to the beneficial effects of the closure taking root. However, this loss in productivity is similar to that caused by *any* management measure that reduces effort (e.g., length or mesh size limits), and as with other measures, a marine reserve may be phased in over time to reduce the short-term negative impacts. Nevertheless, the use of MFRs may still require additional management regulations (e.g., limits on length/mesh size, closed spawning aggregations, controls on effort) in areas outside reserves. The worst that could happen in establishing a reserve is that there is a permanent loss of fishery production. In a fully developed system of reserves, this could constitute 20% of the catch. However, this loss is of the same magnitude that would be achieved under an optimal yield developed using the $F_{0.1}$ strategy (the precautionary approach) (Caddy and Mahon, 1995) or in trying to maximize economic return from the fishery, as oppose to maximizing yield or employment.

DESIGN FACTORS

Size

Ballantine's principles for a system of marine reserves (Table 2), particularly the requirement for replication, necessitate, in a relative sense, the establishment of many small reserves, instead of a few large ones. Nevertheless, there remains the question of how small a particular closed area can be. Roberts and Hawkins (1997) has suggested that even small (2.6 ha) protected areas serve a conservation function, in that some fishes are larger and more abundant within such an area. Yet it is possible that small unexploited areas may attract fish from outlying areas because of the availability of prey or undamaged reef structure, much like a fish attraction device (FAD). What follows from the biological objective of marine reserves is that sufficient area must be protected such that ecological structure and function are maintained. Within a subarea this may be achieved in one of two ways. First, a single area can be closed large enough to contain sufficient habitat representation and connection, and sufficient space to encompass the home ranges of threatened species. In this regard, the home ranges of large reef-associated predators (e.g., Nassau grouper) could be used to define an area large enough to contain the minimum breeding population necessary for stability (e.g., 500 individuals?). This approach has four merits. It concentrates on top predators, which are the most threatened components of the system and important, top-down regulators of community structure. It assumes that larger fish have larger home ranges; thus if large fishes are accounted for, small fishes will also be protected. Home range itself must be some function of habitat biodiversity and content, it that any given home range must supply all the needs of an individual. This allows the amount of area to be closed to be determined on relative biological criteria. Lastly, the persistence of large predators provides a simple metric (in terms of both logistics and interpretation) for the assessing the biological success of the reserve.

While large areas are conceptually the simplest, they are often socially unpopular due to the extent of area that must be closed to contain all the necessary ecological components (e.g., reefs, seagrass beds, mangroves, algal plains). An alternative approach is to network closed areas on a local scale. This may allow a much smaller area to be closed while still maintaining ecosystem function. In areas where nursery habitats are not fished or otherwise environmentally threatened, initial efforts can concentrate on closing areas of adult habitat and spawning sites, as these are the fish most threatened by fishing and the protection and enhancement of spawning stock biomass are important management goals achievable through MFRs.

One desirable benefit of MFRs is the enhancement of fisheries catch in outlying areas due to emigration of fishes from reserve areas. This may be facilitated by increasing the surface to area ratio of the closed area. However, enhancing yield from emigration must be subservient to maintaining the species and ecosystem structure that are the base of fishery production. The maximization of emigration ("leakage") may then require the area to be closed to be still larger, such that emigration does not affect core population size.

Content

The principle of representativeness (Table 2) requires that all habitats, however defined, be included into reserve areas. The objective of maintaining ecosystem function requires that these habitats are functionally connected. Closing contiguous habitats within the same reserve is the best approach, as it facilitates connectivity. If multiple local areas are to be networked, connectivity among different habitats must be maintained through the movement and migratory behavior of species (e.g., feeding, ontogenetic and spawning migrations) and through hydrodynamic dispersal of small organisms and propagules. An understanding of the life-histories of key ecological or commercial species, particularly their habitat requirements and movement capabilities, will be necessary in determining how to network individual closed areas. Connectivity can be enhanced by giving priority to closing areas of greater habitat diversity, such that the distance between habitats is minimized.

Content and connectivity requirements will affect the minimum area needing to be closed in any given location. Thus, Roberts and Hawkins's reserve of 0.4 ha in St. Lucia may indeed enhance survival and conserve production because the closed area, while less than 200 m wide, contains all reef habitats from the shoreline to the reef edge. On wider shelves, such a limited area would represent only a small fraction of the available habitats.

Location

The siting of marine reserves is driven by requirements for connectivity (networking) both on regional and local scales. Nevertheless, the principle of replication (Table 2) is designed, in part, to hedge against errors in siting specific reserves Roberts (1997) has recently documented the range and variability of potential connectivity through passive larval dispersal at 18 locations within the Caribbean. His work clearly identifies potential source and sink areas on a Caribbean-wide basis. Nevertheless, the weight of scientific opinion at present is that most recruitment is "local", and even Roberts's study shows an average interaction distance of only 145 km. Given local complexities in current flow and larval swimming capabilities, real dispersal distances may be substantially less. Given this, some consideration should be given to stock-recruitment relationships at smaller regional scales. Within this context a series of closed areas with a region may contribute differently to the overall conservation and production of a system (e.g., island state). Reserve areas upstream may serve to maximize capture of larvae imported from other areas and function to seed areas further downstream. Downstream areas, in turn, serve to maximize retention of larvae produced within the system.

Table 1. Potential benefits of marine reserves (from Pitcher, 1997)

Non-fishing Benefits of Marine Reserves

A. Protect Ecosystem Structure, Function, and Integrity
- Protect physical habitat structure
    - from fishing gear impacts
    - from other anthropogenic and incidental impacts
- Protect biodiversity at all levels
- Restore population size and age structure
- Restore community composition (species presence and abundance)
- Protect genetic structure from direct and indirect selection
- Protect ecological processes:
    - Keystone species
    - Cascading effects
    - Threshold effects
    - Second order effects
    - Food web and trophic structure
    - System resilience to stress
- Maintain high quality feeding areas for fish and wildlife
- Leave less room for irresponsible development
- Allows the distinction of natural from anthropogenic changes
- Promote ecosystem management
- Encourage holistic approach to management

B. Increased Knowledge and Understanding of Marine Systems
- Provide long-term monitoring sites
- Provide focus for study
- Provide continuity of knowledge in undisturbed sites
- Provide opportunity to restore or maintain natural behaviors
- Reduce risks to long-term experiments
- Provide synergism of knowledge and cumulative understanding
- Provide undisturbed natural sites for certain experiments
- Provide sites for enhanced primary and adult education
- Provide sites for high-level graduate education

C. Improves Non-Consumptive Opportunities
- Enhance and diversify economic opportunities
- Enhance and diversify social activities
- Improve peace-of-mind
- Enhance non-consumptive recreation
- Enhance aesthetic experiences

Table 1. (continued)

Potential Fishery Benefits of Marine Reserves
Provide wilderness opportunities
Enhance spiritual connection
Enhance educational opportunities
Promote ecotourism
Provide natural reference areas for assessing anthropogenic impacts
Improve appreciation of conservation
Increase sustainable employment opportunities
Create public awareness about environment
Stabilize economy
Increase abundance of overfished stocks inside reserves
Increase abundance of overfished stocks outside reserves
Allow increased fishing mortality outside reserves
Reduce overfishing of vulnerable species
Reduce bycatch mortality inside reserves
Simplify enforcement and compliance
Reduce conflicts within and among sectors of users
Maintain sport trophy fisheries
Maintain diversity of fishing opportunities
Provide some resource protection without data or other information
Benefit reproduction:
Increase spawning stock biomass
Increase spawning density
Provide undisturbed spawning conditions and habitats
Increase spawning potential and stock fecundity
Increase egg and larval production
Enhance recruitment
Export juveniles and adults to fishing grounds
Reduce chance of recruitment overfishing
Accelerate stock recovery after collapse
Facilitate stakeholder involvement in fisheries management
Provide data for improved fisheries management
Increase public understanding and acceptance of fishery management
Protect intraspecific genetic structure from fishery selection
Reduce variance in yield
Reduce impacts on fisheries of environmental variability
Allow studies of basic fishery biology
Support marine ethic
Provide ecosystem level protection

Table 2. Principles for a system of marine reserves (Ballantine, 1996).

Representation	Should contain examples of all biotic assemblages (ë habitats)
Replication	Should contain several examples of each habitat within each biogeographic province
Network Design	There should be connectivity between reserves such that system should be self- sustaining 20 - 30% Area closure

The ideas of upstream/downstream areas and source/sink areas also operate on local scales. Within any local system, upstream reefs will tend to have greater larval recruitment than downstream reefs due to the system acting like a filter for settling larvae. Hence, even on local scales the positioning of a single closed area may benefit from an upstream location. However, ensuring larval input is only one factor important in maintaining ecosystem function and structure. The biological function of any reserve, relative to its size, will be dependent upon the mix of habitats within the reserve (content) and the surrounding, supporting habitats. Consideration of the mix of habitats and their local connectivity are important in siting individual reserve areas.

PUBLIC PERCEPTION AND BIOLOGICAL OBJECTIVES

The establishment of marine reserves is a social process, and the objectives of any particular reserve may be biological, economic, social, political or some combination thereof. For a reserve to achieve its biological goals, these goals must be clearly presented within the social process so they are understood and can be properly weighed against potentially competing objectives. The biological objective of a MFR, to maintain ecosystem structure, integrity and stability as a prerequisite of maintaining fisheries production, is one based on fundamental conservation principles. Such fundamental principles are typically understood and accepted widely among the general public, and hence are strongly supported (Ballantine, 1995). Thus, broad-scale public support should be sought in establishing reserves systems. Fishermen, who may claim a greater personal stake in the implementation of reserves, tend to be more suspect but still understand conservation principles related to production, such as the maintenance of spawning biomass and nursery areas, or maximizing larval recruitment. Nevertheless, clear, easily understood demonstrations of reserve effectiveness are needed to win majority support. Recognized measures include the presence of larger, more abundand fish; the presence of top carnivores (or some predator/prey ratio); and the existence of less biased sex-ratios in hermaphroditic species.

REMAINING ISSUES

Detailed studies cannot be conducted in all areas being considered as marine reserves. What is needed is a series of robust guidelines for MFR design that summarize the major components of ecosystem function and translate them into simple principals that can be reasonably applied in data poor situations. Most probably this will require a habitat (landscape) approach. Ballantine's (1997) system (Table 3) is a first step, but clearly improvements and refinements are possible, especially when tuned to specific types of environments, such as reef systems.

Table 3. Null process for establishing reserves (Ballantine, 1997)

Define habitats based on simple proxy measures of marine topology (e.g., Wave/current exposure, Depth, Type of substratum)
Replicate habitats locally and regionally to provide hedge against siting errors
Replicate habitats sufficiently to reduce inter-reserve distance, and thus enhance network connectivity

Coutant (1977) suggested using the idea of normative conditions to assess ecosystem function: "a system is in a normative condition when the specific functional features (as norms or standards) that are essential to maintaining diverse and productive populations of valued species are provided." What needs to be defined are the "norms or standards" pertinent to reef ecosystems and how these are manifest. Recognizing the importance of habitat diversity and connectivity is a first step, but there remains the task of identifying key processes for ecosystem function (and in this case fisheries production) and their specific mechanistic pathways in Caribbean reef systems. As an example, reefs serve to concentrate energy (organic matter) from surrounding areas and channel it into fish production. Two specific pathways identified are the transfer of nutrients from softbottom areas to reefs via feeding migrations (Hobsen, 1973; Meyer *et al*., 1983) and the transfer of nutrient from the pelagic realm to the benthic via plankton feeding fishes (Hamner *et al*., 1988; Dennis, 1998). Is it reasonable to defined the existence of these trophic pathways as normative conditions? If so what are the most important species involved (e.g., grunts, squirrelfishes, parrotfishes for transfer from softbottom areas)? Can we then define the existence of these species as a normative standard? If so, then knowledge of their life histories can be used to determine design criteria for reserves in Caribbean reef systems. Answering these questions will require the combined efforts of community ecologists, fish biologists and ecosystem modelers.

RECOMMENDATIONS FOR FUTURE ACTIVITIES

Recognizing that there is a relationship between fish production and ecosystem sustainability and that Marine Reserves represent a paradigm shift in fisheries management, the development of a Caribbean-wide network of marine reserves is strongly recommended. There are several phases to developing such a system. On a regional basis the ecological units and sensitive areas must be identified (Sullivan and Bustamente., 1997) and potential for regional connectivity determined (Roberts, 1997). Multilatteral funding opportunities exist to target reserve development in priority areas. However, the process of establishing closed areas is a local one. Criteria need to be developed to aid in local MFR design. Equally, if not more important, an advocacy for marine reserves must exist locally, as reserves function best when designed and implemented with the participation of all user groups.

The Gulf and Caribbean Fisheries Institute is an important regional forum for promoting the use of MFRs and developing local advocacy. To realize this function, a concerted effort must be made to have resource managers involved more fully in such forums through the use of travel support (from infrastructure grants) and by developing sessions of key interest. Suggestions for future sessions or workshops include extracting design lessons from case studies and demonstrations of MFR implementation processes involving multiple user groups and managers aided with expert-decision computer programs.

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