Can Marine Protected Areas Optimize Fishery Production and Biodiversity Preservation in the same Ecosystem?

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ABSTRACT

Marine Protected Areas are becoming a method of choice for managing the living marine resources of coastal marine ecosystems in the Caribbean. Their popularity stems in part from the assumption that MPAs reconcile the competing needs of stakeholders to optimize extractive and non-extractive resource usage. Typically the greatest conflict in management exists between the need to sustain or increase fishery yields, and the need to preserve habitat and species diversity in shallow reef and near shore environments (in part for sustained tourism, and in part for long term ecological survival). No evidence is available to demonstrate that MPAs preserve marine biodiversity: but common sense suggests they will help do so. There is unequivocal evidence that MPAs of adequate size and protection do conserve and even enhance fish biomass on Caribbean coral reefs. No adequate time series exist to demonstrate that MPAs sustain or increase production in characteristic near shore fisheries, although theory predicts that spill over and reproductive export may do so. Results from empirical studies of reef fish movement demonstrate that spill over will rarely be sufficient to offset the immediate loss of harvest suffered by a fishery after MPA creation. The delay before putative yield enhancement resulting from increased recruitment exceeds two years in reef fish communities. Artisanal fishers often lack the reserve capital required to absorb the accompanying loss of income, and increase effort to maintain catches. This response can further delay the development of the MPA. Both the biology and economics of Caribbean reef fisheries create a mismatch of investment and benefit that works against joint optimization of biodiversity preservation and resource conservation. External compensation for lost income during the development of MPAs may be required to reconcile management goals.

KEY WORDS: Biodiversity, fishery management, marine protected areas

INTRODUCTION and METHODS

Two themes dominate the design goals of Marine Protected Areas (MPAs): the preservation of biodiversity to sustain natural ecosystems, and the conservation of renewable natural resources to sustain human livelihoods (IUCN, 1994). In the first, a high level of protection from extractive, non-extractive and upstream activities is provided with the goal of preserving critical ecosystems, habitats, communities and species in perpetuity (equivalent to IUCN category I: strict nature reserves, and II: national parks). In the second, selective protection and active management is used to provide sustainable use of natural resources (equivalent to IUCN category IV: habitat/ species management, and VI: managed resource protected area). The most common manifestation of the second theme is the Marine Fishery Reserve (MFR), in which a refuge from fishing mortality is used as a fishery management tool with the goal of maintaining and enhancing fish yields (NOAA/AFS, 1995). (Marine nature reserves and MFRs are viewed here as subsets of MPAs, distinguished by the purposes for which they are established).

These themes converge in coral reef ecosystems, where it has been predicted that both biodiversity preservation and fishery production goals can be achieved by the establishment of MPAs (e.g., Bohnsack, 1993). Yet, coral reefs have been singled out in the Caribbean as exemplars of the incompatibility of non-selective fishing and benthic community health (Hughes, 1994). The underlying assumption of multipurpose MPAs is that they can maintain species diversity and habitat integrity within their boundaries, while exporting enough recruits to sustain fisheries in adjacent areas. I suggest that in most realistic scenarios in the Caribbean, the operational goals of biodiversity preservation and fishery management are competing rather than reinforcing in coral reef ecosystems. Stated simply: MPAs may not necessarily function as effective MFRs for the purposes of fishery management.

Before assuming the use of MPAs as fishery management tools in the Caribbean, it is worth examining the hypotheses that:

i) The goals and objectives of MPAs and fisheries management are compatible.

ii) The objectives of fishery management can be achieved by MPAs as currently constituted in the region's coral reef ecosystems.

Should the second hypothesis be rejected, we should identify the biological, ecological and socio-economic factors which inhibit the effectiveness of MPAs as fishery management tools and try to change them (or we should redefine the goals of fishery management).

In considering these hypotheses I draw on published results from studies of Caribbean fisheries and of MPA function in the Caribbean and elsewhere (including: Bohnsack and Ault, 1996; Koslow *et al*, 1988; Mahon, 1990; Ratikin and Kramer, 1996; Roberts and Polunin, 1993; Rowley, 1994; Russ, 1991). The operational definition of MPA used here is an area of reef habitat permanently closed to extractive activities, in which non-extractive activities such as SCUBA diving are managed so as to minimize negative effects on contained biota. The large majority of MPAs in the Caribbean meet these criteria in intent if not in practice (Kelleher *et al*, 1995). I use the case study of the Soufriere Experiment in Reef Fisheries Sustainability (Hatcher *et al*, 1995), which focuses on a series of recently zoned MPAs on the west coast of St. Lucia, West Indies. The potential export of catchable fish from these small reserves is estimated for two common species in the fishery with contrasting mobilities, using a simple probabilistic model.

RESULTS and DISCUSSION

— Marine nature reserves and marine fishery reserves do not share the same management objectives, but the differences are not incorporated in the selection or implementation of many Caribbean MPAs —

There is a great deal of variability in the terms used to describe marine protected areas in the Caribbean, and they do not always accurately reflect the purposes for which the areas were zoned (Kelleher *et al*, 1995). In some cases multiple objectives are explicitly stated or implied, while in others the general goal of "conservation" is not assigned to any particular attribute of nature or activity of humans. In some cases there is no clearly stated objective of management. In most cases, however, it appears that MPAs have been proposed or established in response to a perceived degradation of living marine resources, and a desire by informed interests to retain certain attributes and, or economic benefits that accrue from their exploitation (e.g. Nichols and George, 1995). Because of the need to accommodate recreational uses, many Caribbean MPAs are primarily marine parks, which have management goals significantly different than maximizing fishery production MPAs selected according to their value for recreation (and, to the extent that they are linked: biodiversity preservation) are MFRs by association, not by design.

When the attributes are "pristine" benthic communities, and the benefits are derived from low volume tourism, then the use of MPAs as a means to maintain or re-establish a status quo corresponding to the pre-exploitation community represents a compatible, shared goal (e.g., Bohnsack and Ault, 1996; Thacker, 1995). When the primary benefits are derived from fisheries, however, the management goal of maximizing fish production from MFRs diverges from that of nature preservation within MPAs. Simply stated: MFRs cater to extractive resource use by aiming to conserve or enhance the production of a small subset of the marine community, while marine nature reserves cater to non-extractive usage by aiming to preserve ecosystems in an unexploited configuration.

The patch scales and dynamics, high species diversity and complex food webs which characterize shallow tropical environments are not an optimal configuraton for sustained yields of a few top predators because of unpredictability, rapid energy dissipation and inefficiencies of multi-gear fishing

(Birkeland, In Press). Ecosystem effects of fishing are pervasive (e.g. Koslow *et al.*, 1988, Jennings and Lock, 1995), and greatly exceed the scales of all but the largest MPAs in the Caribbean. These attributes of marine ecosystems imply different design criteria, depending on the goals of an MPA. For example, the size and configuration of MPAs intended to preserve biodiversity (especially rare species) should be designed to encompass most of an ecosystem and to maintain its integrity by minimizing trans-boundary fluxes (e.g. MPA boundaries should follow natural habitat edges, across which fish as less likely to migrate). On the other hand, MFRs intended to maintain and increase the catch of fish should encompass many small portions of ecosystems containing critical habitats (e.g. spawning sites) and maximize larval export and spillover (e.g. MFR boundaries should cut continuous habitat). In short, the "single large or many small" (SLOSS) debate (Shafer, 1990) may reach different conclusions depending on the goals of a protected area.

— The effectiveness of MFRs in sustaining local fisheries depends on a strong inverse relationship between fishing mortality and export, which has yet to be demonstrated for Caribbean coral reef MPAs —

The density and biomass of reef fish within MPAs has been shown to increase by 2 to 30-fold within 2 to 15 years of protection from fishing (Roberts and Hawkins, 1995; Rowley, 1994; Russ, 1991). Arguably, this response to protection can be taken as evidence that community integrity, and hence biodiversity preservation is being achieved within some MPAs. There is little evidence, however, that these localized increases in fish abundance result in enhanced rates of export to fisheries in adjacent areas (much less, at rates that compensate for the catch lost by relinquishing access to local fishing grounds - Rowley, 1994; Hatcher, 1995).

Several aspects of tropical reef fish ecology act to degrade the putative relationship between the degree of refuge from fishing mortality and the magnitude of export of catchable fish from MFAs. The local distribution of many species of fish that are important to fisheries is usually constrained to the small home ranges characteristic of reef fish. In the Soufriere Marine Management Area (SMMA), all but two of 37 species examined within MFRs (n = 2,301) had an average ambit of less than 55m over a 90 day period (Corless *et al.*, 1996). Site attached life styles and limited home ranges reduce the number of fish statistically predicted to cross the boundaries of an MFR of a given size, even if the boundary is assumed to be invisible to the fish (Table 1).

The distribution of reef fish is also constrained by habitat boundaries which are often resistant to emigration. Most individuals stay on their home reef, while few reef fish venture far off of their home reef substrata (e.g. Holland *et al.*, 1996). The inhibition of fish export from MPAs is exacerbated by the fact that their boundaries generally correspond to the geomorphological edges of reefs, or extend beyond those edges onto land or into deep water in an attempt to mitigate external impacts. Furthermore, fish densities and species packing can achieve very high levels on topographically complex reefs, with correspondingly high levels of natural mortality. These effects suggest that the rate of export of fish from MPAs due to spillover is usually small, and may be largely independent of the density of fish within the reserve (e.g. Rakatin and Kramer, 1996).

The other mechanism by which MFRs may sustain fisheries is by the export of reproductive products that subsequently settle and recruit to fisheries downstream. Higher densities and individual sizes of fish in MFRs are reasonably predicted to result in enhanced reproductive output, although the magnitude of the effect has only started to be measured (e.g., Mitchell *et al.*, in prep.). Given the larval duration of the majority of coral reef fish (weeks to months), the advective regimes characteristic of the region (Shulman and Bermingham, 1995), and the areal extent of all but the largest of Caribbean MPAs (i.e. 10's to a few 100's of km^2), it is highly unlikely that the fish populations within them are self-seeding (Victor, 1984). Indeed, it has so far proven impossible to demonstrate stock recruitment relationships at the scale of entire reefs or even island shelves, much less individual MPAs, although there may be some mechanisms that retain reproductive output in ecosystems that include MPAs at these larger scales.

Much of the putative contribution of MPAs to fish recruitment is based on the application of exponential fecundity-size relationships to the larger individual size of fish that accumulate over time in reserves (PDT, 1990). The implied, non-linear relationship between size-specific mortality and reproductive output from a fish population in an MPA means that even low levels of illegal, large-size-specific fishing mortality (e.g. surreptitious spear-fishing) can greatly reduce the export of reproductive products.

On present evidence then, the argument that MFRs enhance harvestable reef fish production or sustain fisheries is largely theoretical rather than empirical. The spillover rates of catchable fish expected (and measured: Table 1) from Caribbean MPAs are low, and the potential for fish recruitment resulting from reproductive export typically may only be of benefit far downstream of the ecosystems (and even EEZs) in which an MPA is located. It follows that the time lags between the cessation of fishing mortality within an MPA and the realization of substantial fish export from it to local fisheries range from a few years to infinity, due to low spillover, rapid larval advection, and perhaps other factors related to habitat quality and the level of illegal fishing.

Table 1. Spillover of catchable reef fish (# individuals/year, also expressed as % of total MPA population and % of total annual catch from the SMMA) belonging to two species of contrasting mobilities exported from marine protected areas of different sizes in the Soufriere Marine Management Area of St. Lucia, West Indies. Potential calculated from mean densities and 90d mean movement displacements given in Corless *et al* (1996), areas and boundary lengths in Goodridge *et al* (1996), assuming fully permeable boundaries and a random walk model. B:L = boundary to MPA length ratio. SD = Std. Dev.

Marine Protected Area		**Creole Wrasse (*Clepticus parrae*)**			**Black Bar Soldierfish (*Myripristis jacobus*)**		
Area (Ha.)	B:L Ratio	Mean Density (ind./m^2)	Mean Dispacement (m)	Spillover (% pop^n) [% catch]	Mean Density (ind./m^2)	Mean Displacement (m)	Spillover (% pop^n) [% catch]
3.7	0.027	1.624	112.2	9,111 (15.2%)	0.462	12.1	559 (3.27%)
5.5	0.0091	1.336	93.5	3,123 (4.25%)	0.162	10.2	83 (0.93%)
10.0	0.0005	0.416	122.1	1,270 (3.05%)	0.486	15.4	374 (0.77%)
35.4 (N = 5 MPAs)	0.0189	1.463 (S.D.=0.228 n=97)	113.3 (S.D.=16.0 n = 118)	41,439 (8.01%) [136%]	0.335 (S.D.= 0.027 n = 97)	13.5 (S.D.= 0.39 n= 5 27)	2,261 (1.91%) [15.2%]

— The high level of compliance with "no take" regulations required to maintain the potential for export from MPAs to adjacent fisheries is difficult to achieve in many Caribbean MPAs —

Most MPAs in the Caribbean are being established in countries with modest levels of economic development and limited capacity for research and management of marine resources (Kelleher *et al.*, 1995). The infrastructure and operational support required to educate resource users, and to discover, apprehend and prosecute offenders is generally inadequate for all but the smallest of coastal MPAs in the Caribbean. Even very wealthy countries experience difficulty enforcing fishing restrictions in the marine environment because of high enforcement costs (e.g., Barley, 1993).

There are several aspects of Caribbean artisanal fisheries which also serve to inhibit compliance with MPA limitations on fishing activity (e.g. see Mahon, 1990). Often, reef fisheries are the employers of last resort, and the perceived right of free access to marine resources for subsistence or livelihood is widely held by members of society. Fishermen regularly employ multiple gears, prosecute multiple fisheries depending on season and demand, and hold other jobs while fishing part time. Widely different lifestyles and educational experiences in fishing communities complicate communication tourism business people, scientists and resource managers. Fishery management agencies focus primarily on maximizing fishery production through fishery development and application of production models. In addressing these challenges, major advances have been made towards community-based co-management of coastal resources in some countries (White *et al.*, 1994).

The characteristic features of Caribbean reef fisheries act to produce a great deal of reef fishing which is not necessarily justified on an economic basis, but is none-the-less of great importance to the individuals involved. Moving these people out of traditional fishing areas is never easy, and rarely 100% effective. The SMMA for example, despite extensive pre-zoning planning with the local community, is experiencing significant problems of compliance and lack of support from sectors of the fishing community (Nichols and George, 1995), resulting in moderate levels of fishing effort within the reserves in the years after zoning (Goodridge *et al*, 1996; Hatcher, unpublished data).

Competition for marine habitat (especially coral reefs) between fishing and non-extractive resource uses (i.e. tourism) is intense in many Caribbean countries, particularly the small island states (Renard, 1991). Tourism (particularly "ecotourism") is generally argued to be more compatible with the biodiversity preservation goals of MPAs than is fishing, and the financial and political interests involved with the tourism industry are usually eclipse those of the artisanal fisheries (Dixon, 1992). This may result in explicit or implicit promises to fishermen about the positive benefits to fisheries of MPAs, which are yet to be realised (Hatcher, 1995). The capital reserves of many, if not a majority of artisanal fishermen in Caribbean countries may not be sufficient to sustain their livelihoods during multi-year time lag between the loss of fishing grounds to MPAs and the realization of enhanced yields that may possibly flow from the MPAs (e.g., Goodridge *et al.*, 1996). As a result, fishermen may feel discriminated against by other resource users, and MPAs suffer a lack of credibility in the view of many Caribbean fishermen (e.g., Valdes-Pizzini, 1995), which acts to reduce compliance with fishing restrictions. MPAs are unlikely to achieve much of their potential to benefit fisheries until the fishing community experiences those benefits: a "Catch-22" situation.

CONCLUSION

What can we do to reconcile these practical differences in the implementation and effectiveness of various types of MPAs, and to improve the probability of their achieving their respective goals in Caribbean communities?

i) explicitly recognize the substantial differences in management objectives and mechanisms by which MPAs may achieve the overlapping, but different goals of biodiversity conservation and fisheries production.
ii) design MPAs and MFRs according to these differing goals.
iii) measure ecosystem integrity and fish export from MPAs in a statistically rigorous fashion over ecologically and economically relevant time periods (i.e. monitor to support adaptive management decisions).
iv) do not make unrealistic promises to fishermen about the benefits of MPAs.
v) measure the real costs and benefits of MPAs to fishermen, and compensate them for financial losses incurred during the establishment period of MPAs.

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