Can We Stop the Madness? Managing for Resilience in Coral Reef Fisheries

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ABSTRACT

Current fisheries management assumes that with enough data populations can be precisely monitored and regulated. However, coral reef ecosystems (CREs) are complex, nonlinear socio-economic systems that easily overwhelm capacities for data collection and analysis. A more effective approach may be to manage for resilience, which ecologically means taking care of the system's productive capacity. Protecting essential habitats and habitat linkages, trophic pathways and population structures then become the key ecological goals of fisheries management. The main threats to the *local* management of CREs are overfishing, land -based sources of pollution (LBSP) and lack of enforcement. Studies now strongly suggest that overfishing has a strong impact on benthic ecosystem health, most likely through the disruption of trophic structures. While it is unclear how much fishing effort must be reduced below MSY to protect CREs, it is clear that this reduction is significant. Thus, management need not wait for theory to reduce fishing effort and restore lost species and ecological function. Turbidity and eutrophication are the principal LBSP affecting CRE health and productive capacity. Efforts to deal with these go beyond conventional mechanisms of fisheries management and must instead interact with those mechanisms overseeing coastal development and land-use. Effective enforcement is the weak link in current management regimes, yet it is the primary mechanism for re-enforcing the covenant that should exist between stakeholders and managers. Habitat management is explicitly spatial. Marine reserves enhance system resiliency in multiple ways, both biologically and socially, and should be an integral component to CRE management.

KEYWORDS: Coral reefs, resilience, ecosystem-based management

¿Podemos Detener la Locura? Manejando la Resiliencia en las Pesquerías de los Arrecifes de Coral

El manejo actual de pesquerías asume que con suficientes datos las poblaciones pueden ser precisamente monitoreadas y reglamentadas. Sin embargo, sistemas arrecifales coralinos (SACs) son sistemas socioeconómicos no-lineares, complejos, que fácilmente trastornan capacidades para colección y análisis de datos. Una aproximación más efectiva puede ser el manejar para resiliencia, que ecológicamente significa salvaguardar la capacidad reproductiva del sistema.

Protegiendo habitáculos esenciales y conexiones entre habitáculos, senderos tróficos y estructuras poblacionales se convierten entonces en las metas ecológicas claves de manejo de pesquerías. Las amenazas principales al manejo local de SACs son la sobrepesca, fuentes de contaminación terrestres y falta de cumplimiento. Estudios ahora enfáticamente sugieren que la sobrepesca tiene un fuerte impacto sobre la salud del ecosistema béntico, lo más probable a través de la fractura de estructuras tróficas. Mientras no está claro cuánto esfuerzo pesquero debe ser reducido por debajo del "MSY" para proteger SACs, está claro que esta reducción es significativa. Por lo tanto, el manejo no debe esperar por la teoría para reducir el esfuerzo pesquero y restaurar especies perdidas y función ecológica. Turbidez y eutrofización son los principales contaminantes afectando la salud y capacidad reproductiva de SACs. Esfuerzos para lidiar con estos van más allá de mecanismos convencionales de manejo de pesquerías y deben en vez interactuar con esos mecanismos que supervisan desarrollo costero y uso de terreno. Cumplimiento efectivo es el eslabón débil en regímenes actuales de manejo, pero es el principal mecanismo para reforzar el convenio que debe existir entre poseedores y supervisores. Manejo de habitáculo es explícitamente especial. Reservas marinas promueven resiliencia de múltiples formas, tanto socialmente como biológicamente, y deben ser un componente íntegro para el manejo de SACs.

PALABRAS CLAVES: Arrecifes de coral, resiliencia, manejo basado en el ecosistema

Pouvons-Nous Arrêter la Folie ? En Maniant la Résilience dans les Pêcheries des Récifs de Corail

MOTS CLÉS: Récifs de corail, résilience, maniant les pêcheries

INTRODUCTION

Coral reef fisheries are locally important as sources of employment, protein, recreation and external currency through either export or the support of tourism. As such, they have been the subject of intense management interest throughout the world. Nevertheless, the success of these management efforts has been marginal at best. Why is this? Often cited obstacles are a lack of political will to initiate perceived painful management measures, or the lack of enforcement. These are indeed obstacles, and these will be further discussed below. The purpose of this paper is to argue that there is a more fundamental problem we are facing, and a complete paradigm shift in management focus is necessary to face it.

Conventional management advice is centered on reducing catch. For example, in the US Caribbean, under national guidance pertaining to the Sustainable Fisheries Act, a quota must be established for all species/stocks under federal management, and this quota is supposed to be related to the perceived status of the stock relative to some theoretical control point, such as maximum sustainable yield. While catches must somehow be related to level of biological production, there are two fundamental problems with this approach, and both are related to understanding what regulates the productive capacity of the ecosystem as a whole and fishes in particular. First, each species is treated as a separate box, thereby ignoring species interactions. Second, it does not take into account non-extraction damages to the environment that also affect productive capacity. For coral reef fisheries these include habitat destruction and the degradation of water quality through increased sedimentary runoff (sediment, turbidity), eutrophication and pollution. As a result, we are not only eroding overall system productivity, we are reducing the resilient capacity of the system to stress, either from anthropogenic inputs, the shortened and simplified food webs caused by overfishing, or natural factors such as storms and disease.

ECOSYSTEM-BASED MANAGEMENT

Coral reef ecosystems are one of the most diverse and complex within the marine environment (Figure 1). Layered on top of this is an equally complex socio-economic system through which man interacts with the marine environment. Complex socio-ecological systems are inherently nonlinear, and this has serious consequences for fisheries management. First, as resilience is lost, the system becomes increasingly susceptible to regime change. In coral reef systems, this is illustrated by a shift from a coral reef system to an algal reef system (Hughes 1994, Pandolfi et al. 2005). Second, complex socio-economic systems are not amenable to what is termed “command-and-control” management. This is the type of top-down, effort/quota management system currently used for fisheries. As the system comes under greater stress, the data needs for this type of approach, both in quantity and quality, increase exponentially. These increasing needs, coupled with the non-linearity of the system, result in equally dramatic increases in uncertainty. As a consequence, to paraphrase Napoleon, there exists a fog of fisheries: A manager never knows anything with certainty, never sees the fishery clearly, and never knows positively where the stock is (Appeldoorn 2011).

Managing fisheries under these conditions and constraints requires a paradigm shift. No longer would the goal be to maximize catch relative to some target. Under ecosystem-based management the goal is to maintain the ecosystem in a state that will lead to productive and sustained fisheries production over the long term. In short, the goal is to maintain ecosystem function. The regulation of catch is subservient to the health of the ecosystem, and as a consequence, allowable catches will be significantly reduced, although economic return may be buffered by the increased value of the catch and lower costs. Table 1 presents seven first principles for ecosystem-based fisheries management. These constitute the code that underlies and guides the subsequent development of objectives and regulations. Note that the first four deal with maintaining healthy resilient ecosystems, and only the last of these deals with regulating overall catch per se.

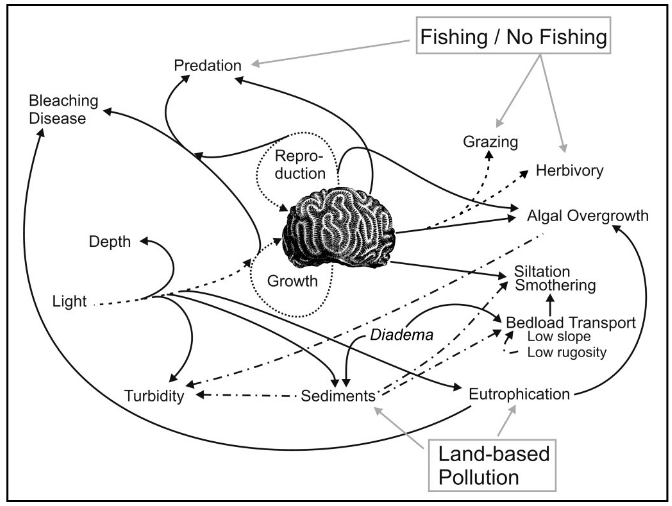

Figure 1. Complexity of factors affecting coral development, not accounting for factors related to climate change. Fine dotted lines indicate processes leading to increases in coral. Dashed lines indicate external processes that enhance coral growth and reproduction/recruitment. Solid lines indicate processes and factors that detract from coral growth and reproduction/recruitment. Gray lines indicate local sources of anthropogenic stress. Dash-dot lines indicate connections among stress factors.

While there are many natural and anthropogenic factors stressing coral reef ecosystems, and hence fisheries production, only a few are under local control and able these are generally well acknowledged: overfishing and land-based sources of pollution, which contribute to eutrophication, sedimentation and turbidity, bacterial load and contamination from toxic substances. Fisheries management agencies traditionally have little authority in the latter area, and it is one of the reasons we are fighting a losing battle. Without management authority, fishermen will be constantly being offered a progressively smaller portion of the ecosystem pie. Yet, overfishing is having serious impacts, and ameliorating these will serve to offset, to some degree, the impacts faced by local and global threats.

Table 1. First principles for ecosystem-based fisheries management (from Appeldoorn 2008)

Maintain Ecosystem Integrity (Biodiversity conservation)
Maintain ecosystem function
Rigorously protect habitat
Protect water quality
Use a precautionary approach
Maintain reference points for monitoring
Match extraction to sustainable productivity

OVERFISHING AND RESILIENCE

The first step is to recognize the extent to which the ecosystem is being overfished. In Puerto Rico and the US Virgin Islands, for example, *every* fisheries assessment in the last 30+ years has reported evidence of overfishing (Table 2). Given the probable historical changes that occurred before this (Jackson et al. 2001), the picture portrayed by these studies would constitute a gross underestimation of the impacts. Figure 2 illustrates what happens when an ecosystem is overfished. Although a multispecies maximum sustainable yield is theoretically possible, there are severe environmental costs incurred. In the particular situation illustrated (Georges Bank; Worm et al. 2009), 60% of the stocks would be collapsed and mean maximum size (Lmax) would decline by 30%. These losses would primarily come from the larger, more valuable species, which also means that maximum economic yield would already have been passed. Yet, reducing catch just 10% would avoid almost all species collapses and result in only a 10% reduction in Lmax. The default management objective is one that maximizes employment, although the net result is that the many fishers earn little. However, it is worse than that, for as species and functions are lost, more productivity ends up going into species of little to no economic value, such as jellyfish (Pauly and Watson, Pauly et al. 2009), which will support few fishers at all.

A similar situation is already occurring in the Caribbean. While poor catch records may make it difficult to predict the status of individual stocks, it is clear from the studies listed in Table 1 and in comparison to unfished areas (e.g., Friedlander and DeMartini 2003) that the system is grossly overfished. Key reef fishes such as the large snappers and groupers, hogfishes, and the large parrotfishes are now rare (Pittman et al. 2010, Beets Pers. comm.), and even grunts, normally considered a prey species, are overfished. This represents both a loss of ecological function and a reduction in the length of trophic webs. Key lost functions are that of herbivory and predation. The loss of predation on the urchin *Diadema antillarum* is thought to have contributed to the rapid spread of the disease that resulted in the region-wide mass mortality (Hay 1984), and the absence of fish-based herbivory did not allow the system to absorb this loss, resulting in rapid algal overgrowth in many areas, which is still continuing (e.g., Ruíz and Ballantine 2009). Reduced ecosystem resilience to disease following loss of biodiversity has also been evidenced for coral diseases (Keesing et al. 2010), which now constitute one of the primary sources of coral mortality. Being an ecosystem driven largely by benthic production, the coral reef equivalent of jellyfish may be cyanobacteria, i.e. slime (Pandolfi et al. 2005).

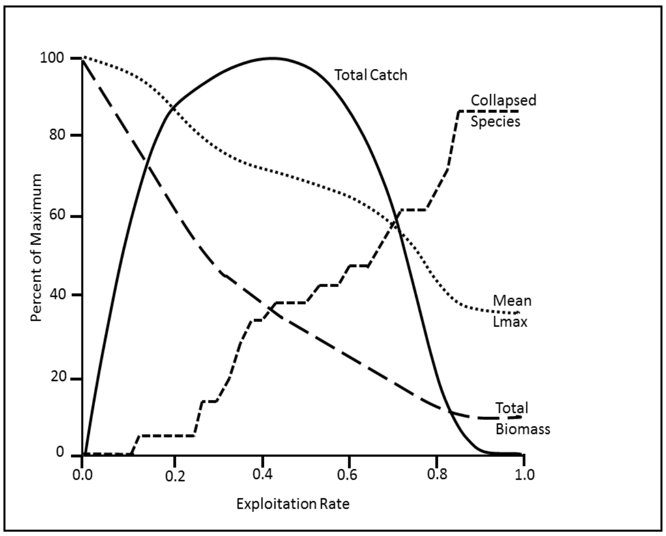

Figure 2. The effects of fishing on a community basis (redrawn from Worm *et al*. 2009). Mean Lmax = average maximum length any species can attain. Collapsed Stocks = fish with biomass <10% of unfished biomass. Total biomass = fish biomass left in the ecosystem. Figure 2. The effects of fishing on a community basis (redrawn from Worm *et al*. 2009). Mean Lmax = average maximum length any species can attain. Collapsed Stocks = fish with biomass <10% of unfished biomass. Total biomass = fish biomass left in the ecosystem.

Table 2. Studies showing overfishing in Puerto Rico and the US Virgin Islands

Olsen and LaPlace 1978	*Epinephelus striatus* (VI)
Stevenson 1978	Trap fishery (PR)
Colin 1982	*Epinephelus striatus* (PR)
Appeldoorn and Lindeman 1985	*Haemulon* spp. (PR)
Dennis 1988	*Haemulon* spp. (PR)
Appeldoorn et al. 1990	Reef fishes (PR-VI)
Acosta and Appeldoorn 1991	*Lutjanus synagris* (PR)
Bohnsack et al. 1991	*Panulirus argus* (PR-VI)
Dennis 1991	*Ocyurus chrysurus* (PR)
Appeldoorn 1992	*Strombus gigas* (PR)
Appeldoorn 1993	*Strombus gigas* (PR)
Appeldoorn and Posada 1992	Trap fishery (PR)
Beets and Friedlander 1992	*Epinephelus guttatus* (VI)
Beets and Friedlander 1997	*Epinephelus guttatus* (VI)
Appeldoorn and Meyers 1993	Demersal fisheries (PR)
Mateo and Tobias 2002	*Panulirus argus* (VI)
Stump 2004	Fisheries (PR-VI)
Ojeda et al. 2007	Spawning aggregations (PR)
Ault et al. 2008	Snapper-grouper complex (PR)
Pittman et al. 2010	Large species (PR)

MANAGEMENT FOR RESTORATION

If we are to restore coral reef fisheries, management must start focusing on protecting the health of the ecosystem as a whole by promoting strategies that will ensure habitat protection, trophic balance, and system production. Specific objections should be developed to accomplish the following:

i) Protect juveniles,
ii) Protect fish spawning aggregations,
iii) Protect forage species,
iv) Avoid destructive fishing practices,
v) Protect habitat and fish community composition, and
vi) Maintain size and trophic structures.

Appeldoorn (2008) lists several strategies to achieve these objectives. Principal among these is the use of marine reserves, or at least other forms of MPAs offering significant protections. The focus on reserves and MPAs would also allow a place-based management basis to develop, where interagency cooperation could be fomented to address the additional ecosystem stresses from land-based sources of pollution, and were protocols for stakeholder interactions and co-management could be developed and tested. Such an approach would also constitute a logical introduction into the larger issue of implementing marine spatial planning.

At some point, however, it will come down to enforcement. This is the weakest link in fisheries management and should be given high priority. The reasons for inefficient enforcement are many and include insufficient resources, lack of training, lack of will, unresponsive vertical authority structures, unclear regulations or legal bases, or deliberate neglect to serve politically powerful private interests. Bottlenecks to effective enforcement should be a priority for scientific study and legal review. Enforcement is the primary mechanism that re-enforces the covenant between stakeholders and managers, so enforcement structures must be responsive to local management. Without it, stakeholders have no trust that managers will comply with their responsibilities. Again, placed-based management, with enforcement tied to MPAs may provide a breeding ground for horizontal enforcement structures (enforcement personnel being responsible to MPA managers) and, hence, effective management.

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