ISRS BRIEFING PAPER 4

SUSTAINABLE FISHERIES MANAGEMENT IN CORAL REEF ECOSYSTEMS[1]

SYNOPSIS

The sustainable management of coral reef fisheries is challenged by the high diversity of target and nontarget fish and invertebrate resources, poverty, and the high spatial variability in resource production. These complications largely preclude strict species-specific management of stocks, quotas, or human fishing effort, which are preferred restrictions used in temperate, wealthy, and industrial fisheries.

- Restrictions on fishing gear, fish sizes, times and space that are enforced by traditional or indigenous management and corroborated by national and international institutions and policies are more likely to succeed in this environment.
- Gears that are destructive to habitats and catch small fish are easily observed and enforced by cultural traditions and national laws. Nonetheless, even fairly low levels of fishing with non-destructive gear will reduce top-level carnivores and the maintenance of their populations will require closures to fishing in time and space.
- Closed areas may range in sophistication and cost from areas that are viewed as too dangerous to fish by virtue of existing technology or tradition to highly managed tourist or enforced wilderness areas.
- The globalization of coral reef fisheries products is often responsible for excess and unsustainable harvesting and needs to be discouraged, regulated, or stopped depending on the state of the resource. National and international laws and management institutions need to support local efforts; culture and institutions to maintain a local balance between resource production and consumption and discourage export and globalization of the resource.

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INTRODUCTION

Sustainable use is the concept that resources should be used in way that there is a balance between resource production and human consumption such that harvesting will not reduce future production and options for resource use. Sustainable management therefore requires a shift in focus from short- to long-term use and profits, and places importance on sustaining species with potential future uses. It is also closely aligned with ecosystem management concept where resource use is expected to maintain the many ecological processes and diversity of the utilized ecosystem while managing for multiple present and future needs of people. These concepts are generally acceptable and desirable by most members of society but the problem with implementing these concepts is that they can frequently conflict with the daily practices and desires of the individuals that use resources, which are frequently focused on minimizing effort and maximizing short-term harvests and profits (Aswani 1998). Further, the continual improvements of technology and increases in human populations have produced harvesting and marketing potential beyond the production potential of most ecosystems. Coral reefs are no exception but because they are often viewed as a "common-pool resource" with exceptionally high biological diversity and potential uses they pose special problems for management.

The discussion that follows will outline some of the characteristics of the coral reef ecosystem and resource use and suggest ways that these characteristics can be managed for sustainability of the harvest and the ecosystem. The challenge to describe and present useful recommendations is considerable given that over 100 mostly tropical, poor, and culturally diverse countries have coral reef fisheries that range from subsistence gathering of intertidal snails to industrial trawl fishing and the export of luxury items. Consequently, there will ultimately be a need to gather information and develop management systems sufficiently useful for specific people and coral reef ecosystems but this does not preclude the value of developing global policies and guidelines for programs of study and management that can assist site-specific management objectives. This, therefore, is the primary purpose of this short overview of fisheries sustainability.

The Coral Reef Fisheries Environment

Coral reefs are limited to tropical environments that experience high light, water temperatures and water motion, and low nutrients, land-based influences or pollution. The coral reef environment houses many species because corals skeletons, both live and dead, provide refuge for fishes that find protection from predators among the crevices and hollows provided by coral. The reef is also productive but in many places the production is less than the demand by consumers that inhabit the reef and many fish travel away from the coral reef to find additional food. Consequently, many fish use the coral reef as a home where they find refuge after they return from foraging in more distant seagrass, mangrove, and other ecosystems. This high concentration of fish makes them excellent fishing grounds and are, therefore, a target habitat for fishermen.

Production and its limits

One of the curiosities of the coral reef ecosystem is the high productivity of the plants and algae but the low net production of fish (Nixon 1982). The benthic algae production rivals agriculturally intensive and productive systems such as sugar cane but humans can use less than 1% of this production in the form of fisheries (Hatcher 1997). This occurs because of the high internal demand for this production by the coral reef species themselves such that most coral reefs maintain a balance between production and consumption, with only small excess that can be exported or used by humans. Other ecosystems, such as oceanic up-welling systems can produce nearly 50 times more fish than coral reefs for each unit of algal production. Consequently, coral reefs should not be seen as a source for fisheries production for global trade, but rather as a repository of biological diversity. Nonetheless, coral reefs do support important fisheries for tropical people with reported yields ranging greatly from 0.5 to 50 tons per kilometre per year (Dalzell 1996). The average yield from over thirty fishery studies is around 8 tons per square kilometre and may be near the maximum sustained yield but the variation around this mean is larger than the mean itself, suggesting high variation among study sites and difficulties in making reliable estimates and recommendations.

Estimated yields vary greatly depending on the fishing gear, effort and its history in the coral reef. For example, in lightly fished reef areas, such as the remote Chagos Islands of the Indian Ocean, the catch per person is around 60 kilograms per day (Mees 1999) whereas heavily fished reefs in Kenya produce around 3 kilograms per person per day (McClanahan and Mangi 2001). Ironically, the sustainable yields from the Chagos and Seychelles have been estimated at the low end of production between 0.10 and 0.22tons per square kilometre where as the Kenyan reefs produce around 5 tons per kilometre and have potential for higher production if the high fishing effort could be reduced. The differences between these two areas are primarily due to the fact that most of the Indian Ocean island fishery is in deep water, up to 150 m deep, uses non-renewable resources and refrigeration, and the fishery is selective while in Kenya the fishery is less than 10 m deep, uses renewable resources, and is unselective. Consequently, water depth, aerial extent, technology of the fishery and different histories and selectivity of fishing create difficulties for estimating resource productivity and making precise recommendations on maximum sustained yields. The catch per person is the most frequently collected statistic for coral reef fisheries but, by itself, is not very helpful in determining the maximum sustainable catch, as it always declines with increased effort.

To practically estimate the maximum sustained yield for specific coral reefs without relying on the many assumptions of the equations and models used by fisheries scientists it is necessary to monitor the catch on a per unit area basis over time. When catch per area rises there is the potential for further catch but when declining the maximum sustained yield has been exceeded. Consequently, one of the simplest ways to manage a fishery is to reduce effort whenever the total catch for a specific area declines. Catch per area has a few problems that must be acknowledged in order to avoid the common problems that lead to fishing beyond sustainable levels. The two most common problems are that the both the effort and area that the catch is measured from is often not constant over time unless carefully checked. It is possible for the total catch at a landing site to be constant or increases far beyond the maximum sustained yield of the local fishery because the fished area increases and fishers are expending more daily effort. In a declining fishery, fishers will travel further and fish longer and this makes it necessary to change the effort and area parts of this calculation to get unbiased catch per area estimates. If these factors are considered and the conditions of the environment that influence production do not change greatly between years, than monitoring the catch per area can give good estimates of sustainable fish yields.

ECOLOGICAL INFLUENCES ON PRODUCTION

Light, water movement, nutrients and the aspects of the reef ecology such as the cover of coral and algae and the abundance of herbivores influence production by algae and subsequently coral reef fisheries. Consequently, where light penetration is reduced by depth or dirty water coral fisheries yields are also expected to decline, which is one of the reasons for maintaining clean seawater. The full consequences of dirty water are not that well understood but they do include reduced growth rates of corals and increased decay rates of the dead skeletons, which will reduce the refuge available for fish. There may be other unexpected influences of dirty water such as increases in coral and fish diseases.

Two important aspects of the coral reef community that influence production is the coral cover itself and the herbivores. Coral has lower consumable production than some of the common forms of algae that dominate reefs where herbivores regularly forage. Similarly, algae that are not regularly foraged have lower production than algae that is frequently foraged. Consequently, a very high dominance of coral or low levels of herbivores can reduce production and influence fisheries yields. Coral provides refuge for coral reef fish and their needs to be balance between cover by productive algae and corals to achieve both the production and refuge required by fish. For this reason, reefs with intermediate levels of coral cover of between 25 and 50% of the bottom are likely to be optimal for sustaining high fisheries yields. Fishing gear and methods that destroy coral will reduce the available refuge for fish and fisheries yields. Because many herbivores are needed to keep the production of the algae high there is a need to protect or sustain these populations.

In some cases heavy fishing results in a proliferation of species that influence reef production or refuge. Examples include coral-eating starfish and snails and herbivorous sea urchins that appear to proliferate in the absence or low numbers of predatory fish such as triggerfish, wrasses, and emperors (McClanahan 2000, Dulvy et al. 2004). The loss of coral cover is expected to reduce the abundance of fish that require it for refuge.

In the case of sea urchins, very high numbers can eat virtually all of the algal production and prevent it from being utilized by other species. These species, at low numbers, are part of healthy reef ecosystems but at high numbers they become pests and undermine the health and fisheries production of reefs. High numbers of these pests are an indicator of unsustainable fishing and this recognition can act as a basis for increasing restrictions on resource-use.

CATCH AND EFFORT LIMITS

Management activities are often focused on reducing catch and effort in the face of increasing numbers of people entering the fishery with more effective technology. Management has six basic options. These include restricting 1) the numbers of people or boats fishing, 2) the time allowed for fishing, 3) the fishing area, 4) gear or technology, 5) the sizes that can harvested, and 6) the species being selected. Each or a combination of these alternatives will help to limit short-term harvesting in favour of sustaining long-term yields. In many cases more than one if not all of these options are needed to sustain the fishery, but what is critical to their success is the acceptability, adoption and enforcement success of the options.

Effort

Constraining effort by restricting the number of people or boats is one of the most common management systems that are employed by government fisheries departments. Requiring fishing and boat licences and adjusting the number of licences or the fee for a license are common restrictions. Where fisheries departments and associates are able to patrol and check for licences these restriction can have moderate success but in most fisheries the chances of being caught are minimal and if fishermen do not feel compelled to comply with government restriction, common to many poor tropical countries, there is poor compliance and enforcement and widespread disregard for the licensing system (Sutinen and Kuperan 1999). This has led to some well-earned cynicism toward this method of restriction and greater hope for catch limits, closed areas, gear restrictions, and community or local social control.

In nations with sports and industrial fishing, failure to sustain fisheries with the above system has often resulted to a switch towards a license for the maximum quotas or wet weight of fish where the sustainable net off take of the target species is calculated each year. If the catch is landed at a monitored landing site than it is possible to control catch by this method but in tropical artisanal fisheries where catch is landed at many small sites along an undeveloped coastline it is impractical to monitor catch of individual fishers who may typically catch less than 10 kg per person per day. This has led to recognition that local social or community control may be one of the better options for managing coral reefs fisheries (Bunce et al. 2000).

Area

Closing areas to fishing is also seen as an option for fisheries management (Russ 2002) and these have been used by people with traditional management systems where closure ranges from areas inhabited by spirits, as believed by some traditional African people (McClanahan et al. 1997), to areas restricted for harvesting only during feasts when large quantities of meat are needed, as managed by many Melanesian people (Cinner et al. in review). These area-management systems are considerably different from the modern image of marine parks where tourists are charged park fees by government or private business authorities to enter and the two are not often socially compatible, despite both closing areas to entry for fishing and having potentially similar ecological consequences (McClanahan et al. 1997).

Closed areas have the added benefit of protecting fish and the other components in the ecosystem and have, therefore, received a good deal of attention and excitement as tools for achieving both fisheries sustainability and ecosystem management (Allison et al. 1998). They do appear to increase the density, weight and number of species of fisheries target species (Cote et al. 2001, Halpern 2003) when they do work, but despite the creation of many closed areas only a moderate number have achieved their management potential (Kelleher et al. 1995) and going from government gazettement to full compliance is complicated by many hurdles that seem to be overcome most frequently in areas with high levels of nature tourism (McClanahan 1999). Nonetheless, because some coral reef species are slow-growing and slow to recover from fishing (Goeden 1982, McClanahan 2000) closed areas may be the only way to insure the persistence of these vulnerable populations and the full range of closed areas needs to be encouraged. The types of closed areas will depend greatly on the socio-economic conditions of the sites and should be flexible and utilize systems that are financially sustainable. Large closed areas may be preferable but may only succeed where nature tourism and the economy can afford them, while small-scale and low-cost alternatives will succeed where there is local support but poor external funding.

Gear and size

Increased technological advances in fishing gear is leading to unsustainable harvesting of fish in many areas but even among less technologically advanced fisheries the types of gear used can also result in destruction of habitat and unsustainable fisheries. In coral reefs, a number of gear types are destructive to reef habitat and should be discouraged. These include nets that are dragged, have heavy weights on the drag line, heavy traps made with slow or non-degrading materials, explosives, poisons, and any method that breaks coral to scare or extract fish.

Less obvious is the fact that seemingly different gears can compete for similar resources. As catches decline, the gear that extracts the smallest size and most diverse fish resources may be the "better competitor" and may reduce the catch of other gear types that select larger and more species-specific targets. Well-managed fisheries should have a mix of gear that insures that all target species are utilized but without accelerating competition between gears for smaller fish. This most practically requires that mesh size of gears, including the various nets and traps, have similar meshes that lean towards catching the larger size classes of most species after they have reached their asymptotic size and sexual maturity.

Gear that catch sizes smaller than the alternatives should be eliminated from the fishery or modified to insure no gear has a competitive advantage based on the sizes of caught fish. These generally require constant vigilance by the fisheries managers but fortunately gear are easily seen and evaluated and, if needed, confiscated. Gear use is also often grounded in traditions that can be enforced by culture and laws and this makes them one of the easier restrictions to reach consensus on and enforce.

Species

Restrictions on species are not commonly used in the tropics because of the large number of species and the lack of knowledge on which species require restrictions. Nonetheless, modelling studies of functional groups suggest that choices that fishermen make concerning the catch can greatly influence total yields and ecological processes (McClanahan 1995). In some cases not fishing one functional group such as sea urchin predators, can increase the total yields by insuring that algal production is channelled into herbivorous fish and not into unharvested sea urchins. The evolution of fisheries is, however, to be selective, often focusing on the high-level predators but eventually fishing species further and further down the food chain (Pauly et al. 1998). This maintains the total catch over time even as effort increases beyond what may be sustainable for some top-level predators and slow-growing species. This suggests the need to place restrictions on these vulnerable species. Restrictions on fishing of spawning aggregations, where many of the carnivorous groupers and snappers congregate for short periods of time to breed is one clear example. Unrestricted fishing of these aggregations can quickly reduce their populations and interfere with their reproduction (Sala et al. 2001). Further, as mentioned above restrictions on some specialist predators of sea urchins and starfish, such as triggerfish in the genera *Balistes*, *Balistoides* and *Balistapus* or wrasses in the genus *Chelinus*, and many of the parrotfish in the genus *Scarus, Sparisoma* and *Chlororus* are prime candidates for special status and species-level restrictions due to their important role in coral reef ecology.

THE SOCIO-ECONOMIC DIMENSION

Social, cultural, and economic forces will often determine the success of the restriction options and the challenge for management is to find the right mix of limits for the particular human environment. Many management systems in the past have focused on only a few of these options and if these options are not acceptable by fishers or difficult to enforce there will be poor compliance and success. Consequently, it is recommended that the attitudes and feasibility of the various options be explored early and repeated at intervals during the management process through interviews and public meetings. Once the most acceptable options have been identified, the chances of adoption, compliance and success will improve. Once restrictions are established and their failures and successes have been documented, managers can begin the process of adding and modifying restrictions. This process of including users and their attitudes in the decisions and adaptive management process is likely to build the social capital required for sustainability (Pretty 2004).

INFORMATION AND MONITORING

Information appropriate to the scale of the resource, their users, and its management is a primary ingredient for successful management (Dietz et al. 2004). Conflict resolution, compliance, and building support and adaptation all require that the information is appropriate for decision-making. The level of this information will vary from the most basic concepts of fisheries and ecosystem management to more sophisticated and holistic databases on fishers, the resource, its use and models of their interaction and probabilities of associated outcomes under various scenarios.

In some cases, fishers are not aware of modern fisheries and ecosystem management and the information they need to change unsustainable practices can be as simple as the recognition that fishing effort and fish abundance are related or that a particular gear is destructive to fish habitat. Once fishers are aware of these relationships there is increased chance that they will adjust their behaviour, management and gear towards more sustainable use. In more sophisticated management environments the outcomes and risks of each management scenario may be calculated and fine tuned estimates of probabilities are required. In many cases, however, resource users make decisions based on opportunities for short-term profits and it is the role of managers and society to instil an ethic of compliance that can buffer this behaviour and the consequent fisheries tragedies.

Because decisions are based on multiple conflicts and desires it is best to collect information on a number of aspects of the fishery, not just the fish or the ecosystem but also the socioeconomic environment. This reduces the chances that unexpected consequences, surprises or externalities will disrupt management activities. For example, unemployment or prices of fuel, gear and fish could be as important as fish stock estimates in the decisions made by individuals, politicians or managers. If information about the resource is lacking the decisions may be made on existing economic information, which can be dangerous when resources are depleted. In many cases the resource user has informal but invaluable information about resources that needs to be part of the decision-making environment (Johannes 2002), but often needs to be distinguished from political positions.

Monitoring, or the collection of information over time, is particularly useful when testing for the long-term effects of specific management systems and to generate information that can evaluate the effectiveness of management. In an optimal management environment, monitoring data would be continuously collected and soon result in changes in management. In practice, there is often missing information, lags in time and compliance with management regulations. The challenge to managers is to find the right mix of information, stakeholder involvement, and management action that will facilitate adaptive responses. Additionally, in many of the poor fisheries that are managed at a very local level, there is a need for simple information collection and management decisions. For example, if a particular size or catch per day of a key target species is below a certain level than this target species would be banned from fishing for a period before testing for this threshold at some later date. Simple management heuristics or thresholds that have been established from prior scientific studies or the experiences of resource users may be one of the better hopes for managing small-scale coral reef fisheries.

SUSTAINING THE ECOSYSTEM AND DIVERSITY

Given that it is possible to have a sustainable fishery within a degraded ecosystem and environment it behoves the public and managers to look beyond the mechanics of biomass extraction to the larger issues of the ecology and diversity of the fishing environment. Continuous and long-term fishing of an ecosystem is likely to change the ecosystem significantly in favour of fast-colonizing and growing species that are tolerant of frequent disturbances. These species may be able to maintain high yields into the foreseeable future but there may be a loss of many important components of the coral reef ecosystem. For example, many degraded reefs may be replaced by rubble or seagrass ecosystems that can have productive fisheries but support only a fraction of the species diversity. Coral reef ecosystems are composed of a high diversity of species with life histories considerably different from those that will be selected by the harvesting systems. The challenge is, therefore, to not be complacent with simply achieving fisheries sustainability but also sustaining the ecosystems and all of its components. Maintaining all components of the ecosystem maintains future options and unforeseeable consequences of the changing environment. This has been one of the arguments in favour of closed or reserve areas but there may also be ways that fishing itself can be encouraged to maintain this diversity. As mentioned above, fishing methods that are destructive to coral habitat or eliminate species through destruction of their breeding aggregations will not encourage the broader goal of ecosystem sustainability and should be discouraged.

Global Influences

Coral reef products such as shells, shark fin, sea cucumber, live rock, food fish and valuable invertebrates such as conch and lobster, and ornaments are part of the global trade environment. The globalization of these products has created a demand beyond what is locally sustainable. The trade in coral is presently included under CITES Appendix II and requires permits. Many of the other coral reef products that are equally vulnerable are, however, not well regulated or the extent of their influence on coral reefs is poorly understood. Trade of these products should be undertaken with caution and after some estimates of populations of these species have in their natural environment and the methods used to collect these species are not destructive to habitat. Greater restrictions on trade will improve chances that the species are monitored and protected.

Recommendations

The global value of coral reefs is their high biological diversity and they should be managed for this diversity rather than as a source of food or luxury products for the global trade. Nonetheless, many tropical people rely on coral reef fisheries and management should seek to maintain a local balance between resource production and consumption. This can be achieved by restricting trade of coral reef resources to those species with populations that have been estimated and determined to be above certain ecological viable population thresholds. Further, temporary local restrictions should be placed on species below asymptotic or reproductive sizes. Some species such as some triggerfish and parrotfish species play an important role in coral reef ecology and should not be harvested. Local management can also benefit from thresholds that stop fishing when total catch per area declines or when pest species exceed thresholds. Local, national and international leaders should discourage and ban gear that is destructive to habitat. Restrictions on gear that catch small individuals should be discouraged and management should promote a mix of gear that do not compete for similar resources or smaller sizes of individuals. Management needs to adapt to local conditions and attitudes in a way that management systems are embraced by fishing cultures and self-enforced. Simple adaptive learning heuristics and thresholds for restrictions are needed and should be encouraged such that management can be simple, cost effective, and managed by local authorities.

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