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Chapter 8
Sustainable Management of Coral Reefs in the Caribbean Sea

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Abstract

Coral reefs are based on a fragile and easily disrupted symbiosis between microalgae, collectively called "zooxanthellae", and coral polyps. The corals, together with macro-algae, form the base of a food web that supports a highly diverse ecosystem. The primary productivity of the system is very high but it is vulnerable to the effects of global warming and environmental degradation caused by physical damage to reefs, by sedimentation and by pollution from plant nutrients, chemical wastes, herbicides, pesticides and oil. Fishing with explosives and various poisons can also threaten the integrity of coral reef ecosystems but over-fishing with conventional fishing gears appears to be the greatest problem. Heavy fishing causes changes in community composition and trophic structure of the ecosystem by selective removal of the most vulnerable species and by eventual reduction in the rates at which juvenile fish are recruited to the stocks. Reduction in the abundance of herbivorous fish, principally by fishing with Antillean fish traps, has probably been a major factor leading to overgrowth of reefs by macroscopic algae in many areas of the Caribbean. Methods for sustainable management of reefs are well understood. However, throughout the Caribbean effective management is constrained by ineffective legislation, lack of community awareness, poverty and unemployment. Resolution of the conflict between immediate human needs and the fragility of coral reef ecosystems is the greatest challenge facing the sustainable management of coral reefs.

Key words: Over-fishing, pollution, coral reef ecosystems, climate change

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Distribution of corals and coralline shelves

Coral reefs are distributed throughout shallow tropical and sub-tropical waters, principally on the western margins of the oceans and around oceanic islands. In addition to shallow reef areas and reef crests that emerge on low spring tides, large areas of island and continental shelves have abundant coral patches scattered over sub-tidal areas to depths of up to 100m. These are referred to as "coralline shelves". Shelf edges, particularly those to windward or up-current, often have substantial coral reefs, referred to as sill reefs, which cascade into the depths over the "drop-offs" so favoured by recreational divers.

While some reefs stand alone in the ocean, such reefs are rare. More often, they form an integrated ecosystem with mangrove fringes, stands of sea-grasses, sandy lagoon floors, fringing reefs, reef slopes, coralline shelves, sill reefs and drop-offs. The various forms taken by these ecosystems can cover an infinite variety of combinations and permutations, depending upon local topography, geology and climate.

Fringing reefs surround most Caribbean shores, except adjacent to major inflows of freshwater or sheltered inlets with poor water circulation. Typically, these reefs descend to island or continental shelves, ranging in width from a fraction of a kilometre to over 200 km, before an abrupt drop towards abyssal depths. Oceanic banks, with no or few islands are relatively common in the Caribbean (Pedro Bank, Alice Shoal, Rosalind Bank), while barrier reefs, such as the Belize Barrier Reef and atolls such as Glover Reef are uncommon.

The benefits obtained from coral reefs need little description. In addition to supporting fisheries, the reefs create protected and calm coral lagoons, the fringes of which are so favoured for human settlements and harbours. Hotels cluster around sandy beaches and marinas and boat moorings compete for space in such surroundings. One need only look at tourism brochures for examples of the aesthetic appeal of sparkling coral lagoons. The fringing reefs, invariably backed by narrow lagoons, provide a self-sustaining buffer against storm waves and reduce coastal erosion and damage to shore-side infrastructure.

Coral reef ecosystems

Although reef-building or hermatypic corals create the massive framework of the reef, the coral tissue represents a rather small fraction of the biomass of a reef ecosystem. A large part of this tissue is actually composed of the symbiotic algae zooxanthellae, which play a vital role in the reef ecosystems, both in terms of primary photosynthetic production and in terms of the deposition of the reef framework of calcium carbonate. The other components include a wide variety of algae, diverse invertebrates, fish and a limited array of reptiles, birds and mammals. Seagrass beds, primarily composed of turtle grass (Thalassia testudinum) in the Caribbean, also harbour many fish and invertebrates and are grazing areas for manatees in the Caribbean and dugongs in the Indo-Pacific. In particular, seagrass beds serve as nursery areas for a large number of fish species, particularly commercial varieties, which reside on the reefs when adult. Shoreward of the grass beds, many areas support stands of mangroves. In the Caribbean, with its generally low tidal range, the prop roots of the mangrove systems are also nursery grounds for a number of commercial fish species. The prodigious leaf litter of the mangroves finds its way into the wider ecosystem, by way of detrital food chains.

The primary productivity or the rate of carbon fixation by photosynthesis of reef ecosystems is huge, averaging about 7-10 gC.m-2.d-1 (Lewis 1977), and equal to or greater than that of major agricultural crops such as rice or sugar cane. Part of this primary production is attributable to the symbiotic zooxanthellae, which are provided with living space, nitrates, phosphates and CO_2 by their hosts and through the photosynthetic process, provide the calcium carbonate that is required for growth of the skeleton of the coral. A wide variety of algae compete with corals for vacant surface area on the reef. Phyto- and zooplankton are filtered from the water brought to the reef by tides and currents by myriads of filter-feeding invertebrates (including corals) and fish. These plankters are the primary sources of the nitrates and phosphates that are essential for primary production. Blue-green algae are able to fix nitrogen, and thus also add to this essential resource.

This primary production, together with the energy derived from filtering zoo- and phytoplankton from the ocean, supports an immensely complicated food web, in which tens of thousands of species of micro-invertebrates, thousands of species of macro-invertebrates and about 300 species of fishes are bound in interdependency (Opitz 1996).

Ecosystems that support large numbers of species are inherently robust and are able to recover from catastrophic natural events. This is particularly so if the component populations are isolated parts or metapopulations of a larger scattered population. Thus reefs damaged by hurricanes or other natural events will be re-colonised by propagules arriving from elsewhere. This process can be quite lengthy and randomised, highly dependent on chance arrivals borne on ocean currents, but ultimately a "typical" reef ecosystem will re-emerge. On the other hand, any process that strikes at the symbiotic relationship of corals and zooxanthellae will undermine the very structure of the reef. Reef erosion results from natural breakage of corals by waves, fragmentation of corals by feeding and boring activities of reef organisms, particularly parrotfish, sponges and molluscs. These convert coral skeletons into sand and make desirable white beaches. However, on a healthy reef this erosion is normally balanced by the rapid growth of coral skeletons. If erosion outpaces accretion, the topography of the reef will become less diverse, holes will fill with sand and rubble, reef creatures will lose their refuges and the reef will become reduced to a pile of loosely accreted rubble.

Climate change

It is clear that, in the absence of anthropogenic impacts, coral reefs will manage very well, as they did a few hundred years ago. One solution is to set aside the most pristine areas that are available and vigorously protect them against all forms of degradation so that at least some examples of undisturbed habitat will survive. The Nature Conservancy has recently purchased the entire Palmyra Atoll in the central Pacific Ocean, for US$35 million, for this purpose. Unfortunately, human influence is so all-pervasive that even the remotest islands, the highest mountains, the Antarctic ice shelves and the abyssal depths of the oceans are not immune to environmental change caused by man.

There is mounting evidence that ecosystems are becoming destabilised as a result of global warming. In the case of coral reefs, this has manifested itself particularly through coral bleaching, which is attributed to unusually high surface water temperatures. The process is not well understood, but corals of all species and related organisms such as sea fans, spontaneously expel their zooxanthellae. Alternatively, the symbionts decide to leave because the host is no longer fulfilling its proper role. Without the symbionts, the coral tissue is translucent (bleached), the tissue cannot sustain itself and the coral dies. The thin veneer of tissue rapidly decomposes leaving a white skeleton. This new surface area is promptly colonised by algae or by coral propagules. However, coral spawning is highly seasonal and usually does not happen in the hottest months. Consequently, the algae have the opportunity to cover all available surfaces. Reef erosion then exceeds accretion and the reef declines in size and complexity.

If oceans do systematically warm, corals may die off in the tropical regions of the oceans and slowly spread north- and southwards.

An additional complication that has recently been suggested is that increased atmospheric concentrations of CO2 will interfere with the photosynthesis of zooxanthellae. This is closely inter-related with the deposition of the aragonite skeleton of the corals. The rate of growth of the coral skeleton might be greatly reduced, leading to the progressive decay of reefs. Reefs would be unable to respond to rising sea levels by rapidly growing towards the surface, with terminal consequences for atolls and other low islands.

It seems to be well agreed that sustainable management of any particular resource will not be possible if ecosystems are themselves in a state of change because of global warming. These management solutions are outside of the power of individual states, which can only urge in appropriate fora that necessary action be taken to check and reverse this process.

Hurricanes are a major cause of damage to Caribbean coral reefs, as are their semantic counterparts, cyclones and typhoons in the Indo-Pacific region. Direct hits by hurricanes can reduce reefs to rubble. However, as mentioned above, reef organisms are parts of metapopulations and if all is well elsewhere in the region, devastated reefs will eventually rebuild. If all is not well elsewhere, rebuilding will be a lengthy process and if increased hurricane strikes are a part of global climate change there is little that individual states can do about the situation.

Environmental degradation

The effects of human activities on coral reefs were comprehensively reviewed by Salvat (1987). The primary causes of degradation are discussed below.

Physical damage to coral reefs

Reefs are often damaged by reef users. The careless use of boat anchors, often in prime dive locations, is well recognised and increasingly seems to be fairly well taken care of by dive operators, charter yacht companies and others with a financial interest in maintaining the environment that they use. Likewise, careless or inadvertent damage to corals, particularly by inexperienced divers, seems to be on the wane. Tourists have caused serious damage to shallow reefs by tramping over shallow areas and by standing on corals when snorkelling (e.g. Bucooo Reef in Tobago). Ignorance is a major factor and can be counteracted by resort owners and other interested parties providing appropriate information.

Individual fish traps cause little damage. Most fishers aim to set their traps in sandy areas adjacent to corals and when hauling the trap are careful to rapidly get it clear of the reef to avoid damage to the trap. When numerous traps are set attached to a single line, usually on relatively flat shelves, damage to patch reefs is a real possibility, particularly if the line is hauled in heavy seas. Fortunately, destructive techniques such as "muro-ami fishing", which is practised in parts of East Asia, are not prevalent in the Caribbean.

Catastrophic damage to reef crests and adjacent areas that is caused by the grounding of large vessels and by subsequent efforts to recover the vessel is, like hurricane damage, a circumscribed event, with no lasting damage to the reef ecosystem even if the immediate effect is distressing.

The major physical factor impacting on coral reefs is sedimentation. Poor land use, whether for forestry, agriculture, mining or infrastructure development, results in mud, silt and sand flowing into the sea. Heavier particles that settle on corals will simply smother the corals and they will rapidly die if the sediments are not dispersed by strong wave action and currents. Habitat availability is reduced if the interstices of the reef are filled by sediments and biodiversity loss ensues. Turbidity caused by suspended solids reduces photosynthesis and promotes reef erosion. Reefs do not develop adjacent to major rivers for this reason. The damaging sedimentation comes from small streams and ravines passing through vegetated areas. When these areas are logged, the related effects can be catastrophic. The real costs of logging, both to marine and to terrestrial ecosystems, seems likely to be greater that the value of the timber. Progressive clearing of vegetation for small-scale agriculture has effects that are more insidious but the long-tem result is the same. The solution is profoundly difficult if land shortage and lack of alternative employment are the causes of farming on steep slopes.

Sedimentation resulting from infrastructure development seems mostly to arise from ignorance and sometimes merely from greed. Careful engineering and construction can avoid problems but this only happens when relevant authorities take the care to ensure that environmental guidelines are followed and transgressors punished. Some of the worst offenders are resort and marina developers.

Simple application of environment laws can provide remedies if commercial agriculture, mining or infrastructural developments cause sedimentation.

As with all commercial developments, if developers are not prosecuted because of their personal standing or political connections, the efforts of conservation agencies become meaningless.

Pollution and contamination

Pollutants fall into four broad categories; plant nutrients, chemical wastes, herbicides and pesticides and oil.

Normally, coralline seas have barely detectable quantities of nitrates and phosphates and those that are released by decomposition are rapidly recycled. When treated or untreated sewage, other organic wastes or agricultural fertilisers run into sea water the growth rates of both phytoplankton and benthic algae are greatly enhanced. Transmission of light through seawater can be greatly reduced and in such cases insufficient light reaches the zooxanthellae. The corals consequently die. In shallow reef areas sufficient light may reach the seabed, causing rich growth of macroalgae with the same result; the corals are shaded out and die.

Chemical wastes in industrial and mining effluents and in drilling mud can act and interact in innumerable ways, some chemicals being directly toxic to reef organisms and other acting at subtler levels in disrupting physiological and genetic functions (Brown 1987). Early larval stages are particularly susceptible and aquaculturists are well aware that nothing but the purest seawater will suffice when attempting to rear marine larvae.

Herbicides and pesticides derived from agricultural sources are selectively toxic to many species of marine organisms, as are chemicals traditionally used in anti-fouling paints or coatings. The specific actions of most such chemicals are unknown.

Oil spills can be lethal to all organisms in intertidal zones. Below the tides, the effects on coral do not seem to be very serious, at least in the short term (Loya and Rinkevitch 1987). The vast quantities of oil released in Kuwait waters during the 1991 Gulf War apparently had no visible effects on reef health in adjacent areas (Vogt 1995).

Fishing

Physical damage

As mentioned previously, most fishing techniques used on reefs are not seriously destructive, primarily because the fishing gears are usually quite fragile and fishers are eager to avoid loss or damage to their equipment. The exceptions are the massive roller trawls that are designed to roll over or tear through irregular benthic terrain. Such trawls are known to have eliminated coral and associated sponge and seafan communities over large shelf areas of the South China Sea (McManus 1997), the Arufera Sea off Northern Australia and around the Florida Peninsula – to the extent that the roller trawls are no longer needed to fish in these areas. The reefs have been reduced to rubble and sand.

Fishing with explosives is a widespread problem and is regarded as criminal behaviour in even the most tolerant of communities. The reef infrastructure is simply shattered by blasts and most species of organisms are either crushed if they are in the reef framework or die of embolisms if they have swim bladders or lungs.

Intoxicants and poisons

Fish poisons, most often derived from derris root, have been used for fish capture for many centuries. Although high concentrations are usually fatal to small fish, when used in moderation, the effects are usually as an aid to spearing larger fish. The modern derivative, rotenone, is seldom available to artisanal fishers and those wishing to use poisons have easy recourse to inexpensive sodium cyanide or household bleach (Eldredge 1987).

Cyanide has received prominence through its use in the live fish trade in South East Asia. It stupefies the fish and makes them easy to capture. If they are rapidly removed from the tainted water they will recover. This has resulted in the virtual elimination of many of the top predators, mostly groupers and Maori wrasse, from many Indo-Pacific reef systems. Because of the extremely high prices paid for live seafood in Southeast and East Asia, and hence the profitability of the fisheries for these species, the problem has been extremely difficult to overcome (Lau and Parry-Jones 1999). Fortunately, it does not appear to have affected the Caribbean. Cyanide has also been used for the collection of ornamentals for the aquarium trade.

Bleach with sodium hypochlorite as the active ingredient is available from any grocery or supermarket. It is fatally toxic to most marine organisms, from bacteria to groupers even in very low concentrations. It has been a serious problem in some countries when used by divers, not only killing the target reef fish in caverns or reef crevices, but most of the reef life in the vicinity. Fortunately, most reef fishers are simply unaware of its possible use in fishing.

Changes in community composition and trophic structure ca used by selective fishing

About 180 species of coral reef fish can be found in Caribbean fish markets, of which about 30 species normally make up about 90% of the catch (Munro 1999). Most of this catch is taken in portable fish traps made of wire mesh supported on a framework of mangrove poles. Very few species of reef fish will not enter traps. Hooks are selective for predatory species and spear-fishers will usually shoot at the largest fish they see, regardless of species.

Very few Caribbean reefs are not heavily fished and most are seriously over-fished. The vulnerability of a species to over-fishing depends on its biological characteristics and its catchability. Small species with high growth rates, high fecundity and early maturity are the most resilient to exploitation, while large, slow-growing species, which mature at a substantial size, are easily over-fished. If fishes are taken by fishing gears when they are immature, they are liable to recruitment over-fishing. That is, the numbers of juveniles entering the fishery will decrease because of the scarcity of mature adults. Additionally, catchability (the fraction of a fish stock that is removed by one unit of fishing effort with a particular fishing gear) is very variable, for a variety of biological, behavioural and physical reasons. For example, groupers have high catchability. They will enter fish traps very readily, often to prey on smaller fish already trapped and, once caught, are not very adept at escaping from traps. In contrast, squirrelfish have no particular reason for entering traps and when captured seem to have little difficulty in finding their way back out of an entrance funnel.

As a result of these factors, when all of the coral reef species are concurrently taken, the most catchable, large, species face rapid local reductions in biomass and numbers of mature individuals. They become technically over-fished while less catchable, small, species are still being exploited at levels below the maximum possible catch. The composition of catches thus changes progressively. Catches of the large predators soon reach peak and then decline and modest-sized omnivores then dominate the catch. Eventually, small herbivorous fish become the main components of the catch, and may actually increase in relative abundance for a while because of the absence of predators, before they too become over-fished.

In large-scale fisheries for a limited array of species, serious damage to stocks may be limited and species extinctions are not very likely because, while catch rates decline, the cost of fishing remains the same. Eventually the value of the catch equals these costs and fishing ceases, unless governments unwisely intervene with subsidies. However, in most coral reef fisheries the equipment is relatively inexpensive and it is often fabricated by the fisher. For persons with no other skills and no opportunities for employment, the opportunity cost of labour is effectively zero. Thus fishing can remain a source of income and profits, however marginal, even when stocks have been decimated and the most vulnerable species have become extinct.

This is happening throughout the Caribbean. In Jamaica, which probably has one of the most intensively exploited fisheries in the Caribbean, catch rates have declined to a tiny fraction of those obtained from unexploited stocks. Valuable groupers, snappers and jacks are very seldom caught and small species of low-valued parrotfish and surgeonfish predominate in catches. Deep-bodied fish such as triggerfish and angelfish have virtually disappeared because, owing to their body shape, they become catchable in traps in the first few months of their lives.

The recruitment problem

The view held by fishery scientists for many years was that coral reefs around different islands were closely interlinked by the drift of larvae downstream with prevailing currents. Thus, even overexploited fish stocks could be replenished by larvae derived from less heavily exploited stocks elsewhere (Roberts 1997). In recent years, this sanguine view has changed.

The weight of evidence now is that recruitment is very largely a local affair (Munro and Polunin 1997) and that individual islands or large reef systems are mostly dependent upon having adequate spawning stock biomasses of all of the species in the ecosystem. This is because mortality rates of marine larvae are high (about 20% per day for fish and shrimp) and ocean currents are very erratic and dispersive (Cowen et al. 2000). Consequently, any fish larvae that are transported offshore and actually survive the 20-50 days required to reach metamorphosis have a very great chance of finding themselves in the open ocean, far from any reef system. On the other hand, postlarvae, usually about 2 cm long, derived from eggs and larvae that are trapped in nearshore eddies or gyres, have a good chance of reaching shore because most species have surprisingly great swimming abilities and have no problem swimming many kilometres (up to 25 km.day-1) towards shore (Stobutzki and Bellwood 1994). The stimuli that tell them in which direction to swim are unknown but could include traces of organic reef-related chemicals or reef noises.

Recent comparative studies of recruitment rates of reef fish in Jamaica and the British Virgin Islands (BVI) have shown that catch rates of most species in Jamaica are two to three orders of magnitude less than in BVI. Juveniles of some species were absent from catches in Jamaica. Small species of parrotfish, which mature before entering the trap fishery, and some surgeon fish, which have larvae adapted for an extended life in oceanic waters, were the only species which were not significantly reduced in abundance (Munro and Watson 1999). Jamaica's stocks are not being replenished to any significant degree by fish spawning elsewhere in the Caribbean.

The groupers, which are some of the most valuable components of reef fisheries, are particularly vulnerable to recruitment overfishing because they are protogynous hermaphrodites. All small groupers are female and they change sex around a certain size. As large fish are the first to be eliminated from heavily exploited stocks, insufficient males may be present to ensure successful spawning. There is evidence that this is happening in the Caribbean and the famed Nassau grouper, Epinephelus striatus, may become the first species of fish to become extinct in the Caribbean (Sadovy 1993).

Ecosystem effects

If predatory reef fish are over-fished, their prey species can be expected to increase in numbers. If the intermediate small predators are over-fished, the herbivores will then respond by increasing in biomass. When they are over-fished there will be no control of algal production and biomasses of algae and seagrasses will increase, with most production simply turning to detritus.

Currently, reefs on the north coast of Jamaica are almost entirely overgrown by macroalgae and the cover of live coral is extremely low. There is not full agreement on the reasons for this situation, but it appears that this can largely be attributed to the long-term effects of over-fishing (Hughes 1994). The narrow island shelf was covered by flourishing coral reefs until 1984. Then in rapid succession, a catastrophic epidemic swept through the herbivorous long-spined sea urchins, Diadema antillarum, throughout the Caribbean and the north coast of Jamaica was hit by Hurricane Allen. The reefs were accordingly reduced to rubble and massive corals stripped of tissue. Macroalgae colonised all the newly exposed surfaces and, in the absence of both sea urchins and herbivorous fish, have remained dominant up to the present. Other parts of the Caribbean with less heavily exploited fish stocks lost their sea urchin populations and suffered hurricanes, but the reefs were not overgrown by algae. Most of the evidence suggests that over-fishing was the cause of this catastrophe. Sea urchin stocks appear to be rebuilding throughout the Caribbean and there are indications of a slow recovery of the reefs on the Jamaican north coast but full recovery is highly unlikely if the herbivorous fish stocks remain drastically depleted.

Changes in the vitality of reefs for any of the reasons mentioned above leads to loss of habitat for many species of fish and invertebrates. Widespread degradation of reefs will lead to extinction of many specialised reef species, reduction in the numbers of linkages in food webs and increasing instability of the component populations of reef ecosystems.

Management tools and information

As a result of many decades of research on coral reefs, we have long had sufficient understanding of reef processes to embark on appropriate management strategies. Large numbers of scientific reports and massive compilations of data are available. The International Centre for Living Aquatic Resources Management (ICLARM's) contributions in this area are particularly important.

ReefBase, a global database on coral reefs and their resources (McManus and Ablan 1997) is available on CD-ROM (Reefbase 2000) and on the Internet. It is close to its objective of covering all of the world's reefs and providing information on reef communities, human and natural stresses, harvests (including mariculture), management and threats. It also provides methods for surveying reefs and for gathering socio-economic data.

A similar concept underlies FishBase, also available on CD-ROM (Froese and Pauly, 2000, FishBase 2000) and on the Internet, and which provides summaries of all available data on almost all fish species in the world. This includes information on nomenclature, distribution, catch statistics, population dynamics parameters, foods and feeding, reproduction, genetics and aquaculture, ichthyoplankton and morphology and physiology. It also enables users to link lists of fish species to biological information and enables country specialists to update country-specific information, including local names of fishes.

In the context of fisheries assessment for management purposes, FishBase allows quick, interactive generation of life-history parameters for species to be assessed, allowing re-calculations using local data if available. Computations include relative yield/recruit, state of exploitation, population resilience indicators, population intrinsic rate of increase and species trophic level. Additionally, use of a spreadsheet routine allows characterisation of the state of exploitation of a species from a length-frequency distribution, calculates lost yield, and provides plots that graphically relate the length frequency profile to length at maturity, biomass and potential biomass. A number of empirical equations are provided that can be used to estimate various life-history parameters such as asymptotic length, length at maturity, life span, age at maturity and length at maximum possible yield per recruit.

A third management tool that is seeing increasing use is the Ecopath software. The original model was applied to French Frigate Shoals in the Hawaiian Islands (Polovina 1984). This was a steady-state model of the reef ecosystem, based on knowledge of biomasses, mortality rates and trophic interrelationships of the main components of the reef communities. Subsequent versions, developed by ICLARM added many levels of sophistication (Christensen and Pauly 1992 1993). The latest version, called Ecopath-with-Ecosim (EwE), has been developed in collaboration with scientists at the University of British Columbia and it is available on the Internet. It can be used to simulate and thus predict the results of changes in aquatic ecosystems. For example, the effects of the creation of a marine protected area on fish catches in adjacent regions can be predicted, or the effect of increased harvests of fish on the biomass of macroalgae on a reef can be investigated. Such models require much data. A routine in FishBase can be used to obtain parameters for Ecopath models of designated ecosystems. One such area already so defined is the Caribbean Sea and a list of fish species can be generated with parameters needed for Ecopath modelling.

Several Ecopath models have been developed for Caribbean coral reefs (Opitz 1998; Arias-Gonzales et al. 1998). Ecopath models are currently under development for the heavily exploited Discovery Bay reef system in Jamaica and the lightly exploited Hans Creek area in BVI, in which the effects of intensive fishing on community structure will be examined (Munro and Watson 1999).

Sustainable management

Education, legislation and community support

Databases and models such as Ecopath, FishBase and ReefBase are useful to scientists in understanding management options and for presenting information to administrators, but much more effort must go into public awareness. Without the support of coastal communities, coral reef management is doomed to failure. This is particularly the case where many sectors have interests, often conflicting, in using the coastal zone for income generation, recreation or as a dump for liquid or solid wastes.

Far more effort needs to be put into educating children about the marine environment, particularly those living in small island states, where the exclusive economic zone is usually vastly larger than the land and where the benefits of sustainable use should accrue to the populace in perpetuity.

It has also been shown that fisheries and conservation legislation is ineffective if the community neither understands nor supports the laws. If impoverished communities perceive that they are disadvantaged by laws, whether or not that is actually true, they will disregard the laws. The police is disinclined to prosecute people who are struggling to make a living. In a recent case in Jamaica, a magistrate treated poaching in a marine reserve as an utterly trivial offence and was clearly unaware that any benefit would accrue to the community from proper management of the reserve.

It has been repeatedly demonstrated that many, if not most coral reef fisheries are overexploited and consequently yield a smaller and much less valuable harvest than is potentially possible. There are simply too many fishers. Invariably, the underlying reasons are the lack of alternative opportunity and landlessness. In many countries, large proportions of the fishing communities are not fishers by tradition. They are landless people who have moved to the seashore to eke out a living from the only open access resource that is available. Many fishers in Southeast Asia do not eat fish. All that is caught must be sold in order to buy rice. In Jamaica, increasing numbers of young men with no alternative opportunities are taking to spear-fishing, which can provide a small income from a small capital outlay and great personal effort. But, as stated previously, the reefs are already over-fished.

Resolution of the conflict between immediate human needs and the fragility of coral reef ecosystems is the greatest challenge facing the sustainable management of coral reefs.

Solutions

Methods for sustainable management of fisheries are well understood, as are the effects of most sources of environmental change. Harvests in overexploited coral reef fisheries in the Caribbean could be improved by increasing mesh sizes of traps and reducing fishing effort. Catches would be more valuable if desirable species were re-established in the reef ecosystems. Spiny lobsters are an immensely valuable resource and, as they are unaffected by being hauled to the surface in a trap, can easily be released if undersized. Almost inevitably, they will be recaptured when they are larger and much more valuable. This seldom happens and lobsters scarcely larger than prawns are a common sight in fish markets.

The underlying problem, so well known as "the tragedy of the commons", is that individual fishers are unwilling to restrain their fishing effort, increase mesh sizes and return undersized lobster to the sea, unless they are convinced that their fellow fishers will do likewise. Anyone who breaks the rules will benefit greatly from the restraint shown by the law-abiding fishers. Much the same applies to other users of the reefs, whether they are divers, hoteliers, yachtsmen, industrialists, agriculturists or government agencies.

The only feasible solution so far advanced is "co-management", in which governments work with all stakeholders in the entire watershed, not just the coastal communities, to arrive at equitable solutions to the use of the resource. This requires considerable organisational skills and reasonable funding so that the disadvantaged sectors can actually afford the time to participate.

While various tourism associations, chambers of commerce and agricultural and industrial groups are commonplace, the fishers, who arguably have the greatest impact on coral reefs, are seldom represented by any co-operative and association and cannot speak with a unified voice. But such associations are the only way whereby fishers can be represented in co-management fora. This should also lead the way to community-based management of the resources they exploit.

Community-based management programmes have been reported to have some success in Southeast Asia (Alcala 1998) and are a traditional form of fishery management in parts of the South Pacific. For this to be successful, fishers need to have exclusive access to the fishery resources along a sector of coast where they are active, free from forays mounted by commercial concerns in urban centres. Some success has been reported from several areas in Jamaica, where resourceful organisers with some financial backing have been able to organise coherent groups. A significant development was the recent decision by fishers in Discovery Bay, Jamaica, to set aside all of the shallows of Discovery Bay as a fishery reserve. This decision largely developed as a result of ten years of patient effort by the Fisheries Improvement Project operating from the University of the West Indies' Discovery Bay Marine Laboratory. The necessary proposals have been put forward to the Government. Coming from a representative group in the community, such proposals are readily supported by politicians.

Marine fishery reserves (MFRs) or marine protected areas (MPAs) are widely seen as a major component of efforts to sustainably manage fisheries and coral reefs. They have to be of considerable size in order to rebuild significant spawning stock biomasses that will replenish fisheries in adjacent or down-current areas. Additionally, they have to be founded on a wide degree of community support. Otherwise, as has been amply demonstrated in the Florida Keys, the local community will fight vigorously to prevent the reserve being established in "their" piece of the seascape.

In countries where fishers are some of the poorest members of the citizenry, MPAs or MFRs will displace established fishers. If they are merely forced to regroup in unprotected areas the fishing intensity in the unprotected area will increase, to the detriment of the entire reef resource. Instead, they must be found alternative employment in the MPA, as rangers, dive guides or boatmen, or given a pension equal to earnings foregone on condition that they do not resume fishing.

Direct interventions to re-establish fish stocks or to increase stocks of desirable species by stock enhancement or restocking are rapidly becoming technically and financially feasible, provided sufficient precautions are observed to avoid ecological and genetic pitfalls (Munro and Bell 1997). Various forms of small-scale aquaculture provide alternative income-earning opportunities for fishers in the Indo-Pacific (Bell and Gervis 1999) but none are clearly feasible in the Caribbean at present.

Finally, it must be recognised that all interventions to manage Caribbean coral reefs are very likely to be difficult and expensive. However, we have known how to manage Caribbean reef fisheries for at least thirty years. Can we calculate the compounded loss from non-management of these fisheries? What is the loss sustained as diving tourists progressively move elsewhere in search of reefs that are more attractive? These are very significant and important questions to consider.

References

Alcala A C. 1998. Community-based coastal resource management in the Philippines: A case study. In: Williams M J (ed). A roadmap for the future for fisheries and conservation. Manila: International Center for Living Aquatic Resources Management (ICLARM) Conference Proceedings 56, pp. 13-20

Arias-Gonzales J E. 1998. Trophic models of protected and unprotected coral reef ecosystems in the South of the Mexican Caribbean. Journal of Fish Biology 53 (Supplement): 236-255

Bell J and Gervis M. 1999. New species for coastal aquaculture in the tropical Pacific – constraints, prospects and considerations. Aquaculture International 7:207-223

Brown B E. 1987. Heavy metals pollution on coral reefs. In: Salvat B (ed). Human impacts on coral reefs: facts and recommendations. French Polynesia: Antennae Museum E.P.H.E., pp.119-134

Christensen V and Pauly D. 1992. ECOPATH II - a software for balancing steady-state ecosystem models and calculating network characteristics. Ecological Modelling 61:169-185

Christensen V and Pauly D. 1993. On steady-state modelling of ecosystems. In: Christensen V and Pauly, D. (eds). Trophic models of aquatic ecosystems. Manila: International Center for Living Aquatic Resources Management (ICLARM) Conference Proceedings 26: pp. 14-19

Cowen R K, Lwiza L, Sponaugle M M, Paris S C B and Olsen D B. 2000. Connectivity of marine populations: Open or closed? Science 287: 857-859

Eldredge L G. 1987. Poisons for fishing on coral reefs. In: Salvat B. (ed). Human impacts on coral reefs: facts and recommendations. French Polynesia: Antennae Museum E.P.H.E. pp. 61-66

FishBase. 2000. FishBase 2000 CD-ROM. Manila: International Center for Living Aquatic Resources Management (ICLARM)

Froese R and Pauly D (eds). 2000. FishBase 2000: Concepts, design and data sources. Manila: International Center for Living Aquatic Resources Management (ICLARM)

Hughes T P. 1994. Catastrophes, phase shifts, and large-scale degradation of a Caribbean coral reef. Science 265:1547-1551

Lau P and Parry-Jones R. 1999. The Hong Kong trade in live reef fish for food. Hong Kong: TRAFFIC East Asia and World Wide Fund for Nature Hong Kong

Lewis J B. 1977. Processes of organic production on coral reefs. Biological Reviews 52:305-347

Loya Y and Rinkevitch B. 1987. Effects of petroleum hydrocarbons on corals. In: Salvat B (ed). Human impacts on coral reefs: facts and recommendations. French Polynesia: Antennae Museum E.P.H.E., pp. 91-102

McManus J W. 1997. Tropical marine fisheries and the future of coral reefs: A brief review with emphasis on South-east Asia. Proceedings of the Eighth International Coral Reef Symposium 1:129-134

McManus J W and Ablan M C A. 1997. ReefBase: a global database on coral reefs and their resources. Manila: International Center for Living Aquatic Resources Management (ICLARM)

Munro J L. 1999. Effects of fishing on coral reef ecosystems. In: Schei P J Sandlund O T and Strand R (eds). Proceedings of the Norway/UN conference on the ecosystem approach to sustainable use of biological diversity. Trondheim: Norwegian Directorate for Nature Management and Norwegian Institute for Nature Research, pp.143-148

Munro J L and Bell J D. 1997. Enhancement of marine fisheries resources. Reviews in Fisheries Science 5:185-222

Munro J L and Polunin N V C. 1997. A decade of progress in coral reef fisheries research: 1986-1995. Proceedings of the Eighth International Coral Reef Symposium 2:2003-2008

Munro J L and Watson M. 1999. Caribbean Marine Protected Areas Project: The role of marine protected areas in fisheries management and biodiversity conservation in coral reef ecosystems. Phase 1 - 1996-1998. Tortola, BVI: ICLARM Technical Report to the United Kingdom Department for International Development

Opitz S. 1996. Trophic interactions in Caribbean coral reefs. Manila: International Center for Living Aquatic Resources Management (ICLARM) Technical Report 43:1-341

Polovina J J. 1984. Model of a coral reef ecosystem. I. The Ecopath model and its application to French Frigate Shoals. Coral Reefs 3:1-11

ReefBase 2000. ReefBase: a global database of coral reefs and their resources. Ver. 2000 CD-ROM Philippines: International Center for Living Aquatic Resources Management (ICLARM)

Roberts C M. 1997. Connectivity and management of Caribbean coral reefs. Science 278:1454-1457

Sadovy Y. 1993. The Nassau grouper, endangered or just unlucky?. Reef Encounter 13:10-12

Salvat B. (ed). 1987. Human impacts on coral reefs: facts and recommendations. French Polynesia: Antenne de Tahiti Museum, E.P.H.E., 253 p

Stobutzki I C and Bellwood, D R. 1994. An analysis of the sustained swimming abilities of pre-settlement and post-settlement coral reef fishes. Journal of Experimental Marine Biology and Ecology 175: 275-286

Vogt H P. 1995. Coral reefs in Saudi Arabia: 3.5 years after the Gulf War oil spill. Coral Reefs 14:271-273.