REEF RESTORATION AS A FISHERIES MANAGEMENT TOOL

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Summary

Coral reef fisheries feed nearly a billion people, almost all in poor tropical countries. Conventional strategies of coral reef conservation and fisheries management focus on controlling fishing within limited “protected” areas, but generally ignore habitat quality or global changes, which are increasingly rendering the methods of the past obsolete and ineffectual. Yet the precipitous ongoing decline of coral reef fisheries stems from habitat degradation as well as over-fishing and cannot be reversed without restoring habitat quality in damaged areas. Reef habitat degradation is largely caused by external stresses like high temperature, new diseases, and land-derived pollution, which kill corals, reduce biodiversity of food supplies for harvested species, and are beyond the capacity of any marine protected area (MPA) to control. Without large-scale restoration of habitat quality the decline will continue, even in the well-managed and funded

MPAs. Due to the accelerating pace of coral mortality from global warming, sea level rise, land-based sources of pollution, and new disease pathogens, new generations of fishing methods are needed that restore habitat quality, fisheries carrying capacity, and standing stocks in degraded areas. Future coral reef fisheries management will require new methods to grow corals faster and more resistant to environmental stress, and to enhance recruitment of corals, fish, and shellfish. Conventional methods of reef restoration fail when water quality deteriorates from excessive temperature, pollution, or sediments. In contrast the Biorock method of coral reef restoration greatly increases coral growth rates and survival from stress, allowing rapid recovery of coral reefs where natural regeneration has failed, greatly increasing fish and shellfish populations, and even turning severely eroding beaches into growing ones. This is done without monoculture or food addition, and avoids the genetic impoverishment, disease, and nutrient pollution problems of conventional mariculture. Some fisherfolk in Indonesia, the Philippines, and elsewhere are now using the Biorock method to grow whole reefs and become sustainable harvesters of the ecosystems they create and manage. This proven technology is easily taught to fisherfolk and applied on a large scale at low cost. Fishing communities are eager to expand their knowledge, skills, and sustainable productivity, but need training in new methods and capital to apply them. Unfortunately there are still currently no mechanisms to provide the resources needed to allow fisherfolk to change from destructive hunters to restorative reef farmers. A paradigm shift is needed by policy makers, funding agencies, conservation groups, and fisheries management organizations in order for this new method to be implemented. Fundamental research is also needed into the genetic factors affecting stress response and resistance, to tide coral reefs and their fisheries over until the fundamental causes of long-term deterioration can be reduced and greatly minimized.

1. Introduction: Coral Reef Fisheries

For over 100 countries worldwide coral reefs are the major source of marine biodiversity, fisheries, sand supply, tourism, and shore protection, and would be the most valuable ecosystem they have, per unit area, if the economic and environmental services they provide were properly accounted for. Yet almost everywhere on the planet, coral reef ecosystem services are rapidly vanishing or lie in ruins. Because human users do not pay directly for coral reef services, they treat this valuable ecosystem with disregard as common free goods, in the false belief that reefs as an infinite resource capable of unlimited exploitation that will endlessly replace itself at no cost to those who exploit it. The true economic value of healthy coral reefs will only be appreciated when countries must import fish to keep poor people from starving, import sand so that tourists have nice clean beaches to lie on so that locals can get jobs in the tourism industry that is the major development strategy of most tropical islands, and when protective sea walls must be built all along the coastlines to prevent hotels, roads, airports, and houses from drowning by the rising seas. Coral reef environmental and economic services are estimated to lie in the range of up to millions of dollars per kilometer of shoreline.

Coral reef fisheries are the major source of protein for nearly a billion people, mostly in developing countries. Like almost all fisheries worldwide, reef fisheries are long known to be in a state of advanced decline but the magnitude of the decline is hard to estimate

because almost all coral reef fisheries is artisanal, and the catch is locally consumed by the families of the fisherfolk, bartered or shared with their neighbors, or sold locally. With the exception of a small number of high value items, such as sea cucumbers, spiny lobsters, Caribbean queen conch, giant clams, live fish, aquarium fish, shark fins, and sea urchins, most of the reef fish and shellfish catch does not enter the international export market, and so is usually not tabulated in national or United Nations Food and Agriculture Organization (FAO) fisheries statistics. Even where reef items are reported, the reported values are often guesses due to lack of information or even serious underestimates due to deliberate under-reporting. Because most fishermen are poor and receive minimal public services, fisherfolk are often suspicious that efforts to find out how much they catch is covertly aimed at taxing them or dispossessing their resources for the benefit of foreign or local elite investors, making fishermen reluctant to divulge their true catches except to those who have earned their trust.

Unlike non-reef fisheries, where the catch focuses on a relative handful of valuable species, coral reef fisheries are far more diverse. This is unsurprising given that coral reefs have hundreds of times more species per unit area than the open ocean. Around a quarter of all fish species are reef dwellers even though coral reefs only cover around 0.1% of the area of the oceans. Furthermore many of these species are very poorly known. For example recently more than a hundred species of fish unknown to science were found on sale in markets on the island of Bali, Indonesia alone. The recent expansion of mariculture, which concentrates on a few high value products like salmon and oysters, has begun to expand in the tropics, but the products, like shrimps, prawns, and milkfish, are largely farmed not in reef habitats but in adjacent shallow estuaries or low lying mangrove habitats, and the loss of soil and nutrient retention by mangroves has caused serious damage to coral reefs and their fisheries wherever large scale coastal mariculture has been introduced.

2. Coral Reef Fisheries Decline

Virtually everywhere in the world where reef fishermen are interviewed they report that catches have severely declined in recent years. This is shown by the disappearance or extreme rarity of species that once were common, dramatic decreases in numbers and sizes, and shifts from more desirable to less desirable species. Almost everywhere the oldest fishermen remember an abundance and size of species that younger fishermen have never seen, and which the latter generally believe to be either “fishermen’s tales”, the delusions of senile old age, or outright lies. Yet it is those who claim that there has been no change who are usually wrong, sometimes because they have been fishing for too short a time to notice changes, because they are unobservant, have forgotten how things used to be, or because they simply distrust authority and fear that claims of decline will be blamed on them and used by government authorities who they frequently do not trust to prevent them from fishing.

Fishermen virtually everywhere report similar tales. For example one fisherman in Jamaica reported that he used to catch so much that he would give away enough fish to feed his entire village, but now can barely catch enough for a little occasional fish soup for his family alone, and must turn away friends who come begging for “just a little piece” of fish. The chief of a Kuna Indian village in Panama said that everybody in his

village used to catch 10 or 15 lobsters every evening right in front of their own houses, but now they must paddle their canoes for hours, dive very deep, and only find fewer and ever smaller lobsters. Indonesian and Philippine fishermen who once had huge catches now are lucky after an entire day of fishing to come back with only a handful of tiny fish that are only enough to be boiled for soup.

Many fishermen now say that they no longer fish because they expect to bring anything back, and only go to sea with no expectations because fishing is a way of life that they love, but they cannot expect young people to follow them. These stories are essentially universal, and the few rare exceptions, such as one case of a Polynesian atoll with so few people and such a large area of reef that the fishermen are still able to catch all their needs next to their village and have no idea of reef condition further away, only prove the general rule. Fishermen must go to further and further and deeper and deeper to find enough to bring back. In place after place, fishing communities around the world complain that they are on the verge of starvation in locations where catches were once so plentiful that even incompetent fishermen were well fed by their neighbors' surplus catches. Fish that were once common catches become steadily smaller and smaller and then disappear, and fishermen switch to less desirable species, until they too are gone, fishing down the food chain.

A classic case of this transition is in Jamaica, where in the 1950s the fish catches were overwhelmingly made up of fish-eating fish species, followed by invertebrate feeders, and the few algae eating fish species were regarded as inedible. The desirable food species like groupers, jacks, and barracuda were wiped out sequentially by overharvesting, and at the same time nutrient pollution of the coastal zone by sewage and fertilizers over-fertilized the algae. The increase in land-based nutrient sources caused algae to proliferate, overgrowing and killing the coral reefs, which resulted in the loss of most of the invertebrates like crabs, shrimps, and worms which fed the majority of the fish species that the carnivorous fish ate. As a result the fish populations are now almost entirely made up of algae eating damselfish, parrotfish, and surgeonfish, which are now so intensively fished that few can reach reproductive age, so their source comes from larvae washed by currents from other parts of the Caribbean where these species are still not eaten. Ironically, although the fishermen were the first to notice that the reef fisheries were being killed by land based sources of pollution from coastal tourism development, foreign scientists blamed the fishermen, who they claimed had eaten all the algae eating fish and caused the algae to grow. In fact there is now no shortage of herbivores, and the fish population is now almost entirely algae eaters because this is the only source of food remaining after the formerly rich coral reefs turned into dense algae lawns.

3. Causes of Decline: Overfishing

The causes of fishery decline are complex but are largely well known. Coastal populations are rapidly growing, and population pressure is a key part of the declines in catch per unit effort. Over-fishing is now virtually universal, not only near populated shores, but also far from them, as fishermen range further and further. Few reefs anywhere in the world are not well known to fishermen, even where they are completely unknown to the scientific community, including very deep reefs that cannot be seen

from the surface. Even the most remote reefs are reachable by large motorized boats, often belonging to wealthy countries, which strip all the fish they can find. The boats from developed countries have sophisticated sonar systems allowing them to find all the fish schools and wipe them out using large nets. In the Lembeh Strait of Sulawesi, Indonesia, foreign poachers stretched a net across a major migratory route for marlins, sharks, dolphins, and whales, wiping them out in short order. Subsistence fishermen are forced to use more and more destructive methods to feed their families. A very extensive recent study by the Law of Nature Foundation in the Visayas Sea area of the Central Philippines, formerly one of the richest reef fisheries in the world, reported that "not a single hectare of reef remained intact" from escalating use of bombs and cyanide poison by fishermen. One reef in this area went from 80% live coral cover to 2% in just two years. In Indonesia spectacular pristine reefs discovered by tourist dive boats in extremely remote locations have often found the following year to have been turned into mere piles of rubble caused by blast fishing.

A classic example is the destruction of the fisheries resources of Hotsarihie (Helen Atoll) south west of Palau, which has been reported to have the greatest diversity of fish, corals, and shellfish of any Pacific Island reef. This atoll was uninhabited because the huge reef has only a tiny shifting sand bank with no fresh water, but it belongs to the people of Hatohobei (Tobi), some 80 kilometers away. Hotsarihie used to have the richest giant clam (*Tridacna* sp.) and precious shell (*Trochus niloticus*) resources in the entire Pacific (the name means Reef of the Giant Clam in the Tobian language). But these resources were plundered by poachers from Indonesia, the Philippines, Taiwan, until finally one foreign factory ship came and within a few days, removed most of the *Tridacna* sp. and *T. niloticus*, leaving a wasteland behind. After the poaching, almost all of the corals bleached and died from heat shock in 1998, causing a further crash in reef fish populations.

In recent years the market for sea urchins, sea cucumbers, shark fins, and live fish has expanded from a regional market in Southeast Asia to a global market, causing rings of depleted resources to expand outward. Once fishermen discover that previously unexploited resources like sea cucumbers and sea urchins, which were locally regarded as inedible, can be sold to foreign buyers for large amounts of money, these resources can vanish practically instantaneously in the most remote parts of the globe as a consequence of opening up a new market.

4. Causes of Decline: Habitat Degradation

Overfishing is the traditional explanation for the catastrophic decline in reef resources that is found almost everywhere. But in reality this is only one component of the problem. Habitat degradation is as severe in most places. The correlation between fish abundance and diversity with live coral cover and diversity has been demonstrated over and over again on many spatial scales. Corals are vanishing worldwide, and with their disappearance the habitat that supports large and varied fish populations is endangered. Without food and shelter, fish rapidly vanish even where there is no fishing activity.

Coral reefs are the most fragile of ecosystems, and levels of stress that would not harm any other marine ecosystem will kill corals, which are adapted to the cleanest, clearest

sea water. The causes of reef decline are well known. They can be classified into local, regional, and global components. Local causes of damage are due to stresses that act on small spatial and temporal scales, like hurricanes, typhoons, and cyclones, ship groundings, anchor damage, diver damage, and damaging fishing methods like use of bombs, poisons, and nets. Regional damage results from impacts from adjacent regions, primarily land-based sources of pollution such as nutrients from sewage runoff, agricultural, lawn, and golf course fertilizers, red tides (often caused by land based sources of nutrients), pollution from oil spills and toxic chemicals, and sedimentation caused by deforestation and bad land management. Global causes of reef death include the impacts of global warming, global sea level rise, and new diseases.

So many factors kill corals, and their rapid spread, increased intensity, and cumulative impacts of these stresses are such that the majority of the corals in the world have been lost in the last decade. Although many people claim that a significant amount of coral reefs have already been lost, this claim results from a semantic confusion between reefs and corals. In fact almost no coral reef structures have disappeared at all, although most of the corals have died. These erroneous claims result from a failure to distinguish between the geological structure of coral reefs and the living corals that slowly build it over millennia. The coral reef is the limestone framework built up by large corals, and it remains long after the corals have died, being only slowly broken down over years to decades through erosion by boring organisms and waves. Dead and dying reefs are vastly inferior habitat both for reef fishes, which require healthy coral for hiding places and the habitat for their prey food. But in most degraded reefs, even though the dead framework remains standing, the corals, the invertebrates, and the fish have almost entirely vanished.

Unless habitat quality is restored, in terms of shelter and food supply, the prognosis for future coral reef fishery recovery is poor even if there were no fishing activity at all. Moreover the death of many calcareous reef organisms eliminates the supply of new sand needed to replace that lost to storm erosion, while the wave-breaking reef framework itself breaks down from bio-erosion by boring organisms and increased physical forces from increased frequency and intensity of tropical storms. The natural protective mechanisms of healthy reefs that reduce wave energy at the shoreline are collapsing, causing increased erosion of most tropical beaches. This erosion will increase as global sea level rise, caused by thermal expansion of surface water and increased melting of glaciers and ice caps, accelerates.

5. Marine Protected Areas in Reef Fisheries Management

5.1. The Marine Protected Area Strategy

The standard solution to marine conservation and fisheries management issues currently being used by all governments, international funding agencies, and large conservation groups is the establishment of marine protected areas (MPAs). It is claimed by many scientists that by stopping destructive fishing practices in designated areas, the habitat and fisheries stocks will rebound by themselves to their prior levels, and moreover that the excess population will “spill over” to greatly enhance fish catches in surrounding areas used for fishing outside designated MPAs. These results are claimed to result from

the dogma that coral reefs can bounce back from any stress due to their capacity for "natural restoration" and "resilience". The benefits claimed have been shown in the case of a handful of very small MPAs in which fish populations have increased after they came under active management, and policy makers and funding agencies hope that all other MPAs will show the same results.

The results are heavily dependent on habitat quality, but this is usually glossed over by MPA proponents. Where the areas being protected contain coral reefs in excellent condition, the results can be rapid and dramatic, as shown in the classic studies at Apo Island and a few other sites in the Philippines. However where the "protected" areas have poor habitat quality the results show that coral cover and fish populations are no different than nearby reefs that have no management or protection at all. For example, a recent study of MPAs and nearby fishing areas in Papua New Guinea found that both protected and unprotected areas showed identical severe declines in both live coral and fish, with no effect of management found. The long term monitoring studies of the Great Barrier Reef Marine Park Authority and of the Florida Keys National Marine Sanctuary, the most lavishly funded and managed MPAs in the world, and often held up as models that should be emulated by all developing countries, show that live coral cover has steadily declined under management, and is down to only around 20% and less than 5% respectively. While there is little evidence that establishment of MPAs has halted the decline of the corals, there is some evidence that protection has resulted in higher numbers of some economically valuable, heavily exploited, long-lived, and slowly reproducing species, such as groupers and lobsters. Yet even if all the very small fraction of reef claimed to be "protected" could in fact be genuinely protected from all external sources of environmental degradation, this will not stem the catastrophic fisheries decline in the vast preponderance of reefs that have no protection whatsoever. Since most coral reef countries are poor, with vulnerable populations relying on subsistence fishing for the bulk of their protein sources, fishermen will have no choice but to invade any small remaining reef areas in good condition to feed their families.

5.2 Top Down and Bottom Up Management Strategies

There are two fundamental models for MPA management, the bottom-up and the top-down. In bottom-up MPAs fisheries management is community-based and relies on consensus of the entire community to manage marine resources in a way that nourishes the whole community while sustaining their marine resources, rather than hastening their destruction through over-exploitation. In the top-down MPAs, especially those in developing countries, which are often established by foreign consultants employed by international funding agencies and conservation groups, fisheries resources are protected using superior force to prevent local residents or outsiders from exploiting them in designated areas or by banning use of specified destructive fishing methods. This is a model that has been carried out by the Komodo National Park in Indonesia. Unfortunately this model often overlooks the rights of local communities, and this negligence can sometimes lead to conflict.

Such conflict will probably become more intense if the top-down, externally-managed MPA model expands, unless large-scale restoration of degraded areas to increase sustainable fisheries carrying capacity is efficiently implemented in surrounding areas

used by subsistence fishermen. Yet unfortunately at this point there is inadequate funding, and not enough personnel trained in restoration of degraded fisheries habitat. It is unfortunate that there is still misunderstanding among developers who promote top-down management models, and who remain skeptical about possible restoration of areas outside MPAs, since they claim, without solid scientific evidence, that restoration is not really needed because they (wrongly) believe that ecosystems will regenerate themselves, unaided, despite clear failure of damaged fisheries to recover in place after place.

There is little evidence that MPAs have resulted in a sustained large scale increase in live coral cover and fisheries habitat quality. Most MPAs are full of dead or dying corals because even the most well-intentioned and funded MPAs are powerless to control or reverse coral habitat degradation from external factors. Too often the complexity and diversity of coral reef ecosystems are misunderstood and methods and techniques designed to assess, monitor, and control fishing efforts designed in much less diverse cold water fisheries, are often irrelevant. In a particularly dramatic and unfortunate case, MPA efforts to protect an endangered marine mammal, the dugong, and the highly diverse coral reef fisheries in Milne Bay, eastern Papua New Guinea, were abandoned due to a wrong initial assessment of the project and its high cost of operation and maintenance.

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Biographical Sketches

Dr. Tom Goreau, President of the Global Coral Reef Alliance, a non-profit organization for coral reef protection and sustainable management, has dived longer and in more reefs around the world than any coral scientist. His father was the world's first diving marine scientist, and he grew up swimming in coral reefs as soon as he could walk. He was previously Senior Scientific Affairs Officer at the United Nations Centre for Science and Technology for Development, in charge of global climate change and biodiversity issues. He has published around 200 papers in all areas of coral reef ecology, and on global climate change, the global carbon cycle, changes in global ocean circulation, tropical deforestation and reforestation, microbiology, marine diseases, soil science, atmospheric chemistry, community-based coastal zone management, mathematical modeling of climate records, visualizing turbulent flow around marine organisms, scientific photography, and other fields. He developed the method to predict the location, timing, and severity of coral bleaching from satellite data with Ray Hayes. He holds patents with Wolf Hilbertz for new methods for preserving coral reefs from global warming and pollution, restoring marine ecosystems, shore protection, mariculture, and non-toxic methods of preserving wood from marine boring organisms, termites, rot, and fire, in order to increase the lifetime of wood and decrease logging. In 1998 he and Wolf Hilbertz were awarded the Theodore M. Sperry Award for Pioneers and Innovators, the top award of the Society for Ecological Restoration. Dr. Goreau led developing country NGO efforts in marine and climate issues at the United Nations Conference on Environment and Development (Rio de Janeiro, 1992), the UN Summits on Development of Small Island Developing States (Barbados, 1994, Mauritius, 2005), and the UN World Summit on Sustainable Development

(Johannesburg, 2002). Dr, Goreau works with tropical fishing communities around the world to restore their coral reefs and fisheries, especially the Kuna Indians of Panama, the only Native people of the Americas who have preserved their cultural and political independence. He is also a hereditary leader of the Yolngu Dhuwa Aboriginal clan of Arnhem Land, Australia, that preserves the oldest creation myth in the world. Of Panamanian origin, he was educated in Jamaican primary and secondary schools, at MIT (B.Sc in Planetary Physics), Caltech (M.Sc in Planetary Astronomy), Yale, Woods Hole Oceanographic Institution, and Harvard (Ph.D. in Biogeochemistry), and is a certified nuisance crocodile remover.

Wolf Hilbertz studied architecture and landscape architecture in Berlin, Germany and at the University of Michigan, USA. He practiced in design offices in both countries and taught/researched at Southern University, a black college in Louisiana, The University of Texas, McGill University, and the Academy of Fine Arts at Bremen. The inventor of the terms Cybertecture (structures that grow and heal themselves) and Seascaping (marine landscaping), he has long been a pioneer in innovative new methods to grow structures, starting with computer controlled spray nozzles to grow buildings out of ice in North Dakota winters. He invented the technology of mineral accretion in seawater in the early 1970s to produce prefabricated limestone building materials in the sea. He has collaborated with Thomas Goreau since the 1980s applying Biorock technology to solve pressing ecological and socio-economic issues globally, and is generally regarded as the guru of the emerging field of seascape architecture. He is a recipient of the Theodore M. Sperry Award for Pioneers and Innovators in Restoration, the top accolade of the Society for Ecological Restoration.