The future of coral reefs

C. Birkeland

Hawaii Cooperative Fishery Research Unit
2538 The Mall, Edmondson Hall
University of Hawaii at Manoa, Honolulu, Hawaii 96822

Abstract: Coral reefs have been degrading faster than they have been recovering (Done 1992; Ginsburg 1994; Hughes 1994; Grigg and Birkeland 1997; McManus and Vergara 1998; Wilkinson 1993, 1998) and they have been accruing in their degraded states because they achieve alternate stable states of algae instead of corals (Knowlton *et al.* 1981; Knowlton 1992; Done 1992; Hughes 1994), and because rates of damage are much greater than rates of recovery (Muzik 1985; Birkeland 1997a). With the accumulation of reefs in alternative stable states, the total area of some reefs previously dominated by coral is decreasing over time (Muzik 1985; Knowlton *et al.* 1981, 1990; Wilkinson 1993), and the balance has been continuously in the negative for corals over the past few decades (LaPointe 1989; Hallock *et al.* 1993; Birkeland 1997a). Furthermore, human activities are now bringing about environmental changes on a global scale (Smith and Buddemeier 1992; Hoegh-Guldberg 1999; Tsuchiya 1999; Wilkinson *et al.* 1999) which alter the basic conditions and nature of environmental processes in the domain.

Coral reefs are almost inevitably going to continue degrading faster and on a broader scale than they can recover because the processes of extraction of important components of the reef community are at a faster rate than the processes of recovery and replenishment. This is because of inherent life-history characteristics of the economically targeted coral-reef species (Birkeland 1997b) and because of the nature of coral-reef ecosystem processes (Birkeland 1997a). Coral-reef ecosystems are based on plant-animal symbioses which allow the ecosystem to have the highest gross productivity of any ecosystem in the sea (Nixon 1982). However, the net productivity is comparatively low (Nixon 1982) because complex interactions even at the physiological level can put constraints on the yield of the ecosystem (Birkeland 1997b). Pelagic phytoplankters can respond rapidly to nutrient input and increase in population density. If intracellular symbiotic zooxanthellae increase too rapidly, in contrast, this can upset the physiological balance within the coral and so they are expelled (Muller-Parker

and D'Elia 1997). Regulatory processes within the symbioses of coral reefs tend to dampen responses of intracellular algae to pulses of nutrient input (Birkeland 1997b). Complex interactions at the population level also dampen net productivity. Predation is intense and recruitment irregular in coral reef systems (Hixon 1986, 1991).

Why are resources of coral reefs especially vulnerable to human activities and environmental changes? Coral reef fishes and invertebrates are adapted to the complex interactions on coral reefs with especially intensive predation and competition (Glynn 1988, 1990; Steneck 1988; Lang and Chornesky 1990) and with irregular recruitment success. Because of this, reef fishes and invertebrates have adapted by repeated, multiple reproduction, and so, when compared with pelagic fishes, they grow slowly, postpone first reproduction, and are territorial (Bohnsack 1994; Birkeland 1997b). Pelagic fishes, on the other hand, grow rapidly, reproduce early, are wide-ranging, and are characterized by high rates of population turnover (Birkeland 1997b).

Examples of the long-term vulnerability of coral-reef resources are the spawning aggregation of groupers in Denges Channel, Palau, that was extirpated in 1986 and has still not returned after 14 years; the snapper population on a pinnacle off Guam that was fished down in about 6 months in 1967 off Guam and has still not returned; the commercial sea cucumbers in Chuuk fished down in the late 1930s and the black-lipped oysters in Pearl and Hermes Reefs (NW Hawaiian Islands) that were fished down in the late 1920s, neither of which have recovered. The life-history characteristics of these species have kept the resources from returning after 14, 33, 60 and 70 years, with no indications that they will ever return (Birkeland 1997a).

That these trends in resource depletion have been recently increasing is indicated by the change in size-distribution of corals. Large 700-year-old colonies used to be plentiful in Guam and Okinawa, but are scarce now. This indicates that disruptions and stress have increased in this last few decades over the intensity that they have been for nearly a millenium. In contrast, pelagic fisheries will usually return each year depending on the strength of oceanographic processes supplying nutrients.

Alternate stable states of algae rather than corals, and of fishes (*Scolopsis* rather than *Lutjanus* or *Lethrinus*, Katnik 1982), persist indefinitely. The north coast of Jamaica shifted from dominance by corals to dominance by algae in 1982-1983 (Hughes 1994) and a 13 km² area of Palau shifted from coral to algae in 1979; neither have recovered to coral over the past two decades. As these events continue, corals are becoming less dominant on a global scale (Wilkinson 1993).

But the most important factors forcing the directional deterioration of coral reefs are the economic processes and human population growth that are proceeding at a much greater rate than is possible for reef recovery to accommodate (Birkeland 1997c). Human economic culture is based on perpetual growth which is incompatible with sustainability of coral-reef resources. Although pelagic fishes can grow 1 - 5 kg per year, some even reaching 14.5 by their second year, coral-reef fishes such as groupers do not grow faster than 0.5 kg per year even when feed excessively in aquaculture (Birkeland 1997b). Coral-reef resources cannot keep up with the perpetual

growth of the human population in the tropics and the economic demands of developed countries (Birkeland 1997a).

The economic demand for efficiency when harvesting multispecies assemblages of resources in topographically complex habitat encourages destructive fishing techniques that are incompatible with sustainability. Also, when large ships are employed to carry live fishes for restaurants in Hong Kong and other parts of Southeast Asia, it is economically inefficient to return these large ships with anything but full holds. Taking fewer fishes to promote sustainability is economically inefficient. Finally, fishes are most efficiently caught while they are in spawning aggregations. Collecting an entire spawning aggregation is economically efficient for the moment, but economically wasteful over the long run because the population may never return (as in the Denges Channel, Palau examples given above). For the live fish trade for restaurants that transport in large ships, sustainability is not considered an option (Johannes and Riepen 1995).

The life-history characteristics of coral-reef resources determines that they have low rates of population turnover. Money, however, grows at greater interest rates than do reef resources and so reef resources undergo depreciation unless they are liquidated. The need to liquidate for economic efficiency is especially detrimental to coral-reef resources and is insidious (Birkeland 1997c).

Palaeontologists have found that ecosystems based on plant-animal symbioses have always been especially vulnerable to environmental changes and been harbingers of mass extinctions. Coral reefs disappeared about a million years before the global mass extinction at the end of the Cretaceous (Copper 1994). Now, as explained in this symposium by Hoegh-Guldberg (1999), the environment is changing on a global scale as indicated by the bleaching of corals around the world in 1997-1998. In addition to bleaching, the increased concentration of CO₂ in the atmosphere may shift the balance away from deposition of CaCO₃ by corals on a world-wide basis. These processes would be of further detriment to the ability of corals to compete with algae and to recover from bioerosion and other environmental stresses.

Does this make it hopeless for us to do anything? No - we can think globally and

act locally. Following our survey of the condition of reefs in Palau after the catastrophic 1997-1998 bleaching, we wrote a press release for the Vice President of the Republic of Palau which was edited and published in the newspapers by the Vice President. The press release urged the people of Palau to restrain from harvesting herbivorous fishes so as to allow the herbivores to help reduce the filamentous and leafy algae on the reefs and thereby facilitate coral recruitment.

Islanders live close to their resources and know that although we can manage terrestrial and freshwater resources, the recruitment of coral-reef resources is too unpredictable to manage directly. So, as the islanders know, we need to manage people in their use of reef resources rather than manage the resources directly. The management of people is based on "economic productivity", rather than in the generation of biomass. The Western Regional Fishery Management Council defines "economic productivity" as the greatest sustained (perpetual, not short-termed) income to the most people (not just to a few individual fishermen, but to the nearby human community).

It is dangerous to claim we can do what we cannot. We undermine our credibility if we claim to be able to manage multi-species coral-reef fisheries directly on a Maximum Sustainable Yield basis. To claim we can restore reefs encourages developers to go full speed ahead with damage because they think scientists can fix it later. Theoretically, we could eventually fix about anything, but when the recovery processes take several times longer than it takes to do the damage, repair is a losing proposition.

This is the basic danger to reefs today - the damage from human activities is rapid and widespread, apparently on a global scale now, while the nature of ecosystem processes and life-history traits causes the recovery of reef systems and resources to be very slow. No matter how carefully we manage extractive processes, the fisheries yield will be either damaging to the coral reef system if the yield is large or economically nonviable if small. In order to obtain economic productivity from a coral reef at the same time allowing the system to persist, we must focus on alternative nonextractive economic development such as tourism or recreational fisheries, keeping the economically viable extractive

fisheries in the pelagic domain where the life-history traits of the species are adjustable to harvest.

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