Mini Symposium 3

HUMAN IMPACTS

Are human impacts, either through traditional or contemporary uses, stabilizing or destabilizing to reef community structure?

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ARE HUMAN IMPACTS, EITHER THROUGH TRADITIONAL OR CONTEMPORARY USES, STABILIZING OR DESTABILIZING TO REEF COMMUNITY STRUCTURE?

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ABSTRACT

The structure of a coral reef community is as much its web of functional relationships as its arrangement in space. This community structure is viewed by some as the result of an ancient, highly evolved system which is stable within certain limits, but fragile if pushed beyond those limits, and by others as a mosaic of inherently unstable structures in time and space undergoing constant perturbations. Both views may have some validity where human impacts are concerned, depending on the scale of structure studied. Reefs subject only to traditional human uses have been so little studied that the supposed lack of major destabilizing effects can only be inferred from the state of the reefs. Contemporary human uses are often correlated with reef degradation, suggesting that such human impacts destabilize or modify the substrate, benthic community structure, mobile populations, species composition, food webs, water quality and underlying materials and energy flows and cycles. The increasing scale of these effects is of particular concern. However, some restoration or improvement of coral reefs may also now be possible.

INTRODUCTION

Any review of the effects of man on coral reefs must begin with some definitions of human impacts and of the effects to be considered. If effects are to be measured in terms of the stability of reef community structure, then it is necessary to clarify what is community structure and what stability means in the highly dynamic coral reef ecosystem.

A coral reef ecosystem may be defined as a community of organisms including hermatypic corals and/or coralline algae which deposit cemented masses of calcium carbonate capable of adding to the substrate to form a reef. Since the key benthic organisms in the coral reef ecosystem, corals (with their symbiotic algae) and algae, require light for massive carbonate production, the system is restricted to coastal substrates in the euphotic zone. The continuing deposition of calcium carbonate is perhaps the best criterion for defining continuing productivity and stability in a coral reef community.

REEF COMMUNITY STRUCTURE AND STABILITY

Reef community structure refers to the qualitative and quantitative composition of reef populations, their spatial organization and functional relationships. It is thus a concept with dimensions in both space and time which must be defined with reference to the impacts being considered. Pollution effects, for example, may have both structural and functional aspects, or, as in the case of eutrophication, may be largely functional.

The complexity of the coral reef ecosystem means that different components of the same system may vary greatly in their scales of occurrence or function. With respect to the structure of benthic coral reef communities, some elements such as massive corals may persist hundreds of years (Done, 1987), while others may be highly variable; fast-growing branched <u>Acropora</u> may produce thickets in 5-7 years (Dahl, 1981). Other benthic organisms such as algae may have a high turnover of individuals in a population on the order of days, weeks or months. The motile organisms are equally dynamic, both individually and as populations. Yet the organisms of the reef system are closely linked through highly evolved types of interactions, ranging from coral-zooxanthellae symbioses through behavioral symbioses and the biological conditioning of surfaces for larval settlement to chemical linkages through substances dissolved in the water. The structure of the coral reef community is thus as much a web of functional relationships as an arrangement in space.

A coral reef is also not an entirely closed system; its structure may be more or less dependent on biological or ecological elements outside the reef itself. To give two recent examples, the problem of larval and juvenile recruitment is important but very difficult to study. On an isolated reef or atoll, what percentage of juvenile fish are from larvae from the reef, or from outside? Larval coral reef fishes have their own ecological requirements and adaptive significance (Doherty, Williams & Sale, 1985), but their relation to the structure and stability of adult reef fish communities is unknown. Even the relationship between recruitment and the stability of reef fish assemblages is complex and far from clear (Mapstone and Fowler, 1988). Research is just beginning on such subjects for all species with planktonic development. The second example, also involving fishes, is the influence of neighboring habitats on reef community structure. After Sale (1980) developed measures of within-habitat diversity (Alpha diversity) and between-habitat diversity (Beta diversity), Birkeland and Amesbury (1988) note "that juvenile coral reef fishes appeared to recruit 3 to 20 times more abundantly on coral reefs near seagrasses and mangroves than near isolated reefs." Thus outside biological elements can be important for the coral reef community structure.

To make the concept of reef community structure even more complex, most reefs are probably not in a "steady state" or a mature primary system. Their very diversity suggests many disturbing influences that prevent dominant species from asserting themselves everywhere. In an undisturbed system interspecific dominance may lead to reduced diversity, but this seems to occur rarely on reefs in nature. There may be annual changes related to seasons or weather patterns, storm damage by waves or reduced salinity, exposure at unusual low tides or sea level shifts, extreme temperatures, or epidemics or mass outbreaks of diseases or predators (such as the Diadema die-off in the Caribbean or Acanthaster in the Pacific). A disturbance may be followed by a shift between different community types, each of which may be persistent once established (Hatcher, 1984), with the selection depending on the chance timing of the disturbance relative to reproductive periods, recolonization abilities, or varying dispersal patterns.

The stresses that lead to a disturbance, either natural or anthropogenic, need to be evaluated. Grigg & Dollar (1988) suggest using mortality as an objective measure of change in reef community structure. "Net mortality could be standardized and expressed in terms of survival by simply subtracting it from 1.0 (e.g. 1.0 - x) where x (mortality) could range from between 1.0 (total destruction) and 0.0 (zero mortality). The expression x for mortality could then be partitioned into natural (N) and man-induced (I) effects...."

Permanence on a geological scale

The community structure of a reef is intimately linked to the concept of stability, which must be considered at different time scales.

Coral reefs have always been subject to instability over geological time. Tectonic movements and variations in sea level produce considerable changes in the land-sea interface which the coral reef system must follow up and down if it is to survive. The deposition of skeletal material in massive reef structures is one way of doing this, at least for rising relative sea surface levels. During periods of stability in the interface, reefs may go through a structural evolution from a "young" reef community growing up to the surface through a "mature" reef consolidated at the surface and growing horizontally to a "senescent" reef which may be overtaken by a younger reef or otherwise so alter surrounding conditions that reef construction stops. Net carbonate deposition should therefore be considered the key characteristic in defining a coral reef ecosystem as opposed to other coastal ecosystems (which may include many of the same organisms). A long-term failure of reef construction across the whole coastal zone would thus be the most reliable characteristic of destabilization in the system.

The present existence of coral reefs demonstrates the capability of this ecosystem to survive millions of years at least somewhere in warm sea waters. The occurrence of enormous masses of reef skeletal deposits is the same geological demonstration. If data from long cores, from the volcanic substratum to the present coral reef flat, show ages without interruption, this shows the persistence of this ecosystem in the same place. Where there are interruptions, recolonization has come from outside. Potts (1985) mentions that in the quaternary, for example, over a period of 140,000 years, the average time that any given bathymetric level remained in the zone of active coral growth (less than 20 m depth) was only 3200 years. Depending on the effects of sea level variation, there are two possibilities. Either the sea withdrew completely and the coral reef started again from outside recolonization when the sea level recovered (as in South East Asian seas), or the sea level moved up and down in the same locality and the coral reef communities shifted accordingly (as on oceanic islands and atolls). Potts (1985) states that 3200 year periods "probably were too short for populations of long-lived corals to complete enough generations to approach evolutionary equilibrium," although in the island case there was continuity in the community over millions of years in the same locality.

In any case, stability over geological time is quite different in scale from most present modifications due to natural events, including catastrophes, or to human activities.

Stability and instability

As more long-term studies of coral reefs are undertaken, their variability at a time scale of years becomes increasingly apparent (e.g. Dahl and Lamberts, 1977; Dahl, 1981). The structure of fish communities as related to temporal scales has been investigated in detail by Galzin (1987a, b). At a daily scale, there were diurnal, nocturnal and crepuscular communities, probably related to diet and feeding behavior; the monthly scale showed a 28 day rhythm where fish abundance was the inverse of species richness; and variation over seasons and years seemed related to modifications in other biotic components of the community and to natural or man-induced disturbances.

There are presently two schools of thought about coral reef stability in the face of natural phenomena (Grigg & Dollar, 1988). For one, the reef ecosystem is stable because of its ancient origin and its evolution of great complexity in an environment where conditions have been uniform over long periods. This complexity has a "buffering" action within certain limits, but the system is still delicately adjusted, and thus very fragile when pushed beyond these limits (Goreau, 1969; Johannes, 1975; Endean, 1976). The second school sees the reef ecosystem as unstable over time and heterogeneous in space, with the present reefs around the world in different stages of structure and organization, being continually modified by natural perturbations (Grassle, 1973; Grigg and Maragos, 1974; Connell, 1978).

Depending on the weight given to one or the other of these views, human impacts can seem to be of greater or lesser importance. In the first case, human effects are seen as bringing catastrophic and probably irreversible changes to the earlier natural and normal state. In the second view, they are only of relative and often of secondary importance when compared to natural perturbations given the permanent instability of the ecosystem.

Both views may well be appropriate in certain situations, and they may in fact be complementary depending on the scale of community structure or function being studied. The stability of many coral reef ecosystems may in fact lie in the dynamic instability of their component parts and spatial subsets, with their constant change assuring the ability to re-establish a balance after any natural shock. However, at a larger geographic scale, human impacts may push the system beyond its limits, leading to rapid degradation in diversity, productivity and elasticity (Dahl, 1985b).

It is the many scales of interaction in the coral reef ecosystem, both in time and in space, which permit both large scale adjustments or recovery across a whole region, and highly localized adaptations to the particular environmental conditions of each coastal area. In the light of these characteristics, the community structure of the coral reef ecosystem must be seen as combining the large scale physical structure (the reef) and its functional processes, with the occurrence of varying mosaics of organisms or "sub-communities" at different spatial scales, plus all the types of interactions that tie them together into a system.

Distinguishing human from natural effects in such a system is not always easy. The main natural events causing damage and mortality on coral reefs have been reviewed by Stoddart (1969) and Loya (1976), particularly floods of fresh water, unusual low temperatures, and long exposure to air. The principal anthropomorphic stresses affecting coral reefs have been reviewed by Johannes (1975), Brown & Howard (1985), Salvat (1987) and Grigg & Dollar (1988); these include sedimentation, dredging, sewage effluents, filling and construction, oil spills and dispersants, and heated effluents from power plants. Many human effects may mimic natural effects, such as siltation from construction or from runoff after heavy rains, while others like pollution by a pesticide may be totally foreign to the ecosystem. Effects may also differ in their duration and the size of the area affected. Localized and short-term effects may be within the natural scales of disturbance and regeneration. Problems arise when effects go farther, last longer and cover larger areas than the system has adapted to.

HUMAN IMPACTS

In considering the types and scales of human impacts on coral reefs, the difference between traditional and contemporary human uses can be significant.

The term **traditional** generally refers to human activities or cultures that date from before the scientific and technological revolution of the last 150 years. Such activities were generally stable or evolved slowly over centuries. Traditional resource extraction, whether removing coral blocks for building construction, or fishing for fish or shellfish, was generally for local subsistence use, either directly by the collector and his family, or for small-scale trade. Such resource use involved simple technologies using natural materials, in a context of generally low population pressure (from high mortality), on a small scale, and with a profound knowledge of local resources accumulated over generations of intimate observation leading to a great awareness of and responsiveness to changes in the resource base.

Contemporary uses, on the other hand, tend to use high technologies, new materials and chemicals, on a much larger scale because of access to commercial markets, with many new types of use or impact, and with less understanding by users of the natural resources involved. These modern uses tend not only to have a greater local impact, but they also occur on a much larger scale, spreading across the whole surface of the planet, either directly through human colonization, population growth, and the spread of industrial and development activity to previously uninhabited areas, and indirectly, such as through the spread of pesticides.

Traditional human uses and their impacts

There has unfortunately been little if any research documenting the impacts of traditional human uses on coral reefs. It is thus difficult to distinguish between unfounded preconceptions and what actually took place. There is much circumstantial evidence to suggest that many reefs were richer and more productive under traditional forms of resource use and management. For instance, in Samoa where the population has always made extensive use of reef resources, reefs that were documented by Mayor (1924) as being very rich while under traditional use have since been extensively degraded by modern human impacts including dredging, urban runoff, and pollution from fish canneries (Dahl and Lamberts, 1977).

Traditional fishing techniques were in many cases more selective than modern methods, and more remote reefs were protected by the difficulty of access with sail or oar-powered vessels. It was generally more difficult for a traditional resource user to exploit or damage a resource beyond its limits. However, even when this was technically possible, it seldom seems to have occurred. There is considerable circumstantial evidence from the nature of traditional reef management practices themselves (Johannes, 1978, 1981; Dahl, 1985a) that such practices often evolved to prevent overuse of reef resources, or possibly even to increase resource productivity. Ownership of or restricted access to reef areas was widespread. Potentially damaging techniques such as poisoning were restricted or allowed only in times of scarcity. Susceptible species were subject to individual management measures. For instance, scarce or seasonal resources such as turtles were subject to social or religions constraints limiting who, when and where to collect them, and who could eat them, perhaps only on special occasions. It would seem likely that such stable long-continued forms of reef resource use would have led to corresponding adaptations in the reef ecosystem, but documenting this would be difficult.

There are, of course, some unecological fishing techniques which appear to be traditional. On the island of Futuna, women fished on the reef by piling up stones in a depression on the reef flat at low tide, and then displacing the pile at the following low tide to collect the fish which sheltered there at high tide; most of the fish collected were juveniles or small adults (Galzin, 1985). Displaced human populations establishing themselves on the coastline in Madagascar fished with traditional nets but used them with no attention to ecological considerations: fishing everywhere, destroying the habitat, catching juveniles with fine mesh nets, etc. (Salvat, personal observation).

Contemporary impacts

The many types of modern human activities that have an impact on the reef environment have recently been reviewed comprehensively (Brown and Howard, 1985; Salvat, 1987; Grigg & Dollar, 1988) and for particular regions (Gomez & Yap, 1985; Yap & Gomez, 1985; Brown, 1986). However, with respect to their effects on the reef system, it is much more difficult to separate human effects from natural changes. For example, the mechanisms behind many population cycles and changes in organism abundance are poorly known, and there is still debate as to whether the population explosions of Acanthaster in the Indo-Pacific and the catastrophic die-off of Diadema in the Caribbean are natural or the result of some human interference.

In a recent paper, Brown (1987) questions whether world-wide deaths of corals are caused by natural cyclical events or man-made pollution. Cases of coral bleaching have been reported across the Caribbean and Indo-Pacific, many related to the El Nino-Southern Oscillation (ENSO) of 1982-83, and others unrelated (Williams, Goenaga & Vicente, 1987); collection of recent information on the extent of coral bleaching is being co-ordinated by Williams & Williams (1988 and in preparation). There is no clear evidence to link world-wide signs of reef stress to man-made pollution. For instance, scientists trying to explain recent reef degradation on Moorea, French Polynesia, are testing the following hypotheses: Acanthaster outbreak, cyclone (hurricane) effects, extended low sea level, agricultural nutrients, tourism pollution, and other natural or human stresses. The situation is made even more complex by the fact that man-induced and natural stresses probably overlap in time and space and interact in their effects on the reef.

Given the difficulty in determining specific causality linking human activities with reef impacts, and in separating anthropogenic impacts from natural changes, it may be most useful at present to consider the types of effects that human (or natural) impacts may have on the reef ecosystem, since these are what can presently be measured in the field.

In some cases, damage is done directly to the substrate through some mechanical activity or force, changing the shape of the reef and often water circulation patterns, producing sediment which covers hard surfaces, and incidentally obliterating the living reef surface and exposing new substrate. Channel blasting and construction activities can have such effects (e.g. Smith and Henderson, 1976; Nontji, 1986). Any new surface created by significant coral mortality will be colonized by opportunistic organisms. Such modifications have a major effect on coral reef community structure and function, particularly on the percent cover of living corals, and these effects are widely documented (Harger, 1986; Dustin & Halas, 1987; Galzin, 1987).

Many human activities destroy larvae or affect recruitment, such as poison and dynamite used for fishing, or the heated effluents from power plants. The mobile populations of plankton and fishes over and around a reef may also be the target of human impacts such as overfishing which may selectively remove certain species. Grigg, Polovina & Atkinson (1984) demonstrate that reefs are extremely vulnerable to overfishing because the ratio of productivity to respiration is frequently close to 1.0. Overfishing is probably one of the most important human stresses affecting coral reef community structure. Modelling overfishing impacts (Grigg, Polovina & Atkinson, 1984) can help to identify better reef fisheries management strategies.

More generally, many effects manifest themselves in changes in the species composition of the ecosystem through changes in reproduction, settlement, growth rate, mortality and succession. The excellent recent simulation work by Done (1987) and experimental work on the effects of specific factors (e.g. Yamazoto, 1986) illustrate how complex these impacts may be. The introduction of alien species can also have significant impacts on species composition.

Given the complexity of interactions in the reef ecosystem, many effects are transmitted along food webs and show up at different trophic levels, as in the accumulation of ciguatera toxins (Bagnis, 1970). This widespread circumtropical foodborne disease is caused by ingestion of a variety of sporadically toxic fishes associated with coral reefs under stress. It is natural but reinforced by human disturbance. Ciguatera can be considered in many cases as an indicator of coral reef stress (Bagnis, 1987).

The most generalized human impacts may result from changes in water quality causing complex effects throughout the reef system. These can include changes in the cycles of chemicals such as nutrients, as in the classic eutrophication of Kaneohe Bay (Smith, Chave & Kam, 1973) now reversed (Maragos et al., 1985). The effects of nutrient enrichment may be more amenable to study in controlled experiments (Henderson & Smith, 1978). Increased turbidity can reduce light availability with profound effects on primary productivity. Temperature changes can also have important effects which are generally negative, except in unusual circumstances where a temperature increase in a marginal sub-tropical coral reef area may even increase coral survival and growth (Coles, 1984).

The increasing evidence of widespread degradation of coral reefs (Chesher, 1984; Dahl, 1985c; Sukarno et al., 1986) raises new questions of the scale of human impacts in time and space. It is increasingly apparent that the stability of any particular coral reef depends on linkages with other more distant reefs, particularly through the supply of reproductive stages or recolonizers, although there is little concrete detail on these linkages. It is thus likely that widespread human impacts may affect the stability of reef systems in unexpected ways over a large area. This largest scale of interaction in coral reef ecosystems is not easily amenable to research, and may, if present trends continue, be damaged or destroyed before it is understood.

In the great majority of cases studied, contemporary human uses of coral reefs have tended to destabilize community structure and to degrade the productivity and diversity of the ecosystem. However, the scientific understanding of coral reef systems has reached the point where trials and experiments in the sustainable management and restoration of coral reefs are possible and should be encouraged (Kenchington & Hudson, 1984). The recovery of reefs in Kaneohe Bay after the removal of human stresses demonstrates the resilience of reef systems and their capacity for natural recovery (Maragos, Evans & Holthus, 1985).

Some information is available on factors affecting the natural recovery of stressed coral reefs. Recovery is only possible if the cause of the disturbance is removed. The time required for recovery is generally measured in decades, and depends on the reef community structure before the stress. An exposed and a sheltered reef in Hawaii required between 20 and 50 years (Grigg & Maragos, 1974), and corals in the Philippines took almost 40 years to regenerate 50% of their surface after a dynamite blast (Alcala & Gomez, 1979, 1987). From a recent review of human impacts on coral reefs (Salvat, 1987), it is clear that we have the knowledge to mitigate or avoid stress on coral reefs due to human activities. The problem is to find the means to manage or control human impacts.

There is no reason why the natural regeneration capacity of coral reefs cannot be accelerated or enhanced, and coral reef rehabilitation is now receiving increasing scientific attention. A workshop was held at St. John, U.S. Virgin Islands, in December 1987 (Goodwin, personal communication) which suggested that three types of manipulation might be applied: transplants, predator-competitor control, and recruitment enhancement.

CONCLUSIONS

While traditional human uses of coral reefs may not have had a great influence on reef community structure, judging from the few scientific descriptions of such reefs prior to modern human impact, there is too little data to relate traditional uses to reef stability. Where modern uses are concerned, there is strong circumstantial evidence from the rapid spread of degraded reefs that most recent human impacts are destabilizing, but it has proven very difficult in practice to separate anthropogenic from natural factors in order to demonstrate causal relationships between human uses and resultant effects on reef community structure. More carefully controlled experimental work, supported by detailed fieldwork and well-constructed simulations, will be necessary to show to what extent human uses are stabilizing or destabilizing to reef community structure.

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