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Coral Reefs: Present Problems and Future Concerns Resulting from Anthropogenic Disturbance[1]

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SYNOPSIS. Coral reefs, with their vast diversity of invertebrate, vertebrate and algal species, have undoubtedly been subjected to natural disturbance since their appearance millions of years ago. Anthropogenic disturbance has been a factor affecting reefs for a fraction of that time, yet in terms of overall impact, may be of greater concern. Data on habitat destruction, pesticide and heavy metal accumulation, nutrient loading, sedimentation, runoff and related impacts of man's activities indicate that many coastal reefs are endangered by these processes through alterations in animal-algal symbioses, shifts in competitive interactions, direct mortality, reproductive failure, and insufficient recruitment. The death of corals critically affects reef communities, as corals provide an important trophic link as well as the main habitat structure. While natural disturbance is an important factor affecting reef interactions, species diversity and evolution, chronic anthropogenic disturbances combined with unsuitable environments for recovery, are of great concern. Physiological stress can be measured in corals in addition to outright mortality, allowing the impacts of specific disturbances to be assessed. Sufficient data for distinguishing real problems from temporal variability are becoming available, allowing scientists to focus on practical solutions to problems in coral reef management and preservation.

INTRODUCTION

Coral reefs are diverse and productive biological communities which thrive in shallow and coastal tropical marine environments. While scleractinian reef-building corals are not necessarily the most abundant or diverse faunal component of coral reefs, they provide the initial trophic link through their symbiosis with algae and produce the majority of the habitat structure for other reef organisms. Many invertebrate, fish and algal species are integral members of a healthy reef community. By understanding trophic relationships and species interactions, we can gain an appreciation for how coral reefs work, and of critical importance, how changes including anthropogenic disturbance, can affect community structure and function.

Coral reefs are unique among high-diversity and high-productivity marine communities, distinguished by their ability to thrive in clear, oligotrophic waters devoid of high levels of nutrients. As in temperate marine communities, unicellular algae are responsible for the initial photosynthetic fixation of carbon on coral reefs; however, here they reside intracellularly within the endodermal cells of the coral host in a mutualistic symbiotic association rather than as phytoplankton. The relationship between reef-building corals and their symbiotic unicellular dinoflagellates ("zooxanthellae") is central to the existence of coral reef communities. Metabolites are exchanged between the algae and the host, and nutrients are conserved in an otherwise nutrient limited environment. Changes in the environment which affect the symbiotic association (*e.g.*, nutrient levels and light) will affect coral nutrition, metabolism and calcification, and hence, the entire reef community.

Coral reefs are biogenic structures which

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may form banks, atolls, islands, and substantial masses like the Great Barrier Reef of Australia. Living reefs not only form land, but provide the sand that lines tropical beaches, and the structures which buffer waves that would otherwise cause extensive coastal erosion. The protection that reefs provide islands is especially evident during typhoons and tropical storms where reef crests, reef flats and windward spur-and-groove formations dissipate wave energy quickly and efficiently. The balance between reef accretion and erosion depends on the living veneer of corals and coralline algae. The death of key organisms or the shift from an autotrophic to a heterotrophic (suspension/detritus feeding) community shifts the dynamics from carbonate deposition to reef erosion.

The economic value of coral reefs is evidenced by the islands and land they produce and protect, the fisheries which they support, the tourists they draw, the recreational opportunities they afford and the diversity of natural products which they produce which have already proven to be of biomedical importance. While the value of a resource is often measured in dollars, one should not ignore the cultural value of coral reefs, which is every bit as important to islanders and tropical coastal populations as the rain forest is to its inhabitants. McAllister (1988) estimated fisheries losses due to reef degradation at over $80 million per year, impacting 127,000 jobs and 637,000 family members. Finally, coral reefs are simply beautiful, and that may be reason enough to warrant their protection.

Coral reef organisms are usually considered stenotypic, exhibiting a relatively narrow range of tolerances to environmental conditions, hence small changes in environmental quality can affect critical biological processes. Reproduction and recruitment are the two processes by which reef populations are maintained, and both can be quantitatively assessed, allowing determination of sublethal effects of environmental changes. While corals and many other reef invertebrates are capable of asexual reproduction (fragmentation, tissue sloughing and regeneration), successful production of larvae, either through release of gametes with external fertilization or via internal fertilization and brooding, is essential for maintaining reef populations (see reviews by Richmond and Hunter, 1990 and Harrison and Wallace, 1990). Water and substratum quality affect reproduction and recruitment success, and hence, should be the focus of studies on long and short term effects of stress and disturbance.

The terms "stress" and "disturbance" have been applied to coral reefs and many other biological communities, with a variety of interpretations. In this paper, I will adhere to the concepts suggested by Rosen (1982) and Brown and Howard (1985) which recognize that a gradient of conditions exists, from ideal to the absolute limits of survival, and that effects short of mortality need to be considered. Stress is a physiological condition which results from adverse or excessive environmental factors and in corals can be measured by decreased growth rates, metabolic differences, and biochemical changes. Disturbance is an ecological phenomenon which includes departures from a routine set of conditions.

There are varying levels of degradation which can be observed on coral reefs, from the extreme and obvious (mortality) to more sublime changes in characteristics including competitive dominance among organisms, decreased growth rates, breakdown of organismal associations, reduced fecundity, reproductive failure, and declining recruitment of larvae. Essentially, whether a coral reef is killed in a week, due to sediment burial, or over a ten year period, due to attrition and lack of recruitment, the result is the same: the loss of the coral reef community and all of the benefits which it offers. The two plenary presentations at the Seventh International Coral Reef Symposium (Guam, 1992) focused on world-wide destruction of coral reefs in the face of increasing pressure from man's burgeoning populations, indicating an awareness among coral reef scientists that anthropogenic (man-induced) disturbance is a critical problem (Buddemeier, 1993; Wilkinson, 1993).

As this paper was prepared for a symposium entitled "The crisis in invertebrate conservation," the focus will be on the effects of disturbance on coral reefs, and specifically, with concerns for the health of reefs in the face of mounting pressure from man's activities. The range of activities which are cause for concern includes runoff and sedimentation from development projects, eutrophication from sewage and agriculture, physical impact from maritime activities, dredging, collecting and destructive fishing practices, pollution from industrial sources, golf courses and oil refineries, and the synergistic impacts of anthropogenic disturbance on top of natural disturbance.

Some coral researchers have argued that natural disturbances such as El-Niño events and typhoons have historically devastated vast stretches of coral reefs, and that by comparison, documented anthropogenic reef loss has been smaller in scale and of indeterminate long-term consequences. For example, Grigg and Dollar (1990) recognize the seriousness of damage to local reefs from human activities, but they remain unconvinced that anthropogenic disturbances are as serious or pervasive as natural disturbances. I disagree with arguments that downplay the importance of anthropogenic disturbance because: 1) we cannot control nature but we can control human impacts; 2) differences do exist between the effects of natural and anthropogenic disturbance; and 3) the synergistic effects of anthropogenic disturbance on top of natural disturbance change the conditions for recovery. This paper addresses the most common types of anthropogenic impacts on coral reefs, important differences between types of disturbance, summarizes the results of some previous studies, and offers some ideas on mitigation measures as well as future areas of research.

IMPACTS ON CORAL REEFS

Sedimentation

Sedimentation, which is the most well-studied impact, may affect corals three different ways: photosynthetically, physically, and chemically. As most reef-building corals obtain the majority of their nutritional requirements via translocation of metabolites from their photosynthetic partners (Muscatine *et al.*, 1981), any reduction in the available quality and/or quantity of light will affect coral nutrition, growth, reproduction and depth distribution. Bak (1978) reported decreased coral growth rates resulting from decreased light levels available to corals due to sedimentation from dredging. Rinkevich (1989) found that planula production in *Stylophora pistillata* is energetically supported by metabolites translocated from symbiotic zooxanthellae, linking photosynthesis to reproduction in corals. Other studies (see reviews by Brown and Howard, 1985 and Rogers, 1990) have also shown that decreased light levels have a detrimental effect on corals, and can limit the depth range over which corals can exist.

Physically, sediments also interfere with coral nutrition by coating the feeding surfaces responsible for catching prey items needed to supplement the energy provided by zooxanthellae. While corals do have the ability to cleanse themselves using a combination of mucus secretion and ciliary action, chronic sedimentation may exact a high energetic cost, adding to the overall impact on the colony. Sedimentation can alter species composition of reefs through photosynthetic and physical effects. Changes in relative abundance of morphological types as well as individual species are an important reflection of how sedimentation as a disturbance affects community structure.

Sediments can also physically interfere with recruitment of coral larvae, which require a solid substratum upon which to settle and metamorphose. Te (1992*a*) found tissue from newly settled and calcifying colonies of *Pocillopora damicornis* "bailed out" of their benthic exoskeleton in response to increased sedimentation, which is a previously described stress response (Sammarco, 1982; Richmond, 1985). Dredging projects have been particularly damaging to reefs, primarily through the initial physical disturbance, habitat alteration and the subsequent problems associated with sedimentation.

Few studies have focused on the chemical effects of sediment on corals, which can be important. Brown and Holley (1982) and Howard and Brown (1984) studied the effects of heavy metals (copper, tin and zinc compounds) on adult coral colonies, with mixed results. Goh (1991) determined low levels (9 ppm) of nickel caused mortality in coral planulae and significantly reduced larval settlement rates at concentrations of 1 ppm. Several studies in Okinawa, Japan, have found that lateritic soils (red clay, high in iron), have been particularly detrimental to reef corals compared to carbonate sediments (Nishihira, 1987; Yamazato, 1987; Sakai *et al.,* 1989).

An aspect of the chemical effects of sediment on coral reefs has not yet been addressed: How do chemically treated soils deposited on coral reefs affect resident organisms? Golf course construction on tropical islands has increased at an alarming rate in the past few years, considering the size of the land masses involved, the quantities of pesticides and fertilizers used, and the fresh water requirements for maintaining greens and fairways. If the pesticides used bind to the soil, and the soil ends up on the reef due to erosion, the question of chemical impacts needs to be addressed. Clay particles, which by their small size will often be carried to the ocean by runoff, have a charge which may change when entering the marine environment. Chemicals bound to particles on land may be released in seawater. Experiments with the organophosphate pesticide Dursban (chlorpyrifos) found seawater passed through a column of soil treated with a quantity of chemical equal to that applied to golf courses, was toxic to the coral *Pocillopora damicornis* (Te, 1992*b*). Acevedo (1991) determined chlorpyrifos at levels of 1 ppm resulted in up to 50% mortality in assays with coral planulae. Bioassays like these indicate the need for more such studies.

RUNOFF/CHEMICAL POLLUTION/WATER QUALITY

A general rule for islands: Whatever is used on land today ends up in the aquifer or coastal zone tomorrow. While sediment carried by runoff has been a major focus of environmental studies, little attention has been paid to the chemistry of runoff water. Salinity changes alone have proven to affect corals, especially on shallow water reef flats which are most likely to be impacted by freshwater runoff (Kato, 1987; Jokiel *et al.,* 1993). What are the specific concerns that need to be addressed?

Having reviewed numerous environmental impact statements (EISs), water quality reports on runoff usually read "all analyses performed found chemicals assayed for were in quantities below detectable limits." This says nothing about the effects of the chemical component of runoff on the local flora and fauna. Bioassays are the appropriate tests to be performed, and should be required before permits are approved. Recent advances in our understanding of invertebrate reproduction in general and settlement and metamorphosis of benthic invertebrate larvae in particular demonstrate the reasons for concern.

Most scleractinian corals are simultaneous hermaphrodites (containing both male and female gonads at the same time) which participate in discrete annual multispecies spawning events (Richmond and Hunter, 1990; Harrison and Wallace, 1990). For Guam and Okinawa, the timing of mass coral spawning events coincides with the height of the rainy season, when coastal marine surface waters are most likely to be contaminated from terrigenous runoff.

During the summers of 1989, 1990, and 1991 coral fertilization bioassays were performed comparing fertilization and development success of gametes and embryos, respectively, among waters of differing salinity and sediment content. In one experiment performed using water samples collected on the night of coral spawning above a reef adjacent to a stream mouth in Okinawa, runoff was found to cause an initial 53% drop in fertilization rate compared to a control, and an additional 51% drop in the number of embryos developing to the planula larva stage (Richmond, unpublished). The experimental treatment seawater was determined to have a salinity of 28.5‰, with suspended solids (red clay) of 1.28 g/liter, while the control water was Millipore filtered (0.45 μm) and had a salinity of 34.4‰.

Since no additional chemical analyses were performed on the runoff-affected seawater, it was not possible to determine if other substances were responsible for the 77% drop in larval production compared to the control. A subsequent experiment to determine the effects of decreased salinity alone showed an 86% reduction in fertilization rate accompanying a 20% dilution of seawater with distilled water. These experiments demonstrated that actual coastal

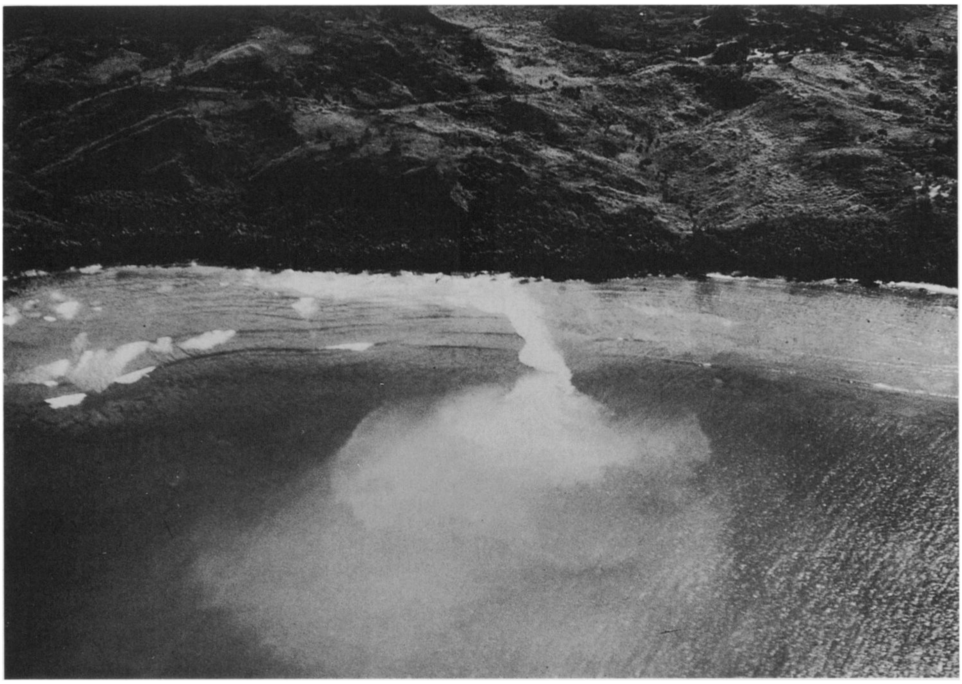

FIG. 1. Sediment plume off Southern Guam. Corals up to several hundred years old were killed by sediment burial. Water samples from plumes like this were found to cause up to an 86% drop in fertilization rates in spawning corals. The plume is *ca.* 1 km in diameter.

surface water quality above reefs during coral spawning events was sufficiently reduced to cause reproductive failure. Considering most coral species spawn once a year, during the rainy season when coastal pollution would be expected to reach its peak, and that most coral eggs are buoyant, floating in the surface water layer for up to several hours before fertilization occurs, it is easy to see the link between terrigenous runoff and reproductive failure of spawning reef species. Furthermore, chemical cues have been found to allow synchronization of spawning in corals (Atkinson and Atkinson, 1992; Richmond, unpublished). Decreased water quality could also affect these critical cues, preventing synchronous release of gametes and resulting in lowered reproductive success.

Suppose spawning occurs in a pristine environment, allowing fertilization and embryological development to occur at natural rates. Can fully developed planula larvae settle in areas of reduced water quality? Recent discussions of larval recruitment in benthic invertebrates have suggested that settlement and metamorphosis are different events which should be addressed separately (Hadfield and Pennington, 1990; Pawlik and Hadfield, 1990). While larvae of benthic organisms may settle out of the plankton and come in contact with the substratum, metamorphosis may not occur without chemosensory recognition of specific inducing molecules (Morse, 1990). The concentrations of metamorphic inducers in nature are far below detectable limits based on present technology, yet are obviously in sufficient quantities in the marine environment to affect metamorphosis ($10^{-10}\,M$ for the nudibranch *Phestilla sibogae,* Hadfield and Pennington, 1990). Pollutants below the detectable limits of high performance liquid chromatography (HPLC) are not necessarily below the limits of interfering with critical chemical cues in marine invertebrates.

Guam's southern reefs provide an example of how water quality impacts coral reefs through sublethal effects. During the period from 1988–90, a major road construction project was undertaken on southern Guam, which is geologically volcanic with steeply sloping, highly erodible lateritic soils. Large

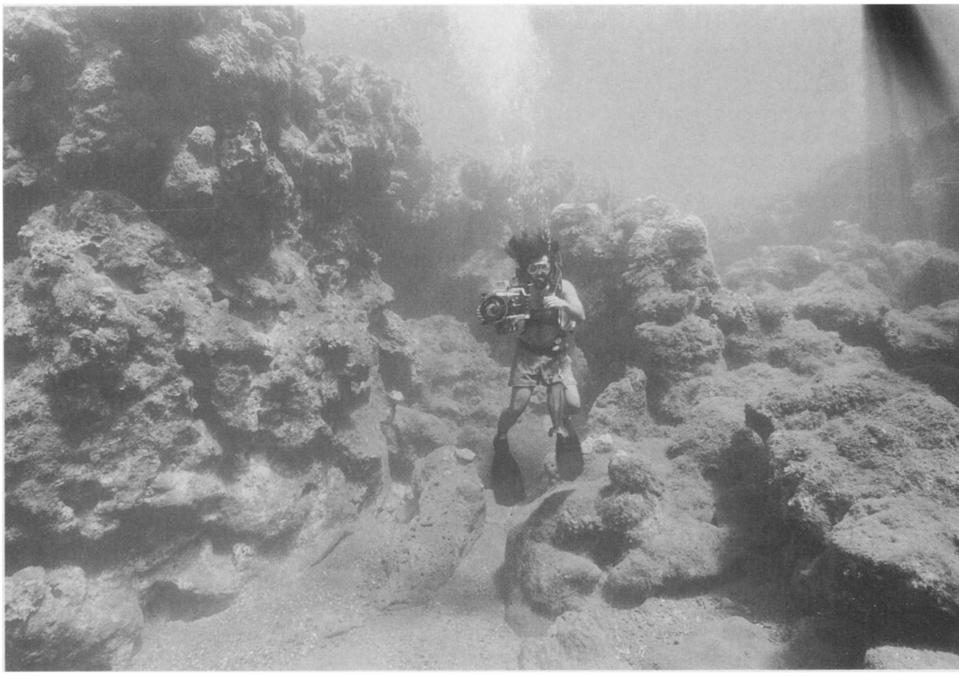

FIG. 2. Coastal reef off Southern Guam which was killed by sedimentation. A fairly dry typhoon removed sediment accumulations from the reef.

quantities of sediment ladened freshwater runoff impinged on coastal reefs, causing high levels of coral mortality, rapid growth of fleshy algal species, and large parcels of reduced salinity/quality seawater (Figs. 1–4). Local fishermen have complained of decreased fisheries and reef vitality not only on these coastal reefs, but also on offshore islands and reefs not directly impacted by contact with the sediment. Inspection of these reefs revealed live adult coral colonies, but no signs of larval recruits for the period coinciding with and following construction activities and increased levels of sedimentation and runoff.

In contrast, surveys of Kossol Reef, Republic of Palau, performed in September, 1992, revealed up to 12 coral larval recruits per square meter in an area devastated by a typhoon in 1989. Coral recruits could be identified from each of the year classes since 1989, including small colonies resulting from the 1992 summer spawning. The point is, while levels of stress may be sublethal to adult coral colonies, they may be sufficient to cause reproductive and recruitment failure on nearby and distant reefs. Considering coral planulae remain competent (able to successfully settle and metamorphose) for periods from days to months (Richmond, 1987, 1988), a regional view of coral reef population dynamics is needed. Reproductive failure in one area may affect recruitment elsewhere. Numerous genetic studies have shown gene flow among populations of marine invertebrates. The significance of environmental degradation in one area on recruitment in another should not be ignored.

Oil pollution is an extreme example of how chemicals, in this case hydrocarbons, can impact reefs. Research performed in the Gulf of Eilat has documented coral mortality, decreased fecundity and recruitment failure in response to chronic oil pollution (Fishelson, 1973; Loya, 1975, 1976; Loya and Rinkevich, 1979; 1980). Chemical fishing techniques including the use of cyanide for collecting aquarium fish and chlorine bleach for consumptive fishing have also had a negative impact on reefs in the Philippines and Micronesia.

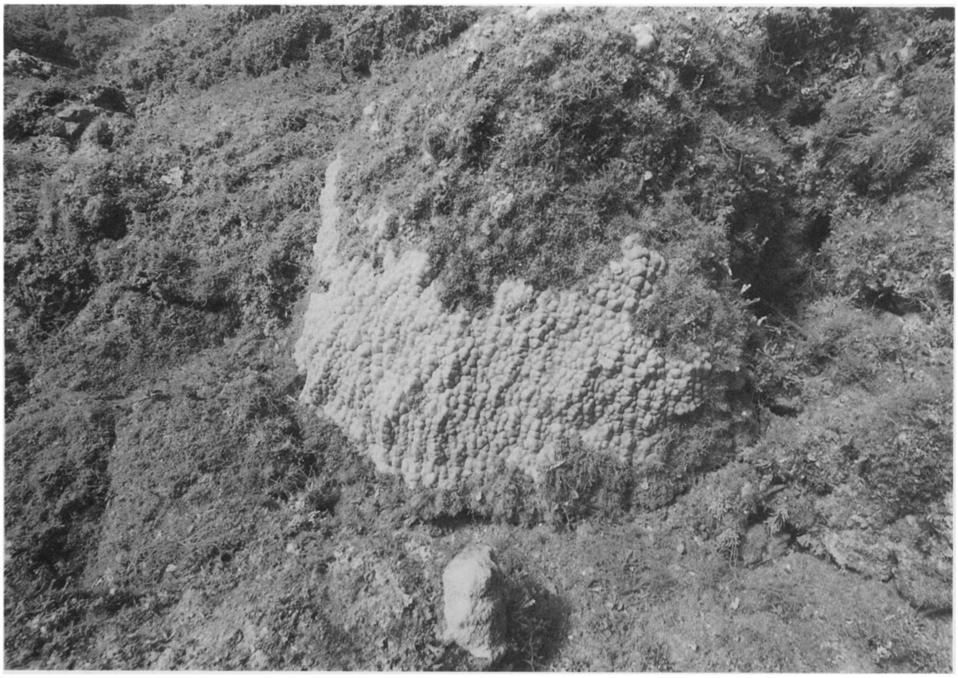

FIG. 3. *Porites* colony being overgrown by algae.

Water quality is a critical consideration in understanding anthropogenic impacts on coral reef communities, especially in how pollutants affect egg-sperm interactions and chemosensory cues critical to reproductive synchrony, fertilization success, larval settlement, metamorphosis and recruitment.

SEWAGE

The effects of sewage on coral reefs, reviewed by Pastorok and Bilyard (1985), result from several factors including nutrients, sediment (suspended solids) and toxic substances. The overall impact of sewage on a coral reef community depends on site-specific conditions including volume of sewage, level of treatment, presence of toxic materials, and receiving water characteristics.

The effects of sewage-related nutrient enrichment on coral reef communities have been documented, and include alteration of competitive interactions, reduction of coral calcification rates from decreased light levels and increased phosphate concentrations, and increased mortality from bacterial infection (Smith *et al.,* 1981; Pastorok and Bilyard, 1985; Tomascik and Sander, 1987). Corals are adapted to live in nutrient poor environments (Muscatine and Porter, 1977), and are relatively slow-growing compared to algae, sponges, tunicates and other groups of sessile, benthic organisms. Nutrients not only increase the biomass of phytoplankton, affecting light transmission and increasing the biochemical oxygen demand (B.O.D.) to the point that corals may be impacted (Guzman *et al.,* 1990), but also give a competitive advantage to faster growing benthic species. The green algae *Dictyosphaeria cavernosa,* formed large mats, covering and killing corals in Kaneohe Bay, Hawaii, due to sewage pollution (Smith *et al.,* 1981; Evans *et al.,* 1986). Additionally, portions of the Kaneohe Bay community shifted from a coral-dominated autotrophic community to an algae-dominated suspension feeding community because of eutrophication. Species of sabellid and serpulid worms and other boring organisms thrived during the period

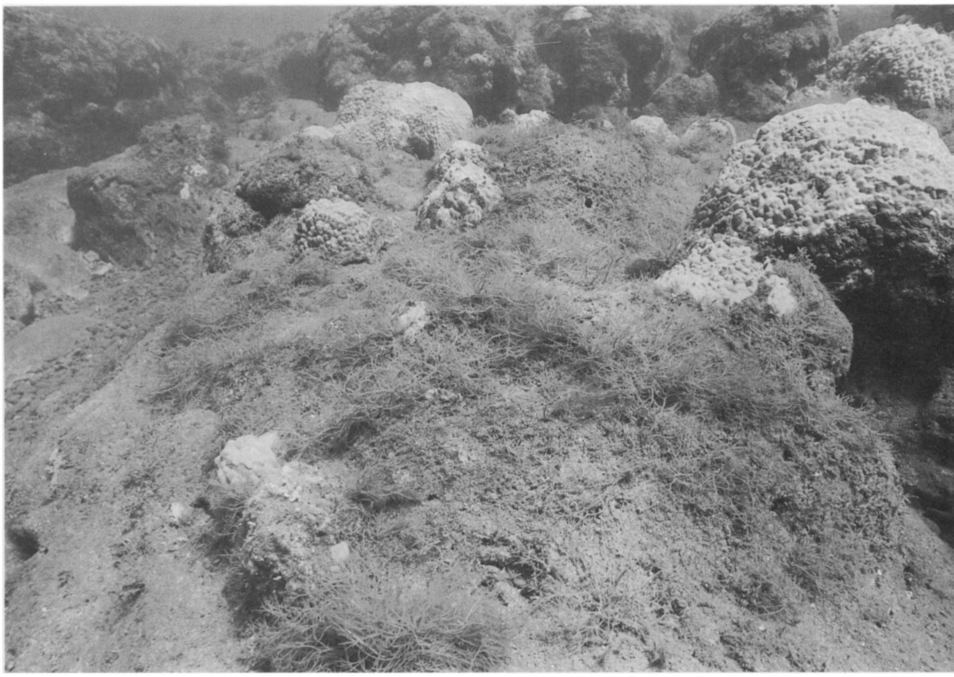

FIG. 4. Nutrient input caused an increase in fleshy algae biomass, which is now binding the sediment, preventing normal turbulence from cleansing the reef of accumulated sediment.

of sewage input, eroding the carbonate structure of the reefs and undermining the base upon which coral recolonization took place following sewage diversion.

Dubinsky *et al.* (1990) have also demonstrated that nutrient enrichment via sewage reduces the photosynthetic efficiency of corals, as algal cells increase in density to the point of becoming self-shading. Since the coral-zooxanthellae symbiosis evolved under nutrient limited conditions, it is reasonable to assume that the relationship will become altered in response to changes in the level of nutrients available. Further studies of the physiological effects of such changes are needed to determine the sublethal or long-term effects of sewage and nutrient enrichment on coral reefs.

While the effects of suspended solids from sewer outfalls have been compared to those from terrigenous runoff and sedimentation, the two types of sediment differ in physical, chemical and toxicological characteristics, which must be considered when assessing impacts (Pastorok and Bilyard, 1985). Sewage suspended solids are primarily organic, can contain adsorbed toxins, and increase B.O.D. more than inorganic sediment associated with runoff. The toxic component of sewage depends on the sources of input, and is primarily a concern in industrial or agricultural areas where industrial wastes and pesticides are included in the effluent.

TEMPERATURE STRESS

The negative impacts of increased temperature on corals have been documented from both anthropogenic and natural sources. Jokiel and Coles (1974) found coral mortality associated with the heated thermal discharge from a cooling system for a power plant in Hawaii. Glynn (1990) reported widespread coral mortality in the eastern Pacific associated with increased temperatures accompanying the 1982–83 El Niño event. In both cases the cause of mortality appeared to be the breakdown of the symbiotic association between the zooxanthellae and the coral host (bleaching). An important distinction between the two sources of stress is duration. Studies following the two examples presented here found corals recovering after the temperature stress was removed, indicating corals can rebound from acute temperature disturbances. The 1982–83 El Niño ended naturally, but it took redesigning and rebuilding the power plant outfall before recovery occurred at the Hawaii site.

CORAL BLEACHING

Widespread coral bleaching (loss of zooxanthellae) has been observed in both the Atlantic and Pacific oceans, and has been linked to unusually high temperatures and irradiance (Williams and Williams, 1988; Williams *et al.,* 1987). This topic is reviewed in a special issue of the journal *Coral Reefs* (vol. 8, no. 4, 1990), which presents discussions of both natural and anthropogenic sources of temperature increase. The relationship between bleaching events and ozone depletion/global warming is presently being studied by several groups of researchers (Buddemeier, 1993). If the connection can be proven, it will be an example of global rather than local anthropogenic impacts on coral reefs.

CORAL DISEASES

Four types of coral diseases have been "identified": white band disease, black band disease, bacterial infection, and shut-down reaction (Antonius, 1981). While there is a degree of uncertainty as to the causes responsible for each disease, they all appear to be stress-related. This is one area where synergisms are believed to play an important role, as stressed corals seem to be the most susceptible. Tumors, bacterial attack and parasitic worms have been observed in areas where corals have been stressed by sediment, sewage, pesticides, heavy metals and other human impacts (Mitchell and Chet, 1975; Brown and Howard, 1985; Glynn *et al.,* 1989; C. Hunter, personal communication).

TOXIC WASTE

Within the last few years, a new threat has emerged, endangering the health of coral reefs of the Pacific Islands. Several companies have been targeting cash-poor developing Pacific Islands as potential sites for disposing of toxic wastes. In 1990, a proposal from an Australian company was submitted to the Government of Palau for the construction of a toxic waste disposal incinerator/power plant. Among the materials listed as suitable to be used as fuel to produce electricity were coal tailings, sewage sludge, dioxins, lead, sulphur, and cyanide contaminated wastes, PCBs, and heavy metal liquors (Graves, 1992; Lohning Brothers, 1990). In 1992, the U.S. Securities and Exchange Commission suspended trading of stock in a company called Pacific Waste Management Inc., which was promoting the development of the toxic waste incinerator in Palau, noting concerns including several name changes of the company, and that the Palau constitution has a provision banning the importation of toxic matter (Graves, 1992; North, 1992).

In December, 1992, a barge containing 5,200 tons of petroleum contaminated soil transited Guam en route to the Marshall Islands, where the material was to be used in construction of a causeway between two islands in Kwajalein Atoll (Brooks, 1992*a, b*; Glauberman, 1993). Concerns about the environmental acceptability of the proposed activity resulted in the fully-loaded barge returning to its point of origin in Honolulu, Hawaii, where alternate means of disposal are being considered.

The costs of handling and disposing of toxic materials are high, and islands in need of income, and without adequate technological expertise, are attractive opportunities for getting rid of such wastes at minimal costs. I believe this situation remains an important concern for Pacific coral reefs. As with pesticide runoff, the problem may be with long-term effects, bioaccumulation of substances by organisms and the results of chronic exposure.

DESTRUCTIVE FISHING PRACTICES

The use of dynamite and poisons, including chlorox and cyanide, have been responsible for the destruction of coral reefs throughout the world. Because of the size of the areas concerned, and the general lack of resources for enforcement, education appears to be more successful than legislation in controlling these practices. Poverty reduces the alternatives for fishermen who must feed their families and rely on fishing as a source of protein and income. This same problem has lead to another anthropogenic disturbance on reefs: overfishing. The use of fish traps made of long-lasting materials with small mesh sizes results in the capture of pre-reproductive juveniles, affecting future populations, and the death of fish when traps become dislodged during storms, yet continue to capture fish which eventually starve. Several types of net fishing have also been responsible for over-exploitation of reef resources as well as impact damage to coral reefs. As with all biological communities, each species plays an important role in the dynamics of balance. The depletion of grazers, for example, may eventually lead to an overgrowth of algae. While it is simple to prove how damaging destructive fishing practices are to the productivity of fisheries, the economic realities of day-to-day life on some tropical islands makes the solution difficult to obtain.

CROWN-OF-THORNS STARFISH

The coral-eating starfish, *Acanthaster plancii,* has been the focus of a debate on the fate of coral reefs since major outbreaks were observed in the late 1960s and early 1970s (reviewed in a special issue of the journal *Coral Reefs,* vol. 9, no. 3, 1990). While it has been documented that hundreds of km^2 of coral reefs have been devastated by population blooms of the starfish, the debate centers on whether the outbreaks are natural events, having occurred repeatedly over geologic time, or if the situation has arisen as a result of man's activities. Although sediment core data have indicated *Acanthaster* outbreaks occurred 10,000 years ago, recent studies have shown a relationship between nutrient input and recruitment success of the larvae (Birkeland, 1982). Studies of echinoderm reproduction have demonstrated that the success of recruitment of their planktotrophic larvae depends on phytoplankton availability following spawning. Events that increase nutrient availability on coral reefs can affect reproduction and recruitment in *Acanthaster.* While outbreaks may be considered natural, an increasing number and/or the persistence of these events may be linked to anthropogenic nutrient input.

DISCUSSION

Anthropogenic versus *natural disturbance*

This is certainly not the first discussion or comparison of anthropogenic *versus* natural disturbance, nor will it be the last. As scientists, we often look for trends, generalizations and rules, perhaps even where such things are not appropriate. It is easy to pick specific examples which support either side of the debate: 1) that there is little qualitative difference between anthropogenic and natural disturbance to coral reefs (Grigg and Dollar, 1990), and 2) that important differences do exist, which affect recovery, mitigation and management decisions (Johannes, 1975; Loya, 1976). For example, Grigg and Dollar (1990) report the impact of a kaolin spill on French Frigate Shoal, Hawaii, was trivial, yet tropical storms cause catastrophic coral mortality. The stress on French Frigate Shoal was acute, kaolin is inert, non-toxic with no B.O.D., and the site is an area with high water motion, far removed from any other chronic sources of pollution. Had the same spill occurred in a harbor, or on a coastal reef adjacent to a populated area, the long-term impact would have been much greater, especially due to synergisms and continued interference with recovery and recruitment. As far as effects of tropical storms and typhoons, while the overall appearance could be described as catastrophic, such events usually crop the reef rather than completely kill the corals. One of my primary collecting sites for studies of coral reproduction is the windward, exposed reef behind the University of Guam Marine Laboratory. During the past seven years, there have been at least eight major typhoons, during which wave wash has reached as high as 33 feet above sea level. There has not been a single year that I have not been able to collect a variety of gravid corals from this site.

When defending projects or activities potentially harmful to coral reefs, paid consultants often argue that if there are no data that prove the proposed activity is detrimental, the project or activity should be allowed. This sets the stage for classical type II statistical error: accepting a false hypothesis. Simply put: the absence of data showing harm often indicates a lack of data rather than no effect. When adequate and accurate data demonstrate no detrimental effects, then and only then should projects be approved.

Data summarized in this paper support the hypothesis that most chronic disturbances are more damaging than acute disturbances, especially when considering coral reef recovery. Anthropogenic disturbances, like runoff, sedimentation, sewage outfalls, and oil pollution are characteristically chronic perturbances. They generally cause problems not only by inducing coral mortality, but by affecting reproduction and recruitment, and hence, recovery. If such problems can be controlled, limiting them to more episodic and acute disturbances, or removing the stress altogether, reefs can, and will recover. Perhaps that is the message of value we can extract from impact studies. Corals in Kaneohe Bay, Oahu, Hawaii, did recover from both fresh water kills and eutrophication when sewage input was diverted elsewhere (Evans *et al.,* 1986; Holthus *et al.,* 1986; Jokiel *et al.,* 1993).

Devastating events normally considered as natural, like *Acanthaster* outbreaks (Endean, 1973) and red tides (Guzman *et al.,* 1990), have been found to have links to human activities increasing runoff and eutrophication (Birkeland, 1982). Recovery of Jamaican reefs following Hurricane Allen (Woodley *et al.,* 1981) appears to have been impaired by anthropogenic impacts of overfishing herbivorous fishes and terrigenous runoff coincident with the loss of grazing urchins by disease. This further emphasizes the types of synergistic interactions that can occur, affecting the extent of mortality as well as the possibilities for recovery (Pearson, 1981).

One solution which would drastically reduce the amount of anthropogenic disturbance on coastal coral reefs is to change the common engineering practice of using the coastal zone as a dumping ground for storm drainage, runoff and sewage. While temperate marine environments and fisheries thrive on nutrient input, coral reefs suffer whenever water clarity goes down and/or nutrient levels go up. Better erosion control standards, increased retention of freshwater on land, and diversion of sewage to areas which carry the material away from reefs are all solutions which can readily be applied.

Globally, coral reef preserves are critically needed to serve as refuges for corals and other reef organisms (Buddemeier, 1993). Wilkinson (1993) estimates 70% of the world's coral reefs are already seriously degraded (10%), in a critical state of being lost within the next 10–20 years (30%), or threatened to disappear within the next 20–40 years (30%), leaving an estimated 30% as stable, and capable of surviving from hundreds to thousands of years. More data and studies, especially in forms and forums available and comprehensible to the general public and decision makers are needed if present trends are to be reversed.

In conclusion, acute, natural disturbances are critical to maintenance of diversity on reefs (Connell, 1978), and in the case of tropical storms and typhoons, may actually serve to reduce anthropogenic disturbance by removing accumulated sediments deposited by erosion and sedimentation. Characteristically chronic, anthropogenic disturbance, while often sublethal, and hence, more difficult to assess on the short term, can cause more serious damage by preventing recovery while acting to weaken corals and other reef organisms to the point of eventual mortality. We cannot control nature, but with adequate and accurate data, can make decisions which control the impacts of man's activities on coral reef communities.

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