CORALS AND HUMAN DISTURBANCE

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Introduction

Coral reefs are the centers of marine biodiversity on the planet. Reefs are constructed by a host of hermatypic (reef-building) coral species, but also are home to ahermatypic (non-calcium-carbonate depositing) corals, such as soft corals, black corals and gorgonians. The major structural components of reefs are the scleractinian corals. Much like their terrestrial rivals the tropical rainforests, reefs combine a host of microhabitats and a diverse array of life forms that is still being discovered and described. Coral reefs are mostly distributed throughout the tropical belt, and a large fraction are located in developing countries.

To understand how human activities affect coral reefs, it is necessary to briefly review their basic life history. Coral reefs are mostly made up of numerous smaller coral colonies; these colonies are in turn made up of thousands of minute polyps, which secrete a calcium carbonate skeleton. The deposition rate for individual coral species varies, but generally ranges between 0.1 mm and 10.0 cm per year. The accumulation of these skeletons over a long period of time results in massive, three-dimensional geological structures. The actual living tissue, however, is only the thin layer of living coral polyps on the surface. Corals are particularly susceptible to contaminants in sea water because the layer of tissue covering the coral skeleton is thin (~ 100 μm) and rich in lipids, facilitating direct uptake of chemicals. Coral polyps feed by filtering plankton using nematocyst (stinging cell)-tipped tentacles, and also receive organic matter through their symbiotic relationship with minute dinoflagellates called zooxanthellae. Zooxanthellae live within the gastrodermal tissues, and chemical communication (exchange) occurs via the translocation of metabolites. These small algal cells use sunlight to photosynthesize carbonates and water into organic matter and oxygen, both of which are used by the polyp.

Coral reefs support complex food and energy webs that are interlinked with nutrient inputs from outside sources (such as those brought with ocean currents and runoff from nearby rivers) and from the reef itself (where natural predation and die-off recirculate organic matter). These complex webs mean that any effect on one group of individuals will ultimately impact another, and single disturbances can have multiple effects on reef inhabitants. For example, the complete eradication of the giant Triton *Charonia trinis* through overfishing can result in outbreaks of the crown-of-thorns starfish *Acanthaster planci*. This can lead to massive coral mortality as the starfish reproduce and feed on the coral polyps. The mortality in turn may reduce habitats and food sources for reef fishes, which again, in turn, could lead to declines of larger predatory fishes. Similarly, the introduction of an invasive species either by accident or through ignorance (e.g., dumping of a personal aquarium contents into local habitats) might disrupt feeding processes and kill resident fishes. The death of key organisms on the reef (which then shifts from an autotrophic to a heterotrophic, suspension/detritus-feeding community) changes the dominant ecological process from calcium carbonate deposition to erosion, and ultimate loss of coral reef. Reef ecosystems may respond to environmental change by altering their physical and ecological structure, and through changes in rates of accretion and biogeochemical cycling. However, the potential for adaptation in reef organisms may be overwhelmed by today's anthropogenic stresses. The following sections provide a review of human disturbances and their general effects on coral reefs.

Collection of Corals

Corals have been mined for construction purposes in numerous Pacific Ocean islands and in South-East Asia. Usually the large massive life forms such as *Porites*, *Platygyra*, *Favia*, and *Favites* are collected and broken into manageable sizes or crushed for cement and lime manufacture. Similarly, the shells of the giant clam *Tridacna* and the conch shell *Strombus* are collected. Coral blocks and shells are used for construction of houses, roads, and numerous other projects. Corals are also collected for use in the ornamental trade, either as curios and souvenirs or as jewelry. Entire, small colonies of branching species such as *Acropora* and *Seriatophora* are used in the souvenir trade and for decoration, while black corals *Antipathes* and blue coral *Heliopora* are used for jewelry. The aquarium industry is also responsible for coral collection either for direct sale as live colonies or through the process of fish collecting. In many cases entire colonies full of fish are brought to the surface and are then smashed and discarded.

The removal of coral colonies decreases the shelter and niche areas available to numerous other reef inhabitants. Juvenile stages of fish that seek shelter among the branching species of corals, and worms and ascidians that take up residence on massive life forms, are deprived of protection and may become prey to other reef organisms. Removal of adult colonies also results in a reduction of overall reproductive output, as the corals no longer serve as a source of replenishment larvae. Further, removal of entire colonies reduces the overall structural stability of the reef, and increases rates of erosion through wave and surge damage.

Destructive Fishing

Destructive fishing pressures are taking their toll on coral reefs, particularly in developing countries in South-East Asia. The use of military explosives and dynamite was common shortly after the Second World War, but today this has shifted to the use of home-made explosives of fertilizer, fuel, and fuse caps inserted into empty beer bottles. Bombs weigh approximately 1 kg and have a destructive diameter of 4–5 m. Blast fishers hunt for schooling fish such as sweetlips and fusiliers, which aggregate in groups in the open or hide under large coral heads. Parrot fish and surgeon fish schools grazing on the reef crest are also actively sought. The bombs are usually set on five-second fuses and are dropped into the center of an area judged to have many fish. After the bomb has exploded, the fishers use dip nets, either from the boats or from underwater, to collect the stunned and dying fish. Many larger boats collect the fish using 'hookah' compressors and long air hoses to support divers working underwater.

The pressure wave from the explosion kills or stuns fish, but also damages corals. Natural disturbances may also fragment stony reef corals, and there are few quantitative data on the impacts of skeletal fragmentation on the biology of these corals. Lightly bombed reefs are usually pockmarked with blast craters, while many reefs in developing countries comprise a continuous band of coral rubble instead of a reef crest and upper reef slope. The lower reef slope is a mix of rubble, sand, and overturned coral heads. Typically at the base of the reef slope is a mound of coral boulders that have been dislodged by a blast and then rolled down the slope in an underwater avalanche. The reef slopes are mostly dead coral, loose sand, rubble, or rock and occasionally have overturned clams or coral heads with small patches of living tissue protruding from the rubble. The blasts also change the three-dimensional structure of reefs, and blasted areas no longer provide food or shelter to reef inhabitants. Further, once the reef structure has been weakened or destroyed by blast fishing, it is much more susceptible to wave action and the reef is unable to maintain its role in coastline protection. Larvae do not settle on rubble and thus replenishment and rehabilitation is minimal. Additionally, the destruction of adult colonies also results in a reduction of overall reproductive output, and reefs no longer serve as a source of replenishment larvae. Experimental findings, for instance, indicate that fragmentation reduces sexual reproductive output in the reef-building coral *Pocillopora damicornis*. The recovery of such areas has been measured in decades, and only then with complete protection and cessation of fishery pressure of any kind.

Another type of destructive fishing is 'Muro Ami', in which a large semicircular net is placed around a reef. Fish are driven into the net by a long line of fishermen armed with weighted lines. The weights are repeatedly crashed onto the reef to scare fish in the direction of the net, reducing coral colonies to rubble. The resulting effects are similar to the effects of blast fishing, spread over a larger area.

Cyanide fishing is also among the most destructive fishing methods, in which an aqueous solution of sodium cyanide is squirted at fish to stun them, after which they are collected and sold to the live-fish trade. Other chemicals are also used, including rotenone, plant extracts, fertilizers, and quinaldine. These chemicals all narcotize fish, rendering them inactive enough for collection. The fish are then held in clean water for a short period to allow them to recover, before being hauled aboard boats with live fish holds. In the process of stunning fish, the cyanide affects corals and small fish and invertebrates. The narcotizing solution for large fish is often lethal to smaller ones. Cyanide has been shown to limit coral growth and cause diseases and bleaching, and ultimately death in many coral species.

Among other destructive aspects of fishing are lost fishing gear, and normal trawl and purse fishing operations, when these take place near and over reefs. Trawlers operate close to reefs to take advantage of the higher levels of fish aggregated around them, only to have the trawls caught on the reefs. Many of these have to be cut away and discarded, becoming further entangled on the reefs, breaking corals and smothering others. Similarly, fishing with fine-mesh nets that get entangled in coral structures also results in coral breakage and loss. In South-East Asia, fishing companies have been reported to pull a chain across the bottom using two boats to clear off corals, making it accessible to trawlers.

Spearfishing also damages corals as fishermen trample and break coral to get at fish that disappear into crevices, and crowbars are frequently used to break coral. The collection of reef invertebrates along the reef crest results in breakage of corals that have particular erosion control functions, reducing the reef's potential to act as a coastal barrier.

Discharges

Mankind also effects corals through the uncontrolled and often unregulated discharge of a number of industrial and domestic effluents. Many of these are 'point-source' discharges that affect local reef areas, rather than causing broad-scale reef mortality. Sources of chemical contamination include terrestrial runoff from rivers and streams, urban and agricultural areas, sewage outfalls near coral reefs, desalination plants, and chemical inputs from recreational uses and industries (boat manufacturing, boating, fueling, etc.). Landfills can also leach directly or indirectly into shallow water tables. Industrial inputs from coastal mining and smelting operations are sources of heavy metals. Untreated and partially treated sewage is discharged over reefs in areas where fringing reefs are located close to shore, such as the reefs that fringe the entire length of the Red Sea. Raw sewage can result in tumors on fish, and erosion of fins as a result of high concentrations of bacteria. The resulting smothering sludge produces anaerobic conditions under which all benthic organisms perish, including corals. In enclosed and semi-enclosed areas the sewage causes eutrophication of the coral habitats. For instance, in Kaneohe bay in Hawaii, which had luxuriant reefs, sewage was dumped straight into the bay and green algae grew in plague quantities, smothering and killing the reefs. Evidence indicates that branching species might be more susceptible to some chemical contaminants than are massive corals.

Abattoir refuse is another localized source of excessive nutrients and other wastes that can lead to large grease mats smothering the seabed, local eutrophication, red tides, jellyfish outbreaks, an increase in biological oxygen demand (BOD), and algal blooms. Similarly, pumping/dumping of organic compounds such as sugar cane wastes also results in oxygen depletion.

The oil industry is a major source of polluting discharges. Petroleum hydrocarbons and their derivatives and associated compounds have caused widespread damage to coastal ecosystems, many of which include coral reefs. The effects of these discharges are often more noticeable onshore than offshore where reefs are generally located, but nonetheless have resulted in the loss of reef areas, particularly near major exploration and drilling areas, and along major shipping routes. Although buoyant eggs and developing larvae are sometimes affected, reef flats are more vulnerable to direct contamination by oil. Oiling can lead to the increased incidence of mortality of coral colonies.

In the narrow Red Sea, where many millions of tonnes per annum pass through the region, there have been more than 20 oil spills along the Egyptian coast since 1982, which have smothered and poisoned corals and other organisms. Medium spills from ballast and bilgewater discharges, and leakages from terminals, cause localized damage and smothering of intertidal habitats. Oil leakage is a regular occurrence from the oil terminal and tankers in Port Sudan harbor. Seismic blasts during oil exploration are also a threat to coral reefs. Refineries discharge oil and petroleum-related compounds, resulting in an increase in diatoms and a decrease in marine fauna closer to the refineries. Throughout many parts of the world there is inadequate control and monitoring of procedures, equipment, and training of personnel at refineries and shipping operations.

Drilling activities frequently take place near reef areas, such as the Saudi Arabian shoreline in the Arabian Gulf. Drilling muds smother reefs and contain compounds that disrupt growth and cause diseases in coral colonies. Field assessment of a reef several years after drilling indicated a 70–90% reduction in abundance of foliose, branching, and platelike corals within 85–115 m of a drilling site. Research indicates that exposure to ferrochrome lignosulfate (FCLS) can decrease growth rates in *Montastrea annularis*, and growth rates and extension of calices (skeleton supporting the polyps) decrease in response to exposure to 100 mg l^{-1} of drilling mud.

Oil spills affect coral reefs through smothering, resulting in a lack of further colonization, such as occurred in the Gulf of Aqaba in 1970 when the coral *Stylophora pistillata* did not recolonize oil-contaminated areas after a large spill. Effects of oil on individual coral colonies range from tissue death to impaired reproduction to loss of symbiotic algae (bleaching). Larvae of many broadcast spawners pass through sensitive early stages of development at the sea surface, where they can be exposed to contaminants and surface slicks. Oiling affects not only coral growth and tissue maintenance but also reproduction. Other effects from oil pollution include degeneration of tissues, impairment of growth and reproduction (there can be impaired gonadal development in both brooding and broadcasting species, decreased egg size and decreased fecundity), and decreased photosynthetic rates in zooxanthellae.

In developing countries, virtually no ports have reception facilities to collect these wastes and the problem will continue mostly through a lack of enforcement of existing regulations. The potential exists for large oil spills and disasters from oil tank ruptures and collisions at sea, and there are no mechanisms to contain and clean such spills. The levels of oil and its derivatives (persistent carcinogens) were correlated with coral disease in the Red Sea, where there were significant levels of diseases, especially Black Band Disease. In addition to the impacts of oils themselves are the impacts of dispersants used to combat spills. These chemicals are also toxic and promote the breakup of heavier molecules, allowing toxic fractions of the oil to reach the benthos. They also promote erosion through limiting adhesion among sand particles. The full effect of oil on corals is not fully understood or studied, and much more work is needed to understand the full impact. Although natural degradation by bacteria occurs, it is slow and, by the time bacteria consume the heavy, sinking components, these have already smothered coral colonies.

Industrial effluents, from a variety of sources, also impact coral reefs and their associated fauna and habitats. Heavy metal discharges lead to elevated levels of lead, mercury, and copper in bivalves and fish, and to elevated levels of cadmium, vanadium, and zinc in sediments. Larval stages of crustaceans and fish are particularly affected, and effluents often inhibit growth in phytoplankton, resulting in a lack of zooplankton, a major food source for corals. Industrial discharges can increase the susceptibility of fish to diseases, and many coral colonies end up with swollen tissues, excessive production of mucus, or areas without tissue. Reproduction and feeding in surviving polyps is affected, and such coral colonies rarely contribute to recolonization of reef areas.

Organisms in low-nutrient tropical waters are particularly sensitive to pollutants that can be metabolically substituted for essential elements (such as manganese). Metals enter coral tissues or skeleton by several pathways. Exposed skeletal spines (in response to environmental stress), can take up metals directly from the surrounding sea water. In Thailand, massive species such as *Porites* tended to be smaller in areas exposed to copper, zinc, and tin, there was a reduced growth rate in branching corals, and calcium carbonate accretion was significantly reduced.

Symbiotic algae have been shown to accumulate higher concentrations of metals than do host tissues in corals. Such sequestering in the algae might diminish possible toxic effects to the host. In addition, the symbiotic algae of corals can influence the skeletal concentrations of metals through enhancement of calcification rates. There is evidence, however, that corals might be able to regulate the concentrations of metals in their own tissues. For example, elevated iron in Thai waters resulted in loss of symbiotic algae in corals from pristine areas, but this response was lower in corals that has been exposed to daily runoff from an enriched iron effluent, suggesting that the corals could develop a tolerance to the metal.

Cooling brine is another industrial effluent that affects shoreline-fringing reefs, often originating from industrial installations or as the outflow from desalination plants. These effluents are typically up to 5–10°C higher in temperature and up to 3–10 ppt higher in salinity. Discharges into the marine environment from desalination plants in Jeddah include chlorine and antiscalant chemicals and 1.73 billion $m^3\ d^{-1}$ of brine at a salinity of 51 ppt and 41°C. The higher temperatures decrease the water's ability to dissolve oxygen, slowing reef processes. Increases in temperature are particularly threatening to coral reefs distributed throughout the tropics, where reef-building species generally survive just below their natural thermal thresholds. Higher-temperature effluents usually result in localized bleaching of coral colonies. The higher-salinity discharges increase coral mucus production and result in the expulsion of zooxanthellae and eventual bleaching and algal overgrowth in coral colonies. Often these waters are chlorinated to limit growth of fouling organisms, which increases the effects of the effluents on reef areas. The chlorinated effluents contain compounds that are not biodegradable and can circulate in the environment for years, bringing about a reduction in photosynthesis, with blooms of blue/green and red algae. Chlorinated hydrocarbon compounds include aldrin, lindrane, dieldrin, and even the banned DDT. These oxidating compounds are absorbed by phytoplankton and in turn by filter-feeding corals. Through the complex reef food webs these compounds concentrate in carnivorous fishes, which are often poisonous to humans.

Many airborne particles are also deposited over coral reefs, such as fertilizer dust, dust from construction activities and cement dust. At Ras Baridi, on the Red Sea coast of Saudi Arabia, a cement plant that operates without filtered chimneys discharges over 100 t d^{-1} of partially processed cement over the nearby coral reefs, which are now smothered by over 10 cm of fine silt.

Solid Waste Dumping

The widespread dumping of waste into the seas has continued for decades, if not centuries. Plastics, metal, wood, rubber, and glass can all be found littering coral reefs. These wastes are often not biodegradable, and those that are can persist over long periods. Damage to reefs through solid waste dumping is primarily physical. Solid wastes damage coral colonies at the time of dumping, and thereafter through natural tidal and surge action. Sometimes the well-intentioned practice of developing artificial reefs backfires and the artificial materials are thrown around by violent storms, wrecking nearby reefs in the process.

Construction

Construction activities have had a major effect on reef habitats. Such activity includes coastal reclamation works, port development, dredging, and urban and industrial development. A causeway across Abu Ali bay in the northern Arabian Gulf was developed right over coral reefs, which today no longer exist. Commercial and residential property developments in Jeddah, on the Red Sea, have filled in reef lagoon areas out to reef crest and bulldozed rocks over reef crest for protection against erosion and wave action. Activities of this type result in increased levels of sedimentation as soils are nearly always dumped without the benefit of screens or silt barriers.

Siltation is invariably the consequence of poorly planned and poorly implemented construction and coastal development, which can result in removal of shoreline vegetation and sedimentation. Coral polyps, although able to withstand moderate sediment loading, cannot displace the heavier loads and perish through suffocation. Partial smothering also limits photosynthesis by zooxanthellae in corals, reducing feeding, growth, and reproductive rates.

The development of ports and marinas involves dredging deep channels through reef areas for safe navigation and berthing. Damage to reefs comes through the direct removal of coral colonies, sediment fallout, churning of water by dredger propellers, which increases sediment loads, and disruption of normal current patterns on which reefs depend for nutrients.

Landfilling is one of the most disruptive activities for coastal and marine resources, and has caused severe and permanent destruction of coastal habitats and changed sedimentation patterns that damage adjacent coral resources. Changes in water circulation caused by landfilling can alter the distribution of coral communities through redistribution of nutrients or increased sediment loads.

Recreation

The recreation industry can cause significant damage to coral reefs. Flipper damage by scuba divers is widespread. Some will argue that today's divers are more environmentally conscious and avoid damaging reefs, but certain activities, such as irresponsible underwater photography finds divers breaking corals to get at subjects and trampling reef habitats in order to get the 'perfect shot'. In areas where divers walk over a reef lagoon and crest to reach the deeper waters, there is a degree of reef trampling, heightened in cases where entry and exit points are limited.

Anchor damage from boats is a common problem at tourist destinations. In South-East Asia many diving operations are switching to nonanchored boat operations, but many others continue the practice unabated. Large tracts of reef can be found in Malaysia that have been scoured by dragging anchors, breaking corals and reducing reef crests to rubble. Experiments have shown that repeated break-age of corals, such as is caused by intensive diving tourism, may lead to substantially reduced sexual reproduction in corals, and eventually to lower rates of recolonization. In the northern Red Sea, another popular diving destination, and in the Caribbean, efforts are underway to install permanent moorings to minimize the damage to reefs from anchors.

Shipping and Port Activities

Congested and high-use maritime areas such as narrow straits, ports, and anchorage zones often lead to physical damage and/or pollution of coral reef areas. Ship groundings and collisions with reefs occur in areas where major shipping routes traverse coral reef areas, such as the Spratley Island complex in the South China Sea, the Red Sea, the Straits of Bab al Mandab and Hormuz, and the Gulf of Suez, to name only a few. Major groundings have occurred off the coast of Florida in the United States, such as the one off Key Largo in State park waters in the 1980s, causing extensive damage to coral reefs. Often these physical blows are severe and destroy decades, if not centuries, of growth. Fish and other invertebrates lose their refuges and foraging habitats, while settlement of new colonies is restricted by the broken-up nature of the substrate. Seismic cables towed during seabed surveys and exploration activities may damage the seabed. Cable damage from towing of vessels (e.g., a tug and barge) has been reported snagging on shallow reefs in the Gulf of Mexico, causing acute damage to sensitive reefs.

Discharges from vessels include untreated sewage, solid wastes, oily bilge, and ballast water. On the high seas these do not have a major noticeable effect on marine ecosystems, but close to shore, particularly at anchorages and near ports, the effects become more obvious. At low tides, oily residues may coat exposed coral colonies, and sewage may cause localized eutrophication and algal blooms. Algal blooms in turn deplete dissolved oxygen levels and prevent penetration of sunlight.

Port activities can have adverse effects on nearby reefs through spills of bulk cargoes and petrochemicals. Fertilizers, phosphates, manganese, and bauxite, for instance, are often shipped in bulk, granular form. These are loaded and offloaded using massive mechanical grabs that spill a little of their contents on each haul. In Jordan, the death of corals was up to four times higher near a port that suffered frequent phosphate spills when compared to control sites. The input of these nutrients often reduces light penetration, inhibits calcification, and increases sedimentation, resulting in slower feeding and growth rates, and limited settlement of new larva.

War-related Activities

The effects of war-related activities on coral reef health and development are often overlooked. Nuclear testing by the United States in Bimini in the early 1960s obliterated complete atolls, which only in recent years have returned to anything like their original form. This redevelopment is nothing like the original geologic structure that had been built by the reefs over millenia. The effects of the nuclear fallout at such sites is poorly understood, and possibly has long-term effects that are not appreciable on a human timescale. The slow growth rate of coral reefs means that those blast areas are still on the path to recovery.

Target practice is another destructive impact on reefs, such as occurred in 1999 in Puerto Rico, where reefs were threatened by aerial bombing practice operations. In Saudi Arabia, offshore islands were used for target practice prior to the Gulf war in 1991. The bombs do not always impact reefs, but those that do cause acute damage that takes long periods to recover.

In the Spratley islands, the development of military structures to support and defend overlapping claims to reefs and islands has brought about the destruction of large tracts of coral reefs. Man-made islands, aircraft landing strips, military bases, and housing units have all used landfilling to one extent or another, smothering complete reefs and resulting in high sediment loads over nearby reefs. Dredging to create channels into reef atolls has also wiped out extensive reef areas.

Indirect Effects

Most anthropogenic effects and disturbances to coral reefs are easily identifiable. Blast fishing debris and discarded fishing nets can be seen. Pollutant levels and sediment loads can be measured. However, many other man-made changes can have indirect impacts on coral reefs that are more difficult to link directly to coral mortality. Global warming is generally accepted as an ongoing phenomenon, resulting from the greenhouse effect and the buildup of carbon dioxide in the atmosphere. Temperatures generally have risen by 1–2°C across the planet, bringing about secondary effects that have had noticeable consequences for coral reefs. The extensive coral beaching event that took place in 1998, which was particularly severe in the Indian Ocean region, is accepted as having been the result of surface sea temperature rise. Bleaching of coral colonies occurs through the expulsion of zooxanthellae, or reductions in chlorophyll content of the zooxanthellae, as coral polyps become stressed by adverse thermal gradients. Some corals are able to survive the bleaching event if nutrients are still available, or if the period of warm water is short.

Coupled with global warming is change of sea level, which is predicted to rise by 25 cm by the year 2050. This sea level rise, if not matched by coral growth, will mean corals will be submerged deeper and will not receive the levels of sunlight required for zooxanthellae photosynthesis. Additionally, the present control of erosion by coral reefs will be lost if waves are able to wash over submerged reefs.

Coral reef calcification depends on the saturation state of carbonate minerals in surface waters, and this rate of calcification may decrease significantly in the future as a result of the decrease in the saturation level due to anthropogenic release of CO_2 into the atmosphere. The concentration of CO_2 in the atmosphere is projected to reach twice the preindustrial level by the middle of the twenty-first century, which will reduce the calcium carbonate saturation state of the surface ocean by 30%. Carbonate saturation, through changes in calcium concentration, has a highly significant short-term effect on coral calcification. Coral reef organisms do not seem to be able to acclimate to the changing saturation state, and, as calcification rates drop, coral reefs will be less able to cope with rising sea level and other anthropogenic stresses.

The Future

Mankind has contributed to the widespread destruction of corals, reef areas, and their associated fauna through a number of acute and chronic pollutant discharges, through destructive processes, and through uncontrolled and unregulated development. These effects are more noticeable in developing countries, where social and traditional practices have changed without development of infrastructure, finances, and educational resources. Destructive fishing pressures are destroying large tracts of reefs in South-East Asia, while the development of industry affects reefs throughout their range. If mankind is to be the keeper of coral reefs into the coming millennium, there is going to have to be a shift in fishing practices, and adherence to development and shipping guidelines and regulations, along with integrated coastal management programs that take into account the socio-economic status of people, the environment, and developmental needs.

Glossary

Ahermatypic Non-reef-building corals that do not secrete a calcium carbonate skeletal structure.

DDT Dichlorodiphenyltrichloroethane.

Dinoflagellates One of the most important groups of unicellular plankton organisms, characterized by the possession of two unequal flagella and a set of brownish photosynthetic pigments.

Eutrophication Pollution by excessive nutrient enrichment.

Gastrodemal The epithelial (skin) lining of the gastric cavity.

Hermatypic Reef-building corals that secrete a calcium carbonate skeletal structure.

Quinaldine A registered trademark fish narcotizing agent.

Scleractinians Anthozoa that secrete a calcareous skeleton and are true or stony corals (Order Scleractinia).

Zooxanthellae Symbiotic algae living within coral polyps.

See also

Anthropogenic Trace Elements in the Ocean. Carbon Cycle. Eutrophication. Gas Exchange in Estuaries. Metal Pollution. Oil Pollution. Past Climate From Corals. Pollution: Effects on Marine Communities. Seabird Population Dynamics.

Further Reading

Birkland C (1997) *Life and Death of Coral Reefs*. New York: Chapman and Hall.

Connel DW and Hawker DW (1991) *Pollution in Tropical Aquatic Systems*. Boca Raton, FL: CRC Press.

Ginsburg RN (ed.) (1994) *Global Aspects of Coral Reefs: Health, Hazards and History*, 7–11 June 1993. Miami: University of Miami. 420pp.

Hatziolos ME, Hooten AJ and Fodor F (1998) Coral reefs: challenges and opportunities for sustainable management. In: *Proceedings of an Associated Event of the Fifth Annual World Bank Conference on Environmentally and Socially Sustainable Development*. Washington, DC: World Bank.

Peters EC, Glassman NJ, Firman JC, Richmonds RH and Power EA (1997) Ecotoxicology of tropical marine ecosystems. *Environmental Toxicology and Chemistry* 16(1): 12–40.

Salvat B (ed.) (1987) *Human Impacts on Coral Reefs: Facts and Recommendations*. Antenne Museum E.P.H.E. French Polynesia, 253pp.

Wachenfeld D, Oliver J and Morrisey JI (1998) *State of the Great Barrier Reef World Heritage Area 1998*. Townsville: Great Barrier Reef Marine Park Authority.

Wilkinson CR (1993) Coral reefs of the world are facing widespread devastation: can we prevent this through sustainable management practices? In: *Proceedings of the Seventh International Coral Reef Symposium*, Guam, Micronesia (Mangilao: University of Guam Marine Laboratory).

Wilkinson CR and Buddemeier RW (1994) *Global Climate Change and Coral Reefs*: Implications for People and Reefs. Report of the UNEO-IOC-ASPEI-IUCN Task Team on Coral Reefs. Gland: IUCN.

Wilkinson CR, Sudara S and Chou LM (1994) Living coastal resources of Southeast Asia: Status and review. In: *Proceedings of the Third ASEAN-Australia Symposium on Living Coastal Resources*, Vol. 1. Townsville: ASEAN-Australia Marine Science Project, Living Coastal Resources.