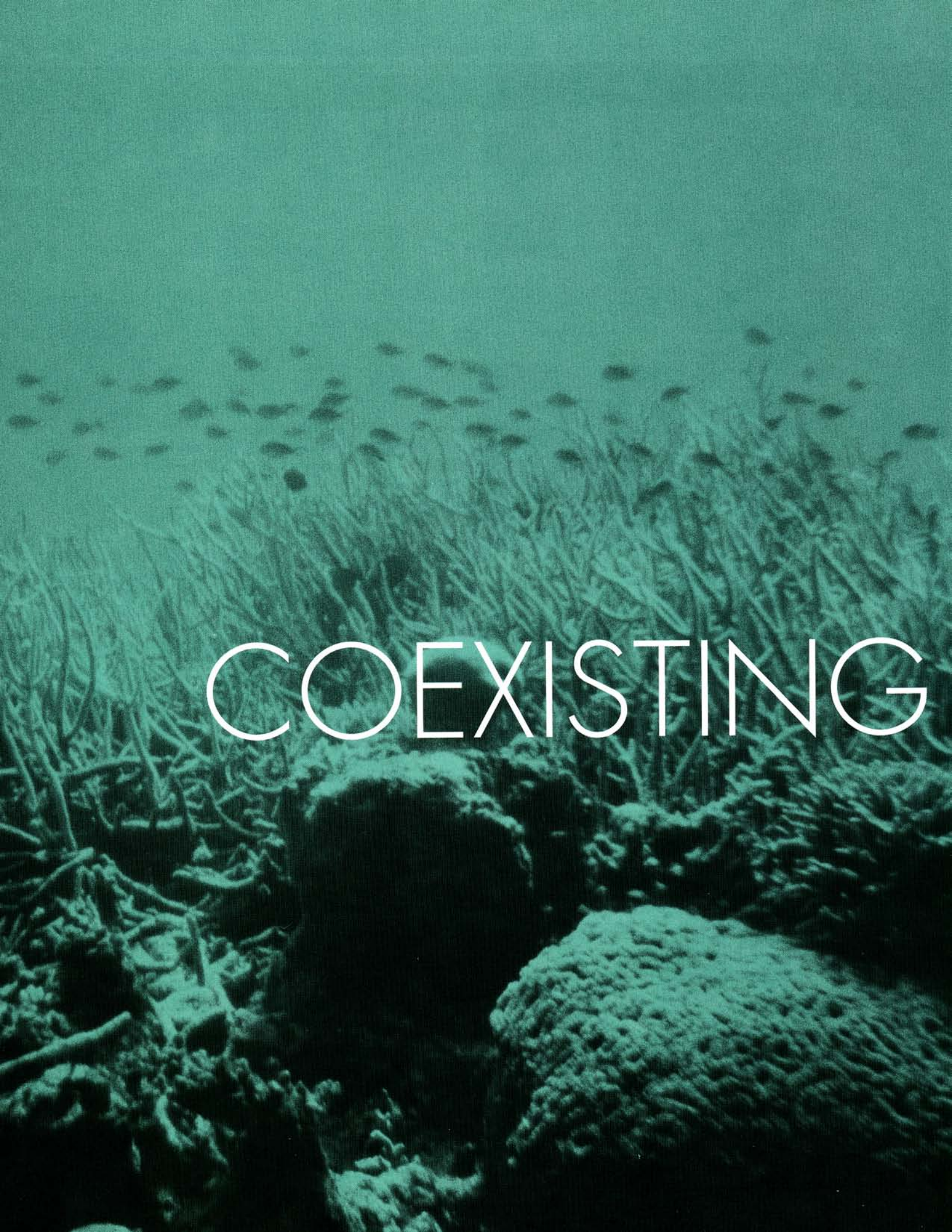

COEXISTING

CORAL REEFS, VALUED FOR THEIR NATURAL BEAUTY, ARE AMONG THE MOST DIVERSE ECOSYSTEMS ON EARTH, SECOND ONLY TO TROPICAL RAIN FORESTS. THEY ARE HOME TO COUNTLESS SPECIES OF FISHES, OTHER VERTEBRATES, INVERTEBRATES, AND PLANTS, AND SUPPORT A RICH VARIETY OF HUMAN CULTURES AND ECONOMIES. IF SUSTAINED RESPONSIBLY, WHICH IS AN ISSUE OF INTERNATIONAL CONCERN, REEFS WILL CONTINUE TO PROVIDE IMPORTANT ECONOMIC AND LIFE-GIVING RESOURCES, PROTECT TROPICAL SHORELINES, AND OFFER NEW POTENTIALS FOR MEDICINAL DRUGS AND AQUACULTURE.

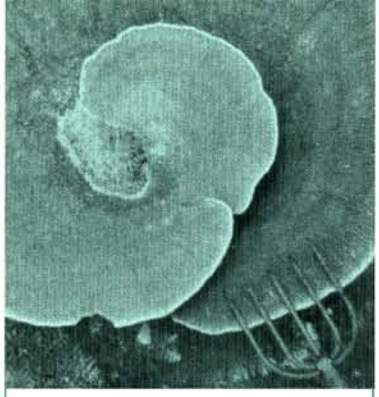
1997 HAS BEEN DESIGNATED THE INTERNATIONAL YEAR OF THE REEF (IYOR)—A MULTIFACETED VENTURE BRINGING TOGETHER SCIENTISTS, ENVIRONMENTALISTS, GOVERNMENTS, EDUCATORS, AQUARIUMS, AND OCEAN ENTHUSIASTS TO STUDY REEFS AND PROMOTE CONSERVATION. IN CONJUNCTION WITH IYOR, THIS ISSUE OF EXPLORATIONS HIGHLIGHTS SEVERAL SCRIPPS SCIENTISTS CONDUCTING CORAL-RELATED RESEARCH AND DESCRIBES SPECIAL CONSERVATION AND EDUCATION EFFORTS AT THE BIRCH AQUARIUM AT SCRIPPS.

WITH CORALS

Sustaining the Ocean's Fragile Reefs

BY PAIGE JENNINGS

TWENTY-FIVE MILLION YEARS ago coral reefs were forming in geographical areas that, because of subsequent changes in climate, are now associated more with pines than with palm trees and coconuts. Throughout the ages, climate change has forced coral reefs into a relatively narrow band in the warm, clear ocean waters between the tropics of Cancer and Capricorn, 24 degrees north and south of the equator. In recent times, the stress of human activities in these regions, especially resulting from increasing population and development, has



"So it is often hard to determine what has been lost. I try to take a moderate, rational approach to conservation. Reef destruction and extinctions go on all of the time naturally, but we don't want to be responsible for causing permanent damage."

WILLIAM NEWMAN

amplified the impacts of climate and other natural forces on reefs.

William Newman, a professor of biological oceanography at Scripps for more than 30 years, has traveled to most of the regions of the world harboring coral reefs. He has witnessed the power that nature and man can unleash on these ecosystems.

"Oceanic islands are not the pristine, quiet, tropical paradises that people might think," Newman explains. "Coral reefs are constantly battling significant physical perturbations for their existence. These physical forces, which include tropical storms, temperature fluctuations such as El Niños, and changes in sea level, can make human impacts look trivial. Many biologists don't appreciate the extent of the changes that occur in the physical habitat over years and decades, much less millennia.

"Unfortunately, we have very little baseline information on coral reef diversity and distribution," adds Newman. "So it is often hard to determine what has been lost. I try to take a moderate, rational approach to conservation. Reef destruction and extinctions go on all of the time naturally, but we don't want to be responsible for causing permanent damage."

Most anthropogenic impacts can be linked to increasing populations and development in coastal areas near coral reef communities. Human activities that threaten the health of reefs are varied and not always easily mitigated: influxes of sediment and pollution into the coastal waters that block out life-giving sun and literally choke the coral; overexploitation of reef resources, such as overharvesting of commercially viable fishes and invertebrates; damaging fishing methods including the use of cyanide, explosives, or dredging; habitat destruction through

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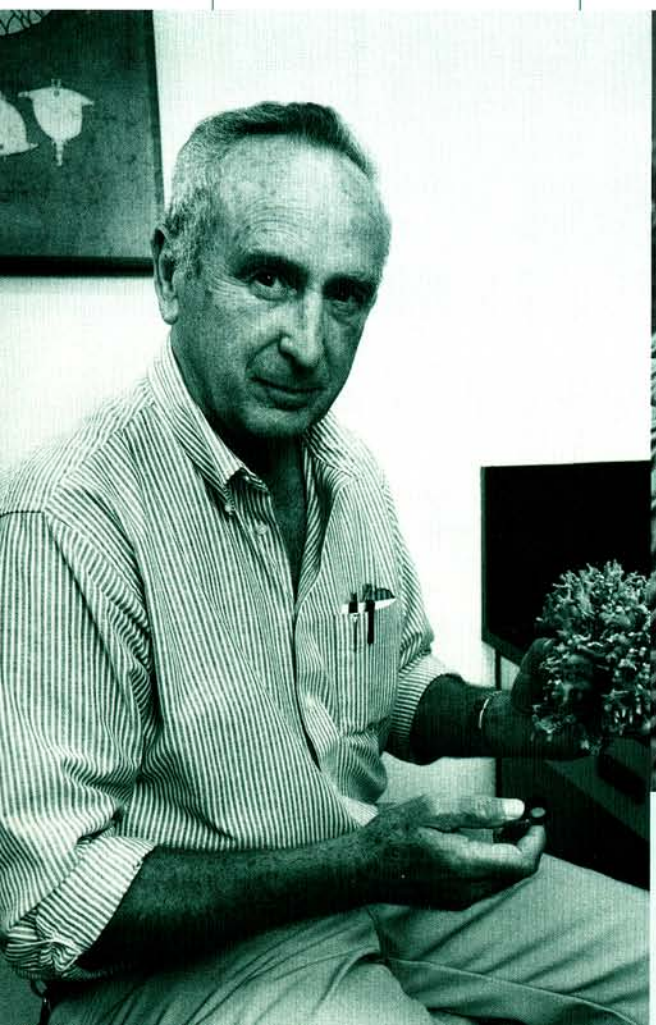
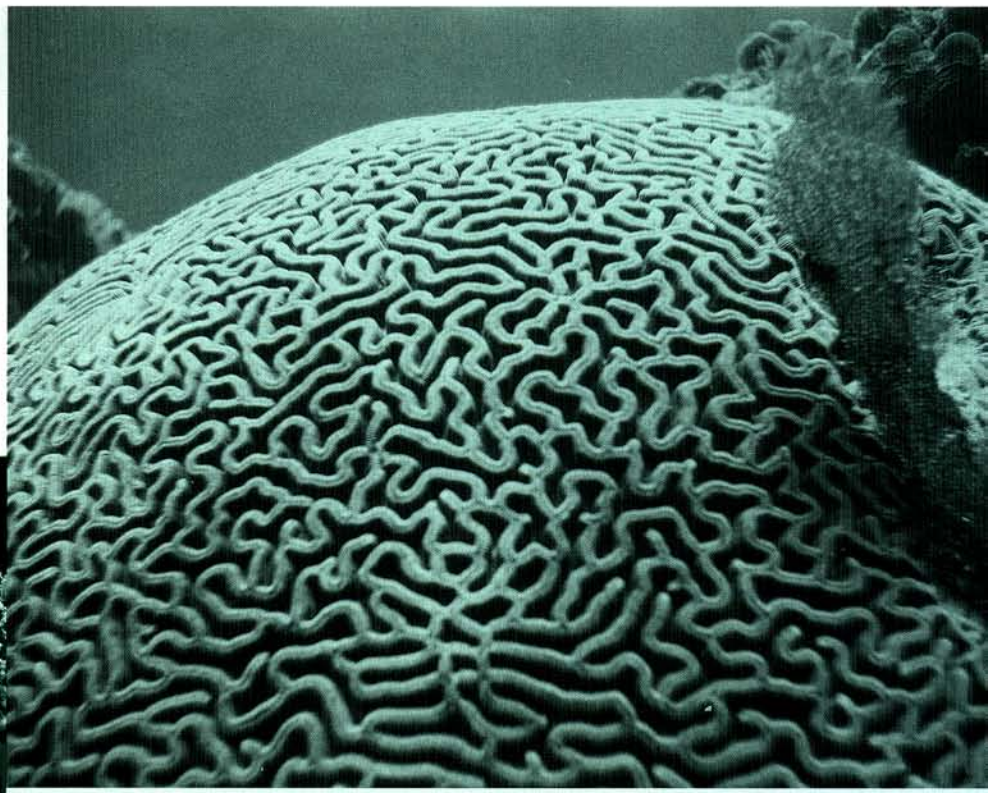




Left, William Newman examines *Allopora* sp., a blue hydrocoral found in the temperate waters off southern California. **Above**, *Colpophyllia natans*, a species of brain coral. The mazelike convolutions that give brain coral its common name are clearly visible.

Top, *Favia fragum*, a colonial coral. **Bottom**, a fungid polyp of the solitary coral, *Meandrina meandrites*.

UNDERSTANDING THE LIVING REEF

CORAL REEF ECOSYSTEMS INVOLVE complex biological, chemical, and geological interrelationships, but the process begins with small animals. Even the Great Barrier Reef, which includes more than 3,000 separate reefs extending 1,430 miles (2,300 km) along Australia's northwest coast, depends on the health and productivity of individual animals ranging in size from a fraction of an inch (a few millimeters) to a few inches (several centimeters).

The small, soft-bodied coral polyp, kin to jellyfish and anemones in the phylum *Cnidaria,* extracts calcium carbonate from seawater to construct a skeleton for protection and attachment to a hard substrate. The reef-building coral polyps proliferate, generally through asexual reproduction, to form colonies. Quickly, other organisms, such as encrusting coralline algae, mollusks, and reef fishes, fill niches in, on, and around the developing reef, adding to its mass and diversity. Growing as much as one-half inch (approximately 12 mm) per year, the reef evolves through continual erosion and regrowth, building upon itself, often into structures miles in length and thousands of yards in depth.

Until 1753, scientists classified corals as plants because of their radial symmetry and arborescent growth form. An individual coral, which appears not to move because of its attachment to the substrate, has a cup-shaped body with a single opening serving as both a mouth and anus ringed by petal-like tentacles. Symbiotic algae living within the polyps' tissues infuse the colonies with vivid colors. These single-celled plants, called zooxanthellae, gain a relatively safe residence while providing—through photosynthesis—some of the corals' nutrition needed for growth and calcification.

Reef-building corals propagate into a multitude of configurations and sizes, from boulder-shaped colonies the size of a large room, to staghorn corals that proliferate in long branching appendages indicative of their name.

As reef structures mature, they develop into three general types, depending on geologic and oceanic influences. Fringing reefs grow along the shoreline and are usually separated from the beach by a shallow lagoon; barrier reefs develop parallel to the shore but at greater distances and are separated by a generally deep lagoon; and atolls are open-ocean circular reefs surrounding a lagoon. In addition to the main types of reefs, there are also banks, which are reefs found in the open ocean at or below sea surface, and patch reefs that sprout up on sandy lagoon floors.

For corals to flourish in any type of reef system, a specific set of ocean conditions must exist. Corals generally are attached to solid substrates on which they build, and they require water movement to deliver food and oxygen and flush away wastes. They need water temperatures between 66°- 86°F (18°- 30°C) and clear water to allow ample sunlight penetration; because of this the bulk of reef-building corals grow within 120 feet (approximately 40 m) of the surface. Salinity must also remain relatively stable, as large influxes of freshwater are deadly. Even when all of these conditions exist, corals lead a precarious existence.

PREDICTED RATES OF POPULATION GROWTH ARE STAGGERING FOR TROPICAL REGIONS OF THE WORLD. WHAT ULTIMATE EFFECTS THIS GROWTH WILL HAVE ON CORAL REEFS AND ON THE CULTURES EXISTING AROUND AND SUBSISTING FROM THEM ARE NOT YET KNOWN, BUT THEY WILL NOT BE TRIVIAL.

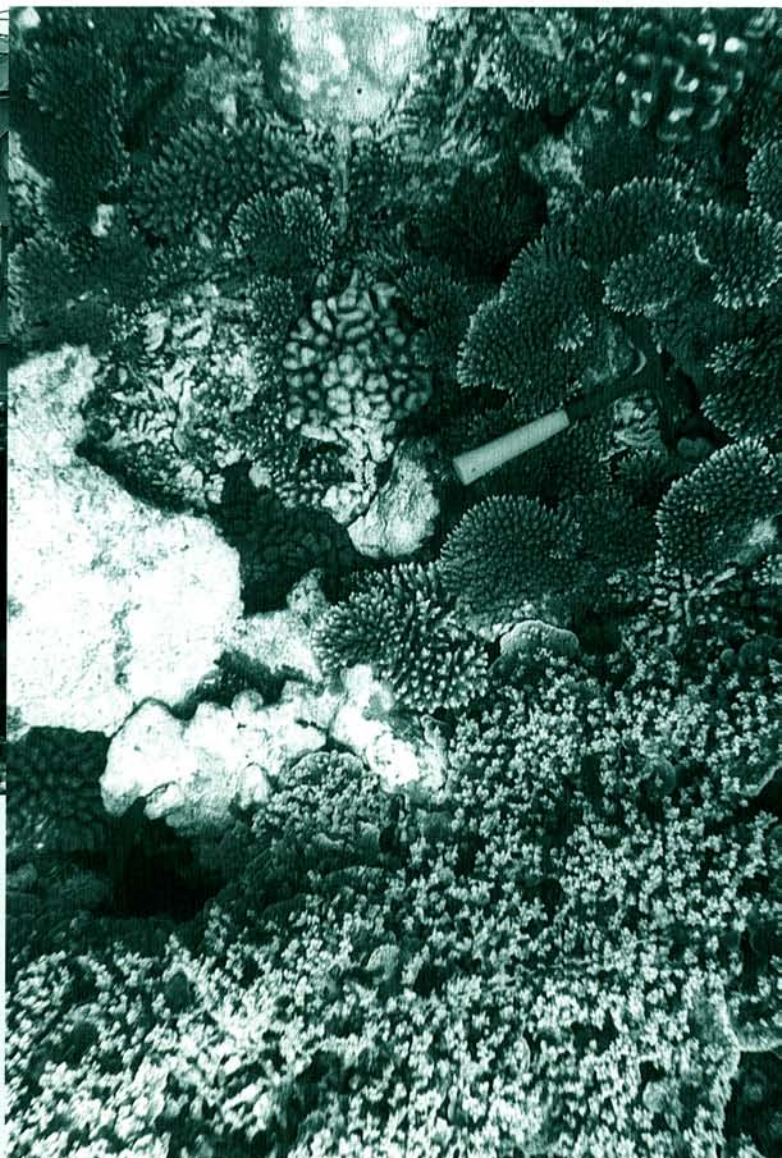
development; mining and extraction of reefs for construction materials; and increasing tourism and recreation.

Sediments, which are usually kept in check by terrestrial vegetation, flush into the ocean when land is cleared to make way for factories, resorts, roads, and agriculture. Sediments can directly cover living corals, depriving them of oxygen and sunlight. Pollution from human waste and agricultural run-off also is being released in coral reef areas at growing rates. This is causing increased nutrient levels that encourage the growth of encrusting alga, which overgrow the coral, and phytoplankton, which reduce the water clarity.

Local impacts by humans in developed and developing regions are having an increasing negative effect, especially in areas where human populations are exploding. Newman recounts one experience.

"I spent two years in the mid 1950s living on Truk in the Caroline Islands, when only the high islands were occupied. People went to the outer reefs to fish and collect coconuts, but they always came back to the islands with the higher elevations. Back then they had a relatively stable population. I went back about 14 years later, and people were living permanently on the outer islands. I asked why, and they said because it was getting too crowded on the higher islands."

This necessity for living space threatens the stability of other organisms that rely on the outer reefs to survive. When the new



Clockwise from top left, Scripps researchers William Newman and Robert Hessler, second and third from right, off Tahiti during an expedition in the early 1970s. A geologist's hammer gives scale to this diverse array of corals on a reef at Fanning Island, in the South Pacific. Newman and other Scripps researchers were among the first to dive, sample, and photograph coral reefs in the central and southern Pacific during the 1960s.

human inhabitants dig wells to access fresh groundwater, they deprive plants, such as coconut trees, of their only water supply. Also, fishing pressures become more intense, and rarely does a turtle's nest go undetected.

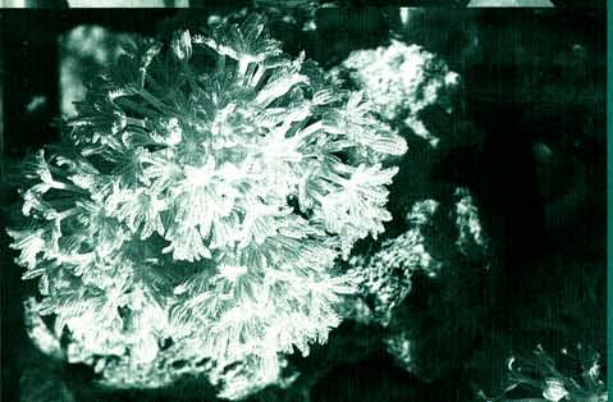
Predicted rates of population growth are staggering for tropical regions of the world. What ultimate effects this growth will have on coral reefs and on the cultures existing around and subsisting from them are not yet known, but they will not be trivial.

Globally, Newman believes that reefs incur more damage from natural forces than from human activities. Islands and coastal areas that lie in the path of tropical storms rely on coral reefs to buffer the destructive power of ocean waves. Corals pay the price and are often badly damaged by extremely powerful hurricanes.

"But," clarifies Newman, "usually when a typhoon or hurricane hits a coral reef, damage is incurred sporadically. You might have a patch of reef that is destroyed adjacent to a patch that is left unharmed because of wave cancellation or headland protection. As long as you have a healthy system some coral polyps will survive, and the reef will rebuild itself within a decade or so."

Coral reefs must also contend with disease and predator outbreaks, as well as fluctuations in water temperature. During the well-documented El Niño of 1982-1983, immense coral die-offs occurred in the Galápagos Islands and the eastern Pacific. Water temperatures were warmed enough by the event to cause the corals to expel their life-giving zooxanthellae, bleaching the polyps of color and depriving them of nutrients.

Newman is a great advocate of research, monitoring, and regulation, but believes that care must be taken to understand the natural history of coral reefs before drastic control measures are implemented. Although people are powerless against most natural climatic forces, the knowledge gained by scientists, such as those at Scripps, and through international efforts like the IYOR, help to define negative human impacts. New ways of preserving life in, on, and around the world's coral reefs may result.



AQUARIUM CORAL FARMING PROMOTES CONSERVATION

AT THE BIRCH AQUARIUM AT SCRIPPS, aquarists are tending colonies of reef-building corals in an effort to learn more about their growth and conservation, while providing beautiful, healthy additions for the aquarium's living reef exhibits.

Honolulu's Waikiki Aquarium donated captive-grown coral fragments to the Birch Aquarium from their propagation program and are consulting with aquarist Fernando Nosratpour (shown at left) on growth and display techniques. Aquarists can monitor and control the intensity of artificial light, water clarity, flow, and water temperature within the coral tank.

"Conservation is a primary goal in this project," explains Nosratpour. "The corals originally come from reefs in the South Pacific, and are harvested by taking only small cuttings from large colonies. Collections are taken from different locations so that there are no long-term impacts on the reef."

These cuttings are propagated in the Waikiki Aquarium and distributed to aquariums internationally. This is possible because of corals' ability to asexually reproduce. In the wild, if a portion of a larger colony is fractured off, during a heavy storm or because of its own weight, that fragment can continue to grow into a new colony.

Nosratpour reports, "Aquarists engaged in coral-propagation projects are able to take advantage of this ability of corals to rebound by transplanting and successfully culturing new colonies in captivity.

"By creating and maintaining living coral exhibits, the Birch Aquarium, and other aquariums with similar conservation missions, bring to the public a part of nature that has, until now, been seen by only a fortunate few. We are able to demonstrate the delicate beauty of the coral reef ecosystem and emphasize the importance of its preservation."

A WORLD VIEW

Persian Gulf and Red Sea
Contain small percentage of the world's coral reefs

Major natural impacts:
- Drastic shifts in air and water temperatures.
- Dramatic variations in salinity because of evaporation and no freshwater influx.
- Damage from endemic predators, such as sea urchins and crown-of-thorns starfish.

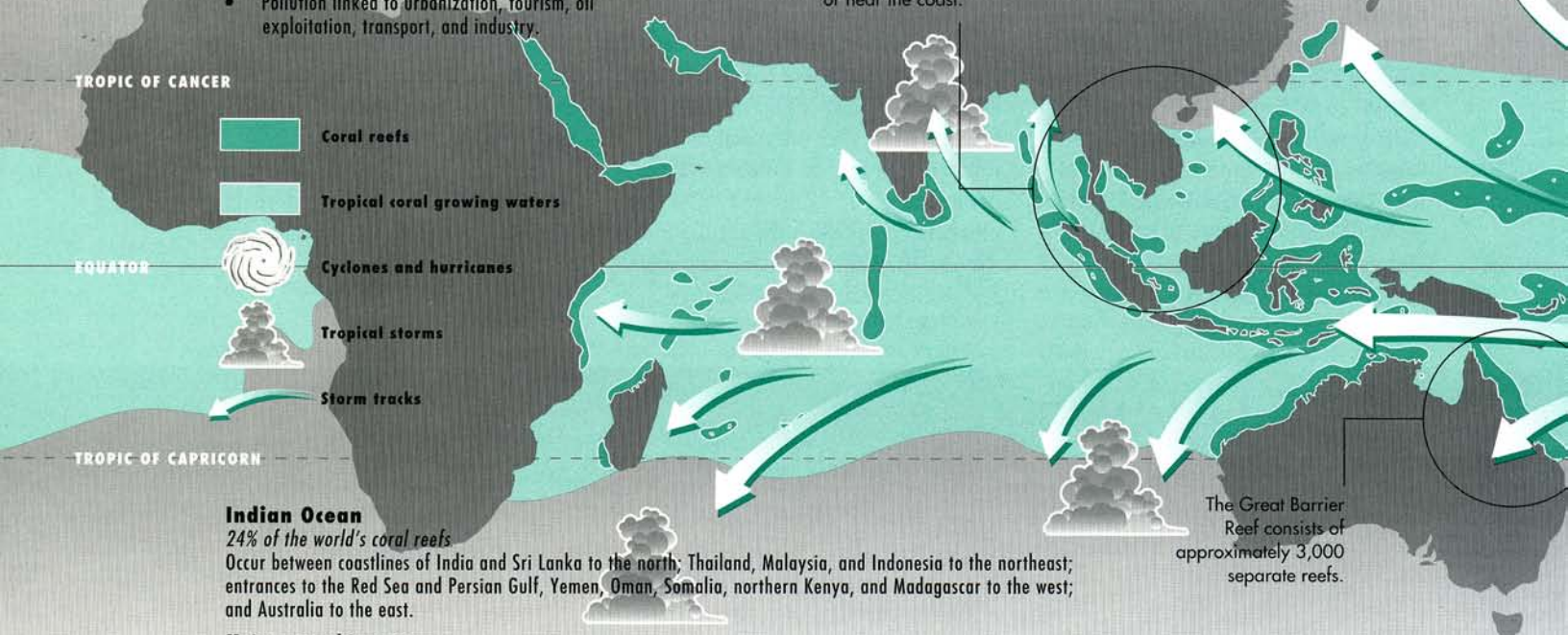
Major human impacts:
- Increasing human population.
- Coastal zone development.
- Pollution linked to urbanization, tourism, oil exploitation, transport, and industry.

In 1993, population of southeast Asia (excluding China), was estimated at 475 million. This number is predicted to grow to 726 million by 2025. 75% of people in this region live on or near the coast.

Southeast Asia
30% of the world's coral reefs
Includes archipelago from Philippines to western Indonesia.

Major natural impacts:
- Freshwater sources (rivers) introduce sediments, nutrients,and pollutants and lower salinity.
- Tropical storms.

Major human impacts:
- Increasing human population.
- Overfishing and degradation of many reef systems.
- Increased influx of untreated sewage.



The Great Barrier Reef consists of approximately 3,000 separate reefs.

Indian Ocean
24% of the world's coral reefs
Occur between coastlines of India and Sri Lanka to the north; Thailand, Malaysia, and Indonesia to the northeast; entrances to the Red Sea and Persian Gulf, Yemen, Oman, Somalia, northern Kenya, and Madagascar to the west; and Australia to the east.

Major natural impacts:
- Monsoonal cycle reverses currents seasonally and provides nutrients through upwelling.
- Damage from endemic predators, such as sea urchins and crown-of-thorns starfish.

Major human impacts:
- Increasing human population.
- Tin mining in western Thailand.
- Dredging for cement industry.
- Development of shipping channels.
- Growing oil industry off coast of Australia.
- Increasing tourism.

Population explosions among predators such as the crown-of-thorns starfish pressure large areas of reef. These are possibly the result of human impact on food webs.

Climate change impacts agriculture, while increasing populations put pressure on marine food resources.

The direct and indirect effects of pollution take their toll on the environment as a whole.

Blasts from dynamite fishing destroy vast areas of coral.

OF CORAL REEFS

Caribbean
14% of the world's coral reefs
Includes Caribbean Sea, Gulf of Mexico, south Florida, the Bahamas, Bermuda, and north Brazil.

Major natural impacts:
- Gulf Stream allows coral reef development north of latitudinal limit, into waters off Florida and Bermuda.
- Heavy terrestrial sedimentation in Gulf of Mexico.
- Tropical storms.
- Diseases, predator outbreaks, and bleaching.
- Influence from Amazon River.

Major human impacts:
- Increasing human population.
- Increasing development of housing, industry, agriculture, and tourism.
- Harvesting of mangroves and dredging of sea-grass beds increases sedimentation on coral reefs.

TROPIC OF CANCER

EQUATOR

TROPIC OF CAPRICORN

A dramatic bleaching episode nearly destroyed the entire coral reef system around the Galápagos Islands following the 1982-1983 El Niño. The relatively warm water temperatures caused by El Niño force the coral to expel the symbiotic algae (*zooxanthellae*) from which they draw nutrients and derive their brilliant coloring.

Pacific Ocean Region
25% of the world's coral reefs
Western Pacific supports richest reef biota, associated with widely separated island chains, including Micronesia, Palau, Papua New Guinea, and Vanuatu.

Major natural impacts:
- El Niño Southern Oscillation (ENSO).
- Tropical storms.

Major human impacts:
- Increasing human population.
- Overharvesting of fish, invertebrates, and other organisms of economic value.
- Escalating development increases coastal run-off of sediments and nutrients.

Tropical storms, some the results of El Niños, do immense damage to reefs.

A growing tourist industry impacts once undisturbed tropical areas.

Siltation, often the result of indiscriminate logging, smothers corals in areas where coastal development goes unchecked.

After coral bleaching episodes, algae may cover reef structures while sea urchins move in to graze the algae. Such pressures can prevent coral recolonization.