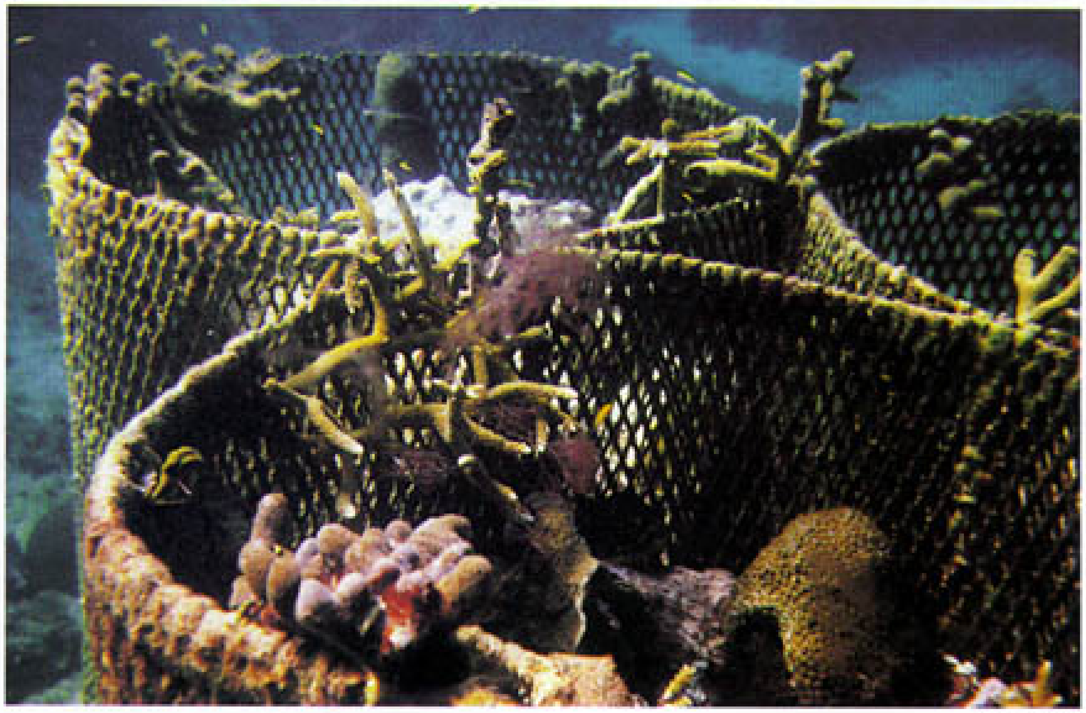
Third Generation Artificial Reefs

Since the early 1950s marine fishery interests have been investigating artificial reefs for manipulation of fish populations, using concrete rip-rap, natural stone, bricks, and a wealth of other materials. All too often, these installations furnished a welcome excuse to discard civilization's refuse, such as automobile tires, cars, ships, planes, busses, tanks, and offshore hydrocarbon platforms ("rigs for reefs"), with little or no regard for marine ecology. In the 1960s and 1970s, power companies even researched the possibilities of using highly toxic fly ash as an artificial reef component. These agglomerations of refuse often leach dangerous chemicals, decompose and dissipate quickly, and at best function as fish aggregation devices. We call them first generation reefs.

During the last two decades Japanese agencies and companies in particular have adopted more sensible approaches to reef-building, trying to increase the yield of protein in relatively barren coastal seas. Specially engineered devices have been installed to help manage the cultivation of fish, bivalves, and crustaceans in hundreds of bays and estuaries along the coast. Even fish- and invertebrate-specific reefs were developed. These reefs are constructed using plastics, sometimes reinforced with fiberglass, concrete made with hydraulic cement, and steel. They are vastly improved versions of their predecessors. Using efficient anchoring techniques, they represent state-of-the-art reef building—the second generation.



Wolf Hilbertz

One of three identical reef frames established in 1993 near Negril, Jamaica, upon which corals naturally attached and settled. Submerged floating objects repeatedly damaged the coral substrate, causing it to fall off. Application of electrical current immediately began to facilitate repair.

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The purpose of these reefs ranges from fish aggregation to mariculture, from providing diving sites for sport divers to environmental mitigation and restoration. Yet their inherent limitations prevent them from ever approaching the wonderful, manifold functions of coral reefs, the most intricate and productive of marine ecosystems. The vast majority of artificial reefs we know are biologically impoverished and do not produce real growing coral reef communities. Rather than becoming part of the marine environment organically, these structures will always remain foreign objects, and sometimes are transformed into dangerous projectiles in storms. For instance, after Hurricane Andrew hit southern Florida, a survey of artificial reefs in the area revealed that not one remained intact. All had moved, and while fragments were found, many vanished entirely.

At the same time, global threats to coral reefs have increased ominously. Global sea level rise of around two millimeters per year; marine pollution and overfertilization; mining of coral rock and sand; damage inflicted by dredging, net, dynamite, and spearfishing; the tropical species aquarium trade; and activities by sport divers have combined to cause ever greater damage of about 10 percent of all reefs. Recent reports point to increasing bacterial and fungal diseases attacking corals. As the sea level rises and reefs deteriorate, coastal areas lose their natural protection, resulting in beach and land erosion as well as salt water intrusion into aquifers. At risk of inundation are all the great and fertile river deltas, vast stretches of coastal land, and all low-lying islands. Entire island states may be washed down in size and as extreme weather conditions increase, may gradually or suddenly vanish beneath the waves. Irreplaceable cropland will be lost, and hundreds of millions of low-landers will be forced to seek higher ground.

One example is the Maldive Republic in the Indian Ocean. Situated on about 107,500 square kilometers of archipelagic ocean floor that is part of a subsiding tectonic plate, it is comprised of about 1,200 small coral rock islands. Slight to severe coastal erosion is evident on most of them. Mining of fossil and live coral as well as sand for construction and beach fortification is widespread. The reef formerly protecting the southern coast of the capital island, Malé, was mined out, leading to severe flooding a number of years ago. Now concrete tetrapods installed along the entire southern flank of Malé and costing more than $8,000 per meter of shoreline may help to avoid future disasters. Huge quantities of coral sand and aggregates, which once had a vital role in supporting biodiversity, have been worked into these ungainly structures, using imported hydraulic cement. This production contributes vast amounts of the greenhouse gas carbon dioxide to the atmosphere, aggravating the problem of rising sea levels even further.

Artificial reef in the Maldives, started in 1996, its spiny legs attaching the structure firmly to the sea floor by mineral accretion.

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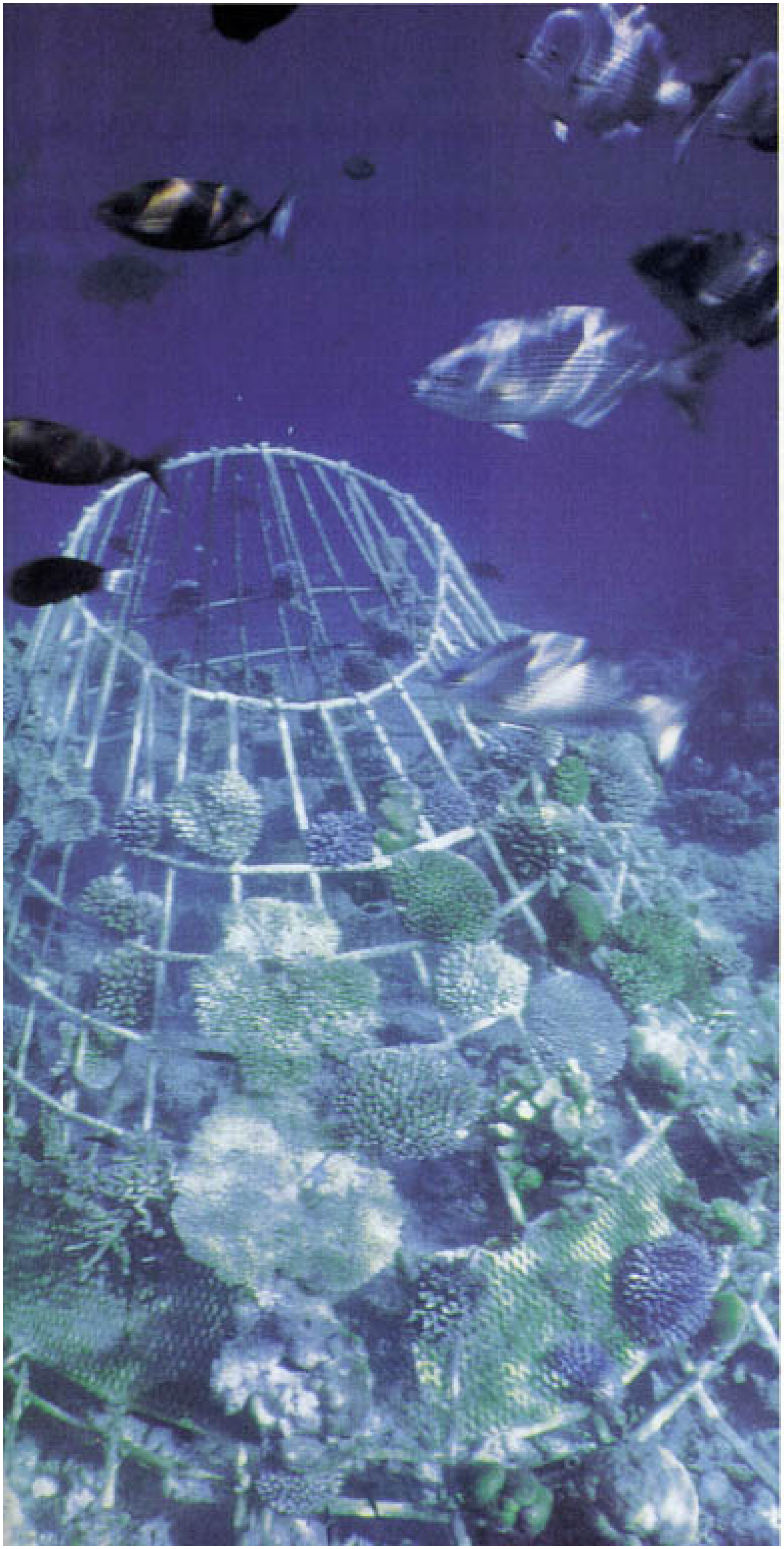

In response to these problems, we have developed a novel technology called mineral accretion, which uses electricity to "grow" limestone rock on artificial reef frames and increase growth rates of corals and other reef organisms. Two electrodes, supplied with low-voltage direct current, are submerged in sea water. Electrolytic reactions at the cathode (a negatively charged electrode) cause minerals naturally present in sea water, primarily calcium carbonate and magnesium hydroxide, to build up. At the same time, a wide range of organisms on or near the growing substrate are affected by electrochemically changed conditions, shifting their growth rates.

Reefs of any configuration and size can be grown for purposes of reef restoration and shore protection. We describe these structures as "third generation reefs" because they have little in common with their predecessors. Rather than being mere agglomerations of deteriorating shapes, they are growing life support systems, bringing about rich and beautiful ecologies. Mineral accretion technology is unique because it is the only method which produces natural limestone, the material which also constitutes coral skeletons, reefs, and sand. As a result, primary settlers and young corals readily settle on the substrate. Naturally settled corals, attached corals, coralline algae, bivalves, and a host of other organisms grow at exceptionally fast rates on these third generation reefs, and the rapid growth of calcareous algae supplies sand for beach nourishment. These growing reefs allow corals to thrive, even when water quality conditions have

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deteriorated to the point of killing surrounding corals, and as reefs grow they cement themselves in place, be it to the sea floor or vertical rock or coral formations, contributing to permanent shore protection. Even if these structures are damaged, renewed application of electricity readily facilitates repair.

Third generation reefs can be grown and maintained using direct or indirect solar irradiance converted by photovoltaics, wind turbines, or ocean energy plants working with thermals, saline gradients, ocean currents, and waves. Thus release of greenhouse gases from burning fossil fuels used in generating electricity and chemical decomposition of calcareous raw materials for cement production can be avoided. In addition, artificial or natural components of accreting structures can be harvested in controlled, sustainable ways to provide building materials for terrestrial use in regions that have to import aggregates and cement. Finally, hydrogen, precipitating at the cathode, can be collected for use as a nonpolluting energy carrier.

Third generation reefs have been grown using shore power, wind-driven generators, and photovoltaics in Texas, the US Virgin Islands, Louisiana, California, British Columbia, Mexico, Colombia, Venezuela, the Turks and Caicos Islands, Jamaica, Panama, Japan, Corsica, on Saya de Malha Bank in the Indian Ocean, the Seychelles, and the Maldives. Most of these are small pilot projects, up to five meters tall and up to forty meters long, submerged in water one to fourteen meters deep. Much larger reef systems, up to 630 meters in length and up to twenty meters wide, are in the planning stages.

Placing negatively charged materials like wire mesh, wire, chains, and conductive polymer formations in conjunction with anodic material on or around natural coral formations can bring about renewed growth and restoration. This method of cathodic reef stimulation (CRS) is currently being investigated at various locations under differing conditions.

In the course of projected global warming, many regions of the world ocean gradually may become suitable habitats for reef-building corals. Other areas, hitherto offering the right conditions for coral growth, may become too hot or cold to sustain reef builders and their ecologies. Under these conditions, solar-based third generation artificial reef technology could play a crucial role in preserving marine biodiversity, facilitating effective shore protection, and providing ecologically