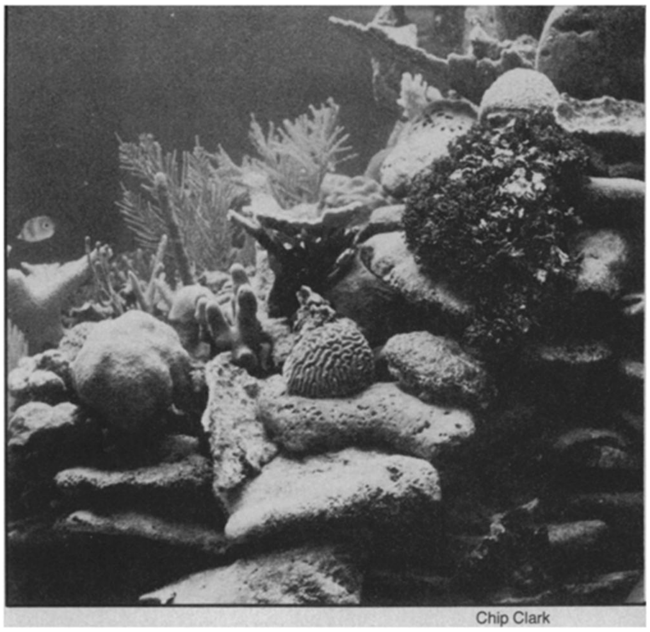
REEF ALIVE



Chip Clark

Vistors are now welcome to view the first flourishing coral reef community to be maintained away from the sea

BY JULIE ANN MILLER

The waves splash quietly as they hit the reef. A yellow fish flashes into view. Corals display their lace, fan and brain shapes. Pink-tipped tentacles of an anemone and feathery coral branches slowly undulate. A black sea urchin waves its long spines as it feeds on algae on the shell of a conch, while the conch, with the speckled neck of its mouth mimicking an elephant trunk, browses on algae on a piece of coral. Without donning scuba tanks or even a snorkel, one can observe the glory of ocean biology.

Standing firm and dry near the head of the blue whale in the sea-life hall of the Smithsonian Museum of Natural History in Washington, visitors can now view a coral reef's living community of plants and animals. And scientists in the comfort of their museum laboratory can explore the intricacies of coral reef life — in many ways more productively than they can by diving into the sea.

On Oct. 15, the Smithsonian opened to the public the first successful large coral reef community to be kept alive in total isolation from the sea. The 3,000-gallon tank system is the new home for more than 200 species of plants and animals, including about 25 different fish and 20 coral species. The structural basis of the reef is more than 3 tons of limestone rocks from the Virgin Islands fitted together with acrylic rods. Most of the plants and animals in the new tank were collected on a scuba-diving expedition to the Caribbean last June. The Smithsonian scientists are making plans to help several other U.S. museums set up versions of the coral reef system.

The coral reef project was started in 1974 when Walter H. Adey decided to see how algae react to the presence of fish and other undersea grazing animals and to predators of those grazers. In an attempt to provide a copy of the natural reef environment with the living algae needed for his experiment, Adey found that he needed to develop entirely new techniques for aquarium management. He tested his progress first in a 350-gallon tank and later in an 1,800-gallon system still operating in the museum basement. Even in the preliminary systems, he was the first person to keep alive a large, representative, ecologically balanced community of tropical reef organisms isolated from the ocean.

Lighting, waves and scrubbers are some of the innovations responsible for Adey's success. Most aquaria don't receive enough light to allow plant growth, explains Susan Brawley, one of the project researchers. But the main tank in the exhibit is lit with a rack of ten 400-watt and four 1,000-watt metal halide lamps, which simulate the intensity and spectrum of tropical sunlight. To mimic dawn and dusk, the lamps go on in the morning and off in the evening sequentially over a two-and-a-half-hour period. Adey finds that the productivity of the reef plants in such a system can equal the highest reported rates measured in the ocean.

Waves are another crucial feature of the successful reef "microcosm." The repeated surges of water carry oxygen and prevent areas of the tank from stagnating. In addition, the waves sweep sediment off the reef plants and animals.

Waves are created in the Smithsonian system by centrifugal pumps that remove water from one end of the tank and deliver it to two receptacles at the other end. The receptacles, which Brawley calls dump truck buckets, become unbalanced when they are full and each tips about every 10 seconds, spilling water into the tank. Because the two buckets sometimes tip at the same time and sometimes separately, the strength of the waves varies, as it does in nature. At the far end of the tank, water drops into a separate reservoir, a "wave catcher," so that waves are not reflected back onto the reef. The volume of water in this reservoir is automatically monitored, and losses due to evaporation are corrected.

The third novel aspect of the system is the scrubber, a turf of algae that maintains the chemical balance (see box). Adey says that although there is no bacterial filtration, air bubbling or chemical conditioning, waste build-up and conspicuous disease do not occur in the tanks. He and his colleagues attribute this success to the ecological balance of the system.

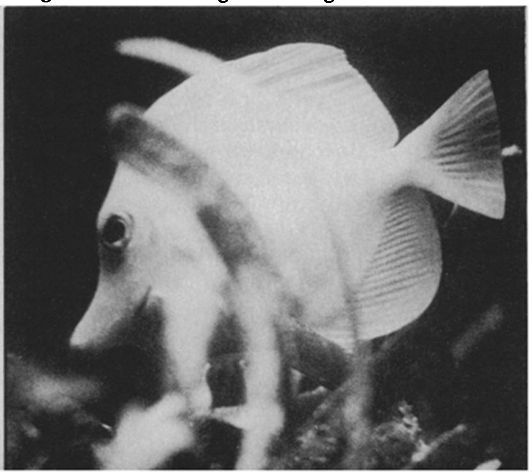
Observations of the reefs, especially the 1,800-gallon model, which has been studied the longest, have revealed that behavioral patterns and community interrelationships operate much as they do in nature. The energy economics of the microcosm are also similar to those of the natural reef.

The museum reef is especially valuable for observing, close up, the behavior of the marine organisms. The damsel fish, for instance, tends an algal garden on the model reef. This blue-backed, yellow-bellied fish fiercely guards its territory of filamentous algae from other herbivores. It not only grazes the territory to keep the algae growing, but it also weeds its plot. For example, while the fish is down in a crevice of the coral reef for the night, investigators can put less desirable types of algae on a clear wire across a damsel fish's territory. First thing in the morning, the fish plucks the "weed" algae from its plot and drops it off the side of the reef, Brawley reports.

In the reef tank most algae and many invertebrates successfully reproduce and grow to maturity. Two species of damsel fish have repeatedly laid and fertilized egg clutches in the reef tanks. The male fish tend the eggs, as in nature, and the eggs seem to hatch normally. Larval fish are found in the tank for about a day, but they are soon eaten by larger animals.

In the wild, larvae of most reef fish escape to the open ocean and return to the reef at a later stage of development, Adey explains. The scientists currently are working to develop tanks that simulate open ocean. These planktonic tanks would be connected to the reef tank. Adey and colleagues plan to use several tanks with limited interconnections, which should

Tang browses in sea grass in lagoon tank.



Victor Krantz

increase the diversity of species their "open ocean" supports. The researchers may also have ultraviolet radiation continually destroying plants or animals on the edges of the tanks to avoid "wall" effects.

Sex change is one fascinating aspect of tropical fish development that the Smithsonian scientists have observed in the coral reef tanks. Juvenile striped parrot fish were put into the tank. As they matured, one exhibited a sudden spurt of growth and after two weeks began to develop the neon blue and orange coloration of a male parrot fish. The other two remained black and white, one female dominating the front of the reef and the other dominating the back. Now in the new tank in the exhibit area, another young parrot fish has begun to show the male colors.

Flowering of turtle grass, a display rarely seen by divers in the sea, also has been observed in the museum basement. There, as in the exhibit, a lagoon tank is connected in series with the reef. In nature a lagoon is separated from a reef by a barren, overgrazed area called the halo. Fish darting off the reef can nibble plants that spring up in the halo and return to protection without encountering open-ocean predators.

The Smithsonian investigators isolated the lagoon community in a separate tank with limited access from the reef, to simulate the distance in nature across the halo to the lagoon. The turtle grass flowered during the first year it was placed in the tank. The blade length of the mature grass is short, but within the range observed on a natural Caribbean reef. When a browsing fish, the yellow tang, was added to the lagoon, it grazed on plants growing on the turtle grass, and the grass blade length, life span and colonization rate increased dramatically.

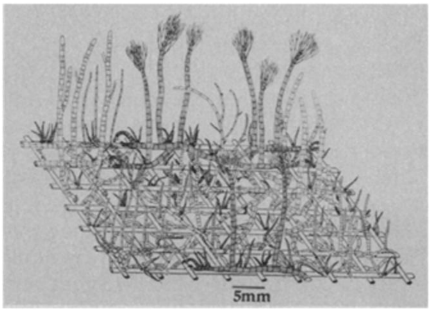
Surprising findings, as well as verification of ocean observations, have come from the reef work. Brawley, for example, has discovered in the tanks a type of green algae that she believes will be important to botanists. The alga, called *Pilinia,* falls in a new family and perhaps new order of plant. Individual cells adhere to each other in a line, and at the boundaries between cells are microscopic structures whose function is still unknown. The structure, called a septal plug or pit connection, had been observed previously in red algae and fungi, but never before in green algae.

The presence of septal plugs is one of the lines of evidence supporting the hypothesis that fungi evolved from red algae. The septal plugs in green algae undermine that argument. Brawley suggests that the newly discovered green algae, only occasionally found in the wild, is one of the first inhabitants of surfaces recently scoured of living things, and she suspects the algae will be in evidence in samples collected soon after the recent destructive hurricane in Jamaica.

Manipulation of the conditions of reef life offers scientists a chance to do experiments. In the system at the Smithsonian, they can run experiments in separate compartments connected by the circulating water to the main reef. For instance, Brawley is studying the role of predators and grazers on algal community structures, picking up at last the topic that launched Adey on the reef modeling project six years ago.

When an empty tank is added to the reef circulation, a wide variety of algae begin to grow. Filamentous species dominate, and only tiny specimens are present of the coarse algae called hypnea. (Hypnea is a commercial source of emulsifiers and of the gelling agent agar.) After four weeks, small crustacea migrate into the tank and begin to graze on the seven species of filamentous algae. When the crustacean population reaches about one animal per centimeter of tank surface, the filamen-

Energy Lawn of the Sea



Algae growing on a plastic mesh are the basis of a new "ocean farming" approach to biomass for energy.

Candy Feller, Smithsonian

The fuzzy turf of blue-green, green, brown and red algae that grows on the surfaces of coral reefs may solve a lot of problems. For the scientists setting up the living coral community at the Smithsonian Institution, this extra algal lawn was the answer to the problem of chemical imbalances. It may also provide a form of pollution control for all aquaria and even a method of treating municipal waste. In addition, says Walter H. Adey, the project's chief scientist, these fast-growing algae may eventually play a major role in the production of biomass for energy use.

Reefs are easy marine systems to maintain, except when you turn off the lights, Adey explains. During the day the plants and animals provide a balance of gas and nutrient production and use. In the dark, which is necessary for maintaining a living community, the animals continue to breathe and excrete wastes, but the plants cease photosynthesis. The result is that oxygen levels in the water fall, carbon dioxide, ammonia and nutrient levels rise and the water becomes more acid. In nature such problems don't arise because the surrounding ocean acts as a buffer, providing an unending exchange of water.

"Our first thought was to connect two reefs with alternating light-dark cycles," Adey recounts. Then the investigators realized they didn't need animals in the second reef; they didn't need anything except filamentous algae, the most productive plants of the reef.

Adey designed a scrubber, a shallowly submerged horizontal plastic screen that is washed with waves of water in circulation with the main coral reef tank. The scrubbers receive light during the night, when the main tank is dark. Algal turfs quickly appear on the mesh from spores in the circulating sea water, and filamentous tropical algae weave horizontal runners through the mesh, extending upright filaments into the shallow water. The algae take up carbon dioxide, ammonia and nutrients and release oxygen. With these scrubbers in place, the coral reef tank requires no traditional filters or aeration devices. Researcher Susan Brawley says, "It's amazing what a little algae will do."

Every few days the scientists scrape the screen of the scrubber to prevent animal grazers from taking up residence and to keep the algae in their "pioneer," and most productive, state. Because the plant bases remain in the screen, the algae grow back rapidly. And the scientists were surprised to find that they could harvest more than 5 grams of algae (dry weight) per square meter of screen per day. Now with increased light levels, that rate is more than doubled. The reef algae appear to have evolved a special capacity for rapid regrowth in response to constant grazing by fish and other undersea animals.

The laboratory has applied for a patent on the scrubber. Because it can produce massive harvestable quantities of algae, Adey predicts it will allow growth of large amounts of algae in the low-nutrient environment of the open sea. Fertilizer will not be necessary because the blue-green algae convert nitrogen from the atmosphere into its biologically useful form. If practical large-scale harvesting methods were developed, the algae could be taken ashore to be converted into alcohol or methane fuel. Floating platforms or plastic strips for algal turf production could be scattered across millions of miles of now unused and unproductive ocean without any polluting effects, Adey says. He concludes, "It is time to take our discovery back to the open ocean."

tous algae disappear. Hypnea flourish in the resultant open space. This finding might be of use commercially; Brawley estimates that mariculture of hypnea can be sped up 300 percent by addition of amphipod crustacea.

In the experimental tank, a single predator of the grazing crustaceans can turn the tables back again. Brawley adds a wrasse fish to the tank, and the filamentous algae reestablish their dominance. Thus, grazers and their predators are crucial determinants of the algal community.

Biogeography is an important discipline that the reef may bolster as an experimental science. It is concerned with what happens when species normally separated by geographic boundaries intermingle. One application of biogeography is prediction of potential problems arising from species migration and interaction in a proposed Central American sea-level canal.

Photos: Patricia Adey

Adey examines specimens underwater and aboard aquarium-equipped research ship.

The exhibit tank provides an example of mid-Atlantic shore microorganisms versus those of the Caribbean. When the exhibit was first put together, the reef tank was filled with water collected from the beaches of Virginia, complete with that area's natural summer algal and protozoan community. The reef material was replete with tropical algal and protozoan life. The scientists are monitoring the microorganisms in the tank to observe how the temperate and tropical populations fare. So far, tropical organisms seem better suited for survival than do their temperate cousins. For example, tropical diatom algae are long with pointed ends and have so much drag in the water that they often break away from predatory protozoa. In contrast, the temperate diatom is wedge-shaped and easier for the predator to engulf. Brawley suspects that the tropical organisms have adapted to withstand higher predation pressure.

When tropical seagrass beds are disturbed, they are slow to recover. Another project in the Smithsonian exhibit reef system, this one in the lagoon tank, is examining some of the factors involved. The bottom of the tank was divided into sections to determine whether colonization by siphonaceous algae is a prerequisite for growth of the lagoon grasses.

Everything that goes into the tank system and everything that comes out is carefully weighed and recorded. The accounting includes all new members put into the community and the small daily supplement of live brine shrimp and dried krill that is added to simulate food (used by filter feeding animals) provided to a natural reef from the open sea.

The scientists occasionally have to remove from the tank animals that have grown too large for the microcosm. "In that way we act as higher level predators," Brawley says. Some lobsters and crabs grow so rapidly that the physical damage they cause requires that they be taken out before they are a year old. The input-output data collected will provide fodder for the computer programs of theoretical biologists, who in the past have been short of reliable data on complex biological communities.

The scientific functioning of the new exhibit will be on display, as well as the coral reef plants and animals. Through windows along the side of the exhibit area, visitors will be able to observe scientists working in a well-equipped and conspicuously labeled laboratory.

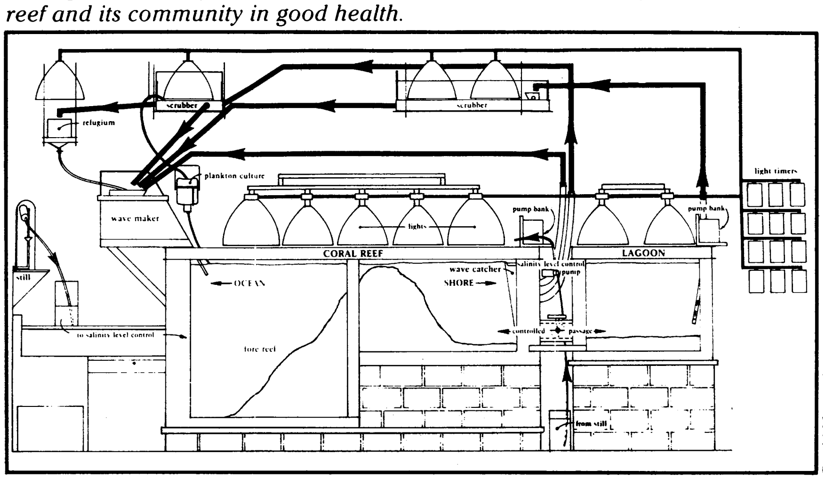
The new techniques for ocean modeling are not limited to the tropical reef. In the basement of the Smithsonian, Adey and colleagues already have a model of a Maine coast community. It is a cold water system with tides, seasonal temperature changes, kelp, rockweed, limpets and starfish. Adey hopes to have the Maine coast community on exhibit as a companion to the tropical reef in a year. Then the next project will be a model of the U.S. northern Pacific coast.

For now, the coral reef alone will have to convey to the public the striking beauty of an underwater community and the complexity of its interrelationships. As the exhibit signs state, the coral reef is an exceptionally productive oasis in a desert of the nutrient-impoverished tropical ocean.

To the scientists, the coral reef significantly improves prospects for experimental marine ecology. Marine biologists have been hampered by inconvenience, discomfort, frustration, expense and danger in performing experiments in the field. Adey says that every worker experiences the urge to take an entire biological community back to the laboratory to grapple with it in more controllable circumstances. By constructing a microcosm with much of the complexity and function of the natural coral reef and its lagoon, Adey has come close to that goal. He views his achievement basically as "evening the odds for field researchers." □

Chip Clark

Wave generator, high-intensity lights and battery of monitoring equipment keep reef and its community in good health.



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