Coral Culture: an Alternative to Coral Reef Harvests

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Introduction

The marine aquarium industry has greatly expanded during the past decade. New filtration and full spectrum lighting technologies have encouraged the growth of mini-reef aquariums. Unlike conventional "fish bowls," reef aquariums consist of a coexisting balance of marine life, including live coral. Besides opening a colorful porthole to the living inhabitants of the deep, the reef aquarium can be used as an educational tool. Not only does it animate an otherwise "dried" collection of shells and coral skeletons, these micro-habitats help to illustrate how a functional marine community operates.

The major drawback to reef aquariums is that most of the animals are captured from the wild. Live coral, a major constituent of reef aquariums, are commonly hammered out of the reef bed. Many of these reefs are already injured from pollution or excessive tourism. Harvesting restrictions are becoming increasingly strict, but poaching is not an uncommon practice. An additional tragedy is that many of the specimens die from transport stress or placement in an unsuitable aquarium (Baquero, 1991).

The reef aquarium is excellent for hobbyists and educators, but its future rests in self-perpetuation. Currently, several commercially-raised species are available to the aquarist such as the Tridacnid giant clams (Heslinga et al., 1990) and clown fish (Juhl, 1992). Most aquarists do not have the resources to dedicate exclusively to propagating fish or other organisms. Fortunately, most mini-reef aquariums with optimal lighting and water quality are capable of coral propagation. Not only is the ability to culture corals a means to guarantee the coral trade's future, it also indicates a healthy marine system.

The mini-reef aquarium

The two most important factors to successful coral propagation are excellent water quality and high-intensity full spectrum lighting. To achieve the former, the pH is maintained at 8.2 and the specific gravity is 1.022-1.023 in my aquarium. A moderate to strong current must circulate the water. The salt water is made by mixing reef-grade salt with either reverse osmosis water or distilled water (providing the pipes are not copper or some other metal). Coral cultivation can be achieved in any size aquarium. Although my aquarium contains only 29 gallons of water, with an extra 10 gallons in the sump and filtration unit, larger aquariums provide greater chemical and thermal stability. Four-gallon (10%) water-changes are conducted weekly. I use kalkwasser as a calcium supplement for the coral, mollusks, and tube worms. I have experimented with adding other trace elements in the past, but found routine water-changes are the best means of maintaining adequate levels of elements. Furthermore, potential problems with invertebrate health could arise if the aquarist substitutes trace element supplements for water changes, overestimates that mineral addition, and the elements accumulate in the tank. The invertebrates are fed a small portion of liquid food weekly. In an attempt to minimize the pollution resulting from this feeding, I recently began experimenting with raising algae suspended in the water as food. The algae is in a separate container and kept with *Artemia* sp. (brine shrimp).

The main filtration sources are a homemade protein skimmer and wet/dry or trickle filter bed. [The benefit of custom designing such items, apart from the saved expenses, is the aquarist can build the units to the aquarium's specifications while incorporating his/her own ideas to maximize the device's efficiency. Care must be applied when selecting materials for a system; use only inert substances such as glass, acrylic plastic, PVC, epoxy, and silicone sealant.] Protein skimmers function by pumping fine air bubbles through a cylindrical vessel. Dissolved organic molecules having hydrophobic properties, such as lipids and many proteins, congregate at the air/water interface. They are removed as surface bubbles accumulate and the foam product spills into a collection cup. Ozone is commonly substituted for air to oxidize waste products, destroy disease-promoting microbes, and stunt microalgae growth, but I find ozone unnecessary to maintain a healthy system.

The wet/dry unit is a biological filter. The water is distributed on a drip plate and trickles down the filtration media on which beneficial bacteria flourish and metabolize the water's nitrogenous waste (primarily ammonia and nitrites). This purifier is superior to the older undergravel biological filters in that more surface area is available for the benevolent bacteria on the wet/dry media. These aerobic microbes receive more oxygen in the wet/dry unit because they are not submerged underwater and thus metabolism occurs more efficiently. The bacteria metabolizing nitrates require low oxygen environments. Generally, they reside in the porous rock in the aquarium, but coarse filtration sponges in a low-flow sump region also provides an ideal habitat.

This filtration system can be supplemented with activated carbon, resins to expedite nitrate removal, and crushed coral to buffer the pH. Phosphates do not harm aquarium animals, but phosphate-removing resins are becoming increasingly popular to control algae growth in lieu of ozone. The remedy I prefer is herbivorous fish and invertebrates. To control macroalgae, I have a *Lo vulpinus* (foxface). Microalgae is kept in check with *Astraea* sp. (turbo snails) and a *Ctenochaetus strigosus* (Kole or yellow-eyed tang), both of which clean the rocks and scrape the glass. Although individual fish temperaments may vary, I have not had a problem with these animals eating coral polyps.

A high-intensity, full spectrum light source is the second essential factor to successful coral propagation. For many years, sunlight was thought to be the single most important factor to coral growth. The zooxanthellae are dinoflagellate algae which photosynthesize sunlight into chemical energy within the tissues of hermatypic (reef-building) coral, sea anemones, and other types of cnidarians. Although the exact mechanism is unclear, previous calcium and carbon radioactive isotope tests revealed that the algae's apparent influence on coral calcification is linked to some of the algal photosynthate produced (Pearse and Muscatine, 1971). Other hypotheses propose the algae's removal of carbon dioxide from the water encourages calcium carbonate precipitation. Another speculation suggests phosphate absorbed by the zooxanthellae improves the calcium carbonate crystal structure. More recent evidence suggests the animals' physiology is responsible for coral growth along the newly-formed tips, but the algal products from the older branch regions drive the system (Fang et al., 1989). The zooxanthellae may at least partially satisfy the animals' oxygen demand. In return, research on corals (Falkowski et al., 1984) and tropical sea anemones (Steen, 1986) have revealed heterotrophic behavior in the zooxanthellae suggesting the algae may consume animal-derived nutrients from their host, especially under suboptimum lighting conditions. Remembering that algae do require some essential compounds for growth and metabolism, these results might not be surprising considering the algal cells are completely enclosed within the animal tissues. The Falkowski study (1984) also demonstrated that the coral examined (*Stylophora pistillata*) used more than 90% of the carbon fixed by the dinoflagellates, despite the light intensity.

The most recent investigation indicates corals calcify about the same in reef-building members (such as *Galaxea fascicularis*), given the appropriate light conditions, as in species lacking zooxanthellae, such as the ahermatypic *Tubastrea faulkneri* (Marshall, 1996). This study also suggests calcium uptake is restricted in the dark by *Galaxea*'s algae instead of accelerated by light. This new theory, which assumes zooxanthellae a regulatory role in calcification instead of actively working in the process, does twist conventional beliefs. Marshall believes multiple mechanisms, yet to be described, are at play in the two coral varieties. Algae-regulated calcification, as opposed to an algae-boosted process, could explain the more rapid growth on the lightened tips of coral where zooxanthellae are not prevalent.

With the importance of lighting for corals established, the aquarium market is deluged with range of techniques to illuminate reef aquariums. To some extent, the lighting selected should relate to the coral species grown. For example, I currently work exclusively with soft corals, mushroom polyps, and sea anemones with moderate light requirements. After much experimentation with full-spectrum fluorescent and metal halide light bulbs, the invertebrates in my aquarium responded best to two Phillips 03 actinic and two CoralLife 50/50 (50% full spectrum, 50% actinic) fluorescent light bulbs. The actinic lighting's deep blue is at a wavelength which is highly important to zooxanthellae photosynthesis. During the first and last half hour of each day, only the actinic lights are used. Direct natural sunlight from a nearby window also irradiates the aquarium for several hours. Above the bulbs is an aluminum reflector; beneath them is an ultraviolet-blocking sheet of acrylic which also protects the bulbs from the aquarium's salt spray. I encourage seasonal cycles in the aquarium by increasing the photoperiod from 12 hours of light in the winter to 14 hours throughout the summer. The water temperature increases from 26°C in the winter to 29°C during the summer.

Coral propagation

Coral culture should only be performed in a healthy, established aquarium with the mentioned water quality and lighting specifications. Ammonia and nitrite levels must be undetectable and nitrates should be below 10 mg/L. No filament or "hair" algae should be present, which thrive in nutrient-rich environments. Full-spectrum lighting assists growth of the cutting and healing of the parent. The actual excision process is a stressful procedure and, if the aquarium conditions are less than optimal, both cutting and parental colony could die. Under good conditions, the success of the culture may be realized as early as several weeks.

The common method of propagating leather corals and tree corals is by trimming a piece from a healthy parental colony (Paletta, 1992). Use a sharp, new razor blade to trim a protrusion or edge off the colony. This piece should be minimally an inch in length. Usually, the larger cuttings have a greater chance of survival. The cutting is either wedged between some rocks, placed in a hole previously drilled into the rock with carbide bits, or set on a surface and gently strapped in place with fishing line (rubber bands deteriorate in water). If I plan to trade the piece, I set the cutting on a large shell or small rock and keep it confined a clear, hole-drilled plastic container in my aquarium.

Employing this technique, I have had the greatest amount of success with *Lobophytum crassum* (pink lettuce coral). Whether the piece is removed from an edge or the base, the specimen usually develops into a colony. In the latter case, polyps begin to develop several weeks after the initial cutting. Edge pieces smaller than a dime have matured into colonies. The risky technique of slicing directly down the parental coral's center (Paletta, 1992) has always worked on this species. If the coral is permitted to grow undisturbed, it will eventually divide itself in half. Other genera for which I have successfully used the excision method, though more sensitive than *Lobophytum*, include *Sinularias* (leather corals), *Cladiella* (colt coral), and the fragile *Lemnalia* (tree coral, similar to *Dendronepthya*). *Lemnalia* also self-propagates by forming large branches at its base. These stalks can be gently removed from the foundation and transplanted.

Some coral species equally capable of aquarium culture have sizable, distinct polyps growing in mats. With genera such as *Xenia* (including pulse coral) and *Clavularia* (star polyps), transfer a section or a portion of the mat with a razor blade onto the desired surface. Care must be taken not to injure the polyps. The mats attach most readily if they are gently wrapped with fishing line. If only several polyps are transferred, they may be wedged into a rock crevice. In less than a year, I have had an entire rock covered with a *Xenia* colony stemming from a single parental polyp!

Colonial anemones and mushroom anemones can be cultured under the same aquarium conditions as said for corals. My past experience with raising *Parazoanthus gracilis* (yellow colonial polyps) and various species of *Rhodactis* and *Actinodiscus* (mushroom polyps) has been phenomenal. The *Parazoanthus* can usually be transplanted into small crevices. A successful (though primitive) means of attaching mushroom cnidarians is by placing the anemone in a clam shell or rock's shallow concavity and carefully setting a second light, smooth rock over the polyp. Within 24-48 hours, the mushroom anemone is sufficiently attached to the substrate such that the rock may be removed. After several more days, the polyp will be completely attached. This procedure should be used cautiously because both light and water circulation are greatly reduced. Ironically, I have not had as much success when clear plastic or glass sheets substituted the second rock.

Unlike coral cultivation, removing sections from colonial sea anemones either does not produce an animal or the parental organism dies. Under optimal tank conditions, these animals will reproduce via budding. Once a carpet becomes dense, individual polyps may be thinned and placed on a new substrate. Some of the moderately sized sea anemones, such as *Bartholomea annulata* (curlicue anemones) are able to be propagated by cutting basal segments. However, the best way to grow most sea anemones is weekly or bi-weekly feedings of krill or squid. Eventually, the animals become large and split themselves. Caution should be used if the food is purchased from a seafood store: the invertebrates may have a malaise reaction if the meats are laced with preservatives. Another consideration is the sea anemone feedings will result in more wastes polluting the water.

The aquarist must remember that, unlike coral, sea anemones are mobile. I have had one incident where several different anemone species wandered near each other. Despite the fact they never touched, they detected the other species and began releasing their nematocysts. Not only did the sting injure the conflicting anemones, it also temporarily injured corals around the battlefield.

If an aquarist is to work with stony corals or keep Tridacnid clams, very high output (VHO) florescent bulbs or daylight metal halide bulbs (at least 5,000° Kelvin) should be selected. With this lighting, the tank is illuminated for 12 hours per day, with all the bulbs lit for 8-10 hours (Thiel, 1989). The conventional florescent lighting will not emit an ample supply of light. Strontium and iodine, in addition to kalkwasser, should supplement the aquarium (Cook, 1995). My aquarium is currently established to raise soft corals, but I have experimented with calcareous species. The *Porites* specimen was growing fantastically along with its accompanying *Spirobranchus* sp. (Christmas tree worms). I documented its growth on a monthly basis, regardless that the genus grows slowly. Unfortunately, I had to remove this piece because it had a hidden, unidentified species of nocturnal polychaete drilling through the coral and devouring both polyps and ornamental worms. Theoretically, cultured corals from pure stocks will not contain such devastating parasites. Other stony species an aquarist could consider include *Acropora* (a genus containing some of the fastest growing reef-building corals), *Pocillopora*, and *Favites*. Sprigs from these corals may be broken and transplanted in the aquarium. *Tubastrea faulkneri* is a resilient calcifying coral and, due to its absence of zooxanthellae, does not require strong lighting. Many aquarists have trouble keeping this species because each polyp must be individually fed a piece of shrimp on a weekly basis. I have not heard of successful, artificial separations occurring in hard corals having larger polyps, such as *Catalaphyllia jardinei* (elegance coral).

Future prospects for coral culture

Aside from the described asexual means of reproduction, corals have been made to sexually propagate in the hobbyists' aquarium (Cook, 1995). Depending on the species, the latter is usually more difficult to achieve: the seasonal cycles should be more amplified than what I discussed; lunar phases should be included; and, much of the gametes/planktonic larvae are sucked into the filtration system before they can be collected or settle onto the substrate.

Large-scale greenhouse coral propagation has been accomplished in Detroit, Michigan (Perrin, 1993). A wide diversity of marine invertebrates is cultivated within this facility. Thousands of gallons are used in conjunction with direct sunlight allowing more natural conditions than in home aquariums. Under these conditions, the vats do have an undergravel system, but promoting/harvesting macroalgae (which absorb dissolved wastes) and massive aeration maintain a healthy habitat. The water is subsidized with trace elements. Only several livestock distributors have recently started selling exclusively captive-bred invertebrates, but this trend is building momentum.

Not only would full scale greenhouse cultivation be able to supply the aquarium industry, environmental applications could stem from this program. Conservatory research conducted by Guzmán (1991), which was directed toward human-inflicted reef damage, suggested transplanting various coral species onto a destroyed reef framework. The test colonies grew and proliferated thereby accelerating the natural recolonization processes. Unfortunately, the transplanted colonies were chipped from an existing reef system; injury occurs to one coral outcrop to help rebuild a second reef. A cross between this greenhouse and Guzmán's restoration program would permit coral reseeding without damaging an existing reef. To prevent an intrusion of exotic species, such a cultivation/restoration program must exclusively consist of indigenous organisms to a given region.

The marine aquarium's future is filled with change. Not only are new technological advances in lighting, filtration, and maintenance bound to surface, the animals highlighting the mini-reef will emerge from an artificial environment. The survival of this intriguing industry relies on its self-perpetuating ability. Perhaps, in the near future, the day will come when aquarists will repay injured reefs with cultivated corals.

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