SOUTHERN REGIONAL AQUACULTURE CENTER

SRAC Publication No. 7214
September 2020

Species Profile: Stony Corals

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Stony corals form the foundation of the tropical reef ecosystems that are a vital part of the world's oceans. These corals are popular because of their striking beauty, the reefs they create, and the animals and plants that live around them.

Aquaculture is increasingly being used to restore wild populations and to produce corals for sale to hobby and public aquariums. In U.S. aquaculture, the types and geographic origins of corals used for these two purposes vary greatly (Table 1):

- **Restoration** coral culture uses species native to the western Atlantic. It occurs primarily in ocean-based nurseries. In the Southern Region, coral culture for restoration is limited to areas with shallow-water coral reef ecosystems—Florida, the U.S. Virgin Islands, and Puerto Rico.
- **Ornamental trade** coral culture generally uses species native to the Indian Ocean and western and central Pacific Ocean, collectively known as the Indo-Pacific. Coral culture for ornamental markets occurs in land-based systems throughout the Southern Region.

Legal issues for restoration and ornamental coral also differ. Most species grown for restoration are listed under the U.S. Endangered Species Act. They cannot be legally bought or sold. The import and export of stony corals are subject to the Convention on International Trade in Endangered Species of Wild Fauna and Flora, commonly called CITES.

Coral aquaculture can bolster conservation efforts for U.S. coral reefs as well as contribute to the sustainability of the marine aquarium hobby.

Table 1. Differences in coral aquaculture for restoration and ornamental trade purposes

	Purpose	
Factor	**Restoration**	**Ornamental trade**
Species origin	Western Atlantic Ocean	Indian Ocean and western and central Pacific Ocean
Propagation site	Ocean-based nurseries	Land-based systems
Southern Region operations	Florida, Puerto Rico, and the U.S. Virgin Islands	Throughout the Southern Region
Regulations	U.S. Endangered Species Act	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)

Taxonomy and description

Stony corals share the phylum Cnidaria with sea anemones, jellyfish, and other aquatic animals that have specialized stinging cells. Within Cnidaria, they belong to the order Scleractinia, which comprises marine animals that are permanently attached (*sessile*) and form hard skeletons of calcium carbonate.

A coral reef is a structure made of millions of tiny animals called *polyps*. Polyps range in diameter from about 1/10 inch (3 mm) to more than 2/5 inch (1 cm).

A coral colony consists of hundreds to thousands of polyps that are genetically identical. Although many coral species form colonies, some stony corals exist as large individual polyps.

Stony coral colonies have a wide range of forms and structures, or *morphologies*. These morphologies include branching, columnar, encrusting, leaflike (*foliaceous*), massive (such as boulder or brain), platy, and solitary forms. Within a species, the colony morphology can vary according to light availability and water movement.

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Colony morphology also affects the growth rates of the different types of coral. Branching species such as staghorn coral (*Acropora cervicornis*) can grow more than 6 inches (15 cm) per branch per year. Massive corals such as grooved brain coral (*Diploria labyrinthisformis*) commonly grow only ⅖ to ⅘ inch (1 to 2 cm) in diameter per year (Fig. 1).

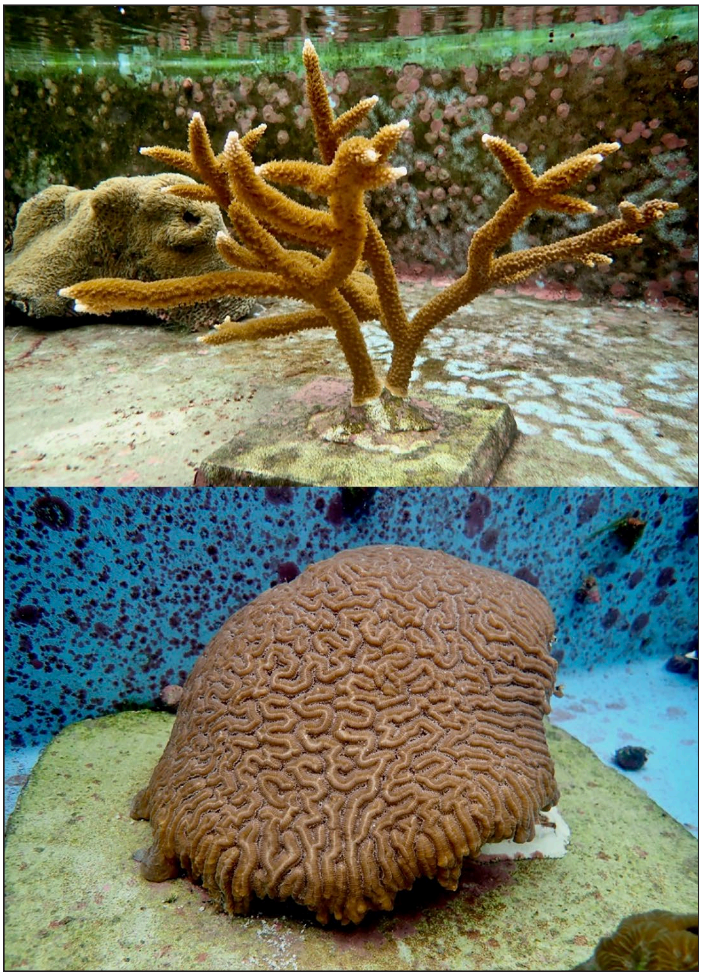

Figure 1. From top: Branching staghorn coral (*Acropora cervicornis*), and massive grooved brain coral (*Diploria labyrinthiformis*) colony morphologies growing at The Florida Aquarium Center for Conservation (Apollo Beach, FL). *Photo courtesy of Joseph Henry.*

Natural history

Range

Stony corals that build complex reef structures can thrive only in relatively shallow tropical seas. They must have clear, low-nutrient water and enough hardbottom for attachment. These ecological requirements limit coral reefs to a total area of less than one percent of the ocean floor.

Geographically, stony corals can be broadly grouped into Indo-Pacific species and Caribbean-Atlantic species, which live in the Caribbean Sea and Atlantic Ocean.

Each of these two large areas contains many ecoregions—distinct regions that share most of their species and have similar environmental conditions. The types of coral species vary among ecoregions, and individual species do not occur in both the Indo-Pacific and Caribbean-Atlantic.

The part of the world with the most coral species is an area of the western Pacific Ocean known as the Coral Triangle. The Coral Triangle includes parts of Indonesia, Malaysia, and the Philippines. Many corals cultured for the ornamental trade originated in this area. The Indo-Pacific region contains more than 700 species, far more than does the Caribbean-Atlantic, which has fewer than 100 species.

Life history

Corals can reproduce both sexually and asexually. An asexual method of reproduction is *fragmentation*.

Fragmentation occurs when part of the parent colony is broken off and forms a new colony. The new colony, called a *ramet,* is genetically identical to the parent colony.

Fragmentation is an effective way to colonize an area quickly. It can create many relatively large fragments that can attach to the bottom or to other corals and grow into new adult colonies. In fact, passing storms have expanded coral populations by fragmenting parent colonies and dispersing the fragments into the surrounding habitat.

Coral species can be hermaphroditic (one colony produces both male and female reproductive cells, or *gametes*) or gonochoric (separate colonies produce male or female gametes).

Further, coral species can be classified into two categories, brooders and broadcasters, based on their mode of sexual reproduction:

- **Brooding corals,** such as mustard hill coral (*Porites astreoides*), produce gametes that are fertilized inside the polyp.
- **Broadcasting species,** such as elkhorn coral (*Acropora palmata*), release their gametes into the water column in mass spawning events, and fertilization occurs there. Many broadcasting corals release huge numbers of eggs and sperm to distribute their offspring over a wide area.

In the Caribbean, brooding species spawn several times between late spring and summer. Broadcasting species release their gametes only once or twice per year in the summer. The timing of these reproductive events is based on temperature and lunar cycles.

The fertilized eggs form planulae, which are mobile larvae that can settle shortly after they are released. The planulae swim freely for a few days or weeks and seek a suitable area for settlement. Once attached, they metamorphose into coral polyps that grow into colonies.

The process by which the larvae settle and become part of the adult population is called *recruitment*. It can take months for a sexual recruit to grow into a thumbnail-sized colony. During this period, the coral is vulnerable to predators, damage by physical disturbance, or competition from other organisms on the reef.

Sexual reproduction is vital because it adds new genetic diversity to a population. The new genetic diversity provides added traits that can enable corals to adapt in different ways to environmental conditions.

Symbiosis

Stony corals live in a symbiotic relationship with microalgae. The coral is the host and the alga (commonly termed *zooxanthella*) is the symbiont. Zooxanthellae are critical to the success of the stony corals that build large, complex structures in shallow seas with very low nutrient content. These microalgae share the products of photosynthesis like sugars and lipids with their coral host, providing more than 90% of the nutrition needed by the coral. Corals can also feed on microorganisms like zooplankton and organic particles to supplement their diet, especially in times of thermal stress.

The diverse array of colors seen on the reef or in a marine aquarium are created by the zooxanthellae living within coral tissues and the animal pigments of the host. When under stress, corals expel their zooxanthellae, and the animal pigments break down. Without the zooxanthellae or animal pigments, the white skeleton of the coral becomes visible. This process is called *bleaching.*

Although bleached corals are not necessarily dead, prolonged bleaching can cause the death of many corals, as seen in the 2005 and 2015 mass bleaching events in the Caribbean.

Culture techniques

Propagation systems

Coral production systems can be broadly classified as either ocean-based (*in situ*) or land-based (*ex situ*). Systems producing corals for restoration are often referred to as *nurseries.*

***In situ* nurseries:** Most corals for placing back onto the reef (*outplanting*) are produced in *in situ* nurseries. These nurseries are usually created in areas that:

- Are less than 30 feet (9.1 m) deep
- Receive plenty of light
- Have good circulation
- Maintain a consistent seawater salinity of 35 to 36 parts per thousand (g/L)
- Range in temperature from 75 to 86°F (about 24 to 30°C). Higher and lower temperatures can lead to coral stress and mortality.
- Have a sandy bottom to enable the propagation structure, or platform, to be anchored easily. The platforms are made of a variety of materials, including PVC trees, cinder blocks, and rebar tables (Fig. 2).

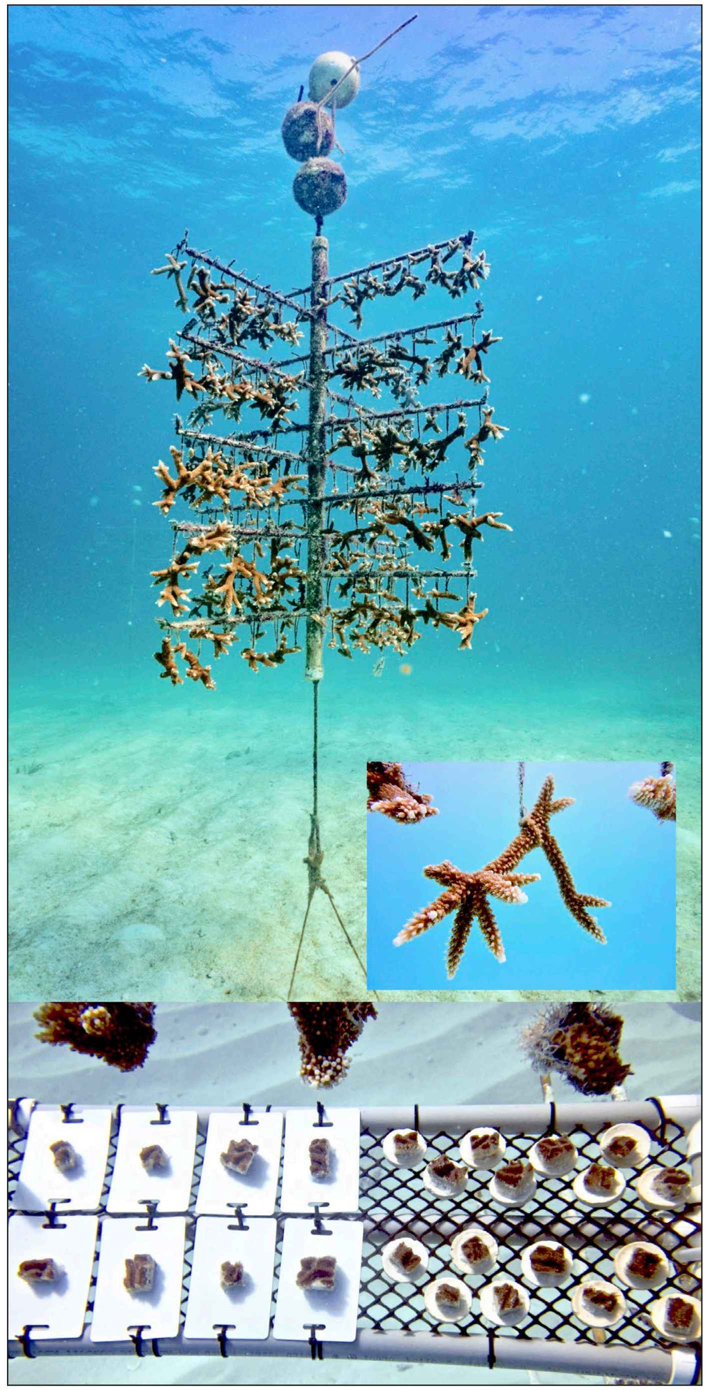

Figure 2. From top: PVC tree growing staghorn coral fragments (*Acropora cervicornis*), and a coral paddle designed to grow massive corals (*Pseudodiploria clivosa*). Both structures located at the University of Miami's coral nursery (Miami-Dade County, FL). *Photos courtesy of Diego Lirman and Dalton Hesley.*

- Are near natural reefs that provide a source of fish to help keep the platform free of competing macroalgae

In each underwater nursery, the corals are tracked by their genetic identity (*genotype*) and are fragmented, allowed to grow, and the process repeated many times to build up restoration stocks.

***Ex situ* nurseries:** *Ex situ* nurseries for coral restoration have primarily been used for sexual coral reproduction or to hold corals that would be susceptible to death by disease in the natural environment.

Ex situ nurseries are increasingly being used to produce corals using a new technique known as *microfragmentation.* Microfragmentation involves cutting the corals into tiny pieces, which are grown and then outplanted. Propagation programs have previously focused on branching coral. However, the microfragmentation technique has also allowed corals with massive morphologies to be propagated quickly.

In the United States, only Florida and Hawaii have *ex situ* facilities growing corals for restoration. Several university labs and aquaria propagate and house corals for research, for public displays, or for species conservation.

Because stony corals need light for growth, *ex situ* systems can be broadly classified as indoor (artificial light) and greenhouse or outdoor (natural light).

Indoor and greenhouse systems (Fig. 3) are used to propagate Indo-Pacific species for the ornamental trade. To prevent the spread of non-native species, these systems do not discharge into the marine environment.

Flow-through systems are an option for culturing native coral species for restoration when high-quality natural seawater is readily available. If a system uses saline groundwater or artificial seawater, it needs some level of recirculation with limited water exchange.

For more information about recirculating systems, please see SRAC Publication No. 0451 *Recirculating Aquaculture Tank Production Systems: An Overview of Critical Considerations.*

Indoor systems have traditionally used metal halide lights to provide the correct wavelengths needed for photosynthesis. However, light emitting diode (LED) technology is increasingly being used because it is more energy efficient.

Unless they have supplemental lighting, greenhouse systems are limited to lower latitudes where days do not become too short in winter and the sun remains higher above the horizon. Greenhouse systems employ shade cloth to manage air temperatures as well as to reduce the solar energy, or *irradiance,* on corals.

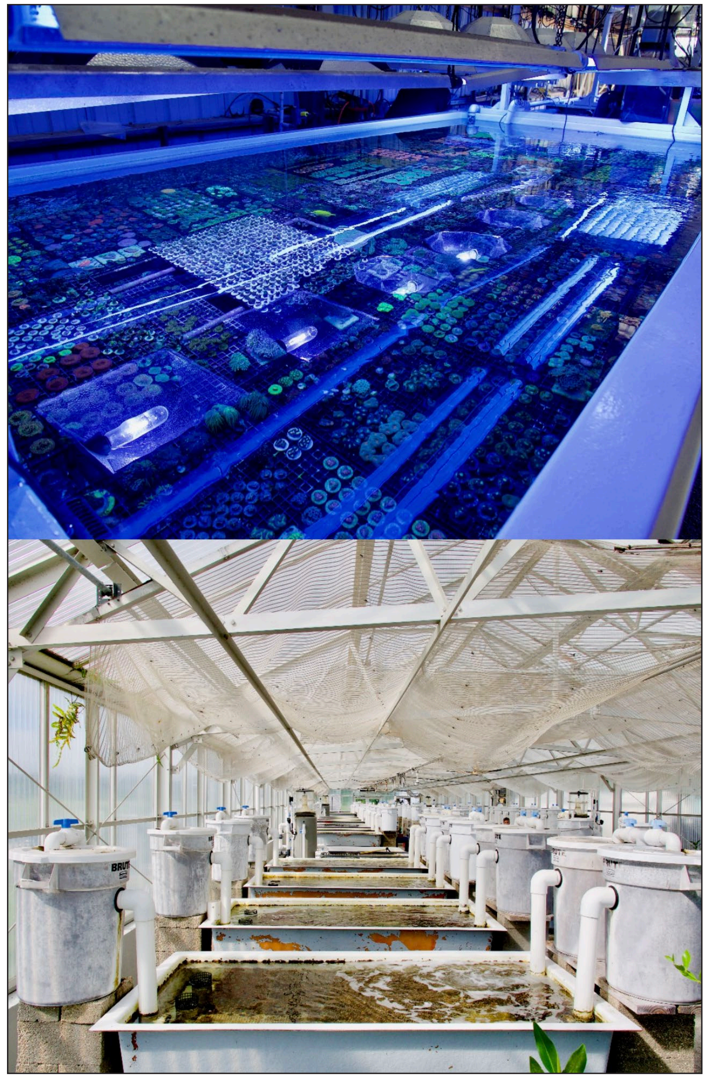

Figure 3. From top: Indoor system at ACI Aquaculture Inc. (Plant City, FL), and greenhouse systems at Oceans, Reefs & Aquariums LLC (ORA; Ft. Pierce, FL). *Photos courtesy of Joseph Henry.*

Because coral reefs are naturally high-turbulence environments, water flow is crucial in coral aquaculture. Water flow is needed to remove waste products and to deliver food, nutrients, and oxygen to the polyps. Options for increasing flow include gravity-driven surge headers and auxiliary pumps within culture tanks.

One of the most time-consuming tasks for coral growers is nursery maintenance. Corals in both *in situ* and *ex situ* nurseries can experience overgrowth and competition by fast-growing macroalgae and animals such as anemones, barnacles, bivalves, fire coral, and sponges. These competitors need to be removed regularly.

In the field, divers use plastic and wire brushes to remove algae and other competitors. Natural grazing by fish, snails, or urchins also helps reduce coral competition.

Broodstock and propagation

In aquaculture, the primary way to propagate coral has been through fragmentation. A large colony (*broodstock*) is cut into smaller pieces, which are stabilized for grow out.

A large piece of the broodstock colony can be left intact and allowed to regrow for a period before being fragmented again. Or, a subset of new colonies can be withheld from outplanting or sale and allowed to grow for the next round of fragmentation.

Pruning larger corals into smaller pieces has been shown to enhance coral productivity and provides the basis for the success of propagation programs.

In *in situ* nurseries, scuba divers commonly fragment coral using hand tools such as chisels, angle cutters, bone cutters, hammers, pliers, and saws. Underwater drills have also been used to core larger colonies to create fragments for propagation.

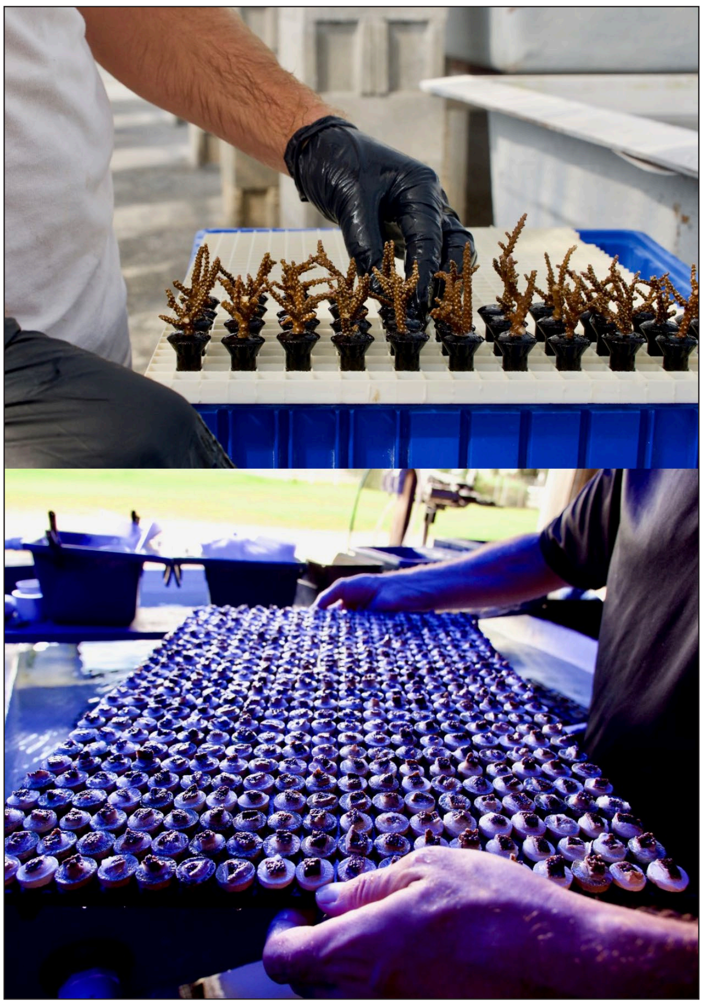

Figure 4. From top: Mounting new branching coral fragments in plastic plugs at Oceans, Reefs & Aquariums LLC (ORA; Ft. Pierce, FL), and a tray of small fragments on ceramic plugs at ACI Aquaculture Inc. (Plant City, FL). *Photos courtesy of Joseph Henry.*

The coral fragments are deployed onto different nursery platforms, where growth is tracked by individuals or by genotype. Fragments of branching species are attached to the platforms using monofilament and metal crimps. Those of massive corals are usually attached to plastic cards, ceramic plugs, or tiles using super glue or epoxy (Fig. 2).

Ex situ facilities use hand tools for propagation but can also use powered tile and band saws to make more precise cuts and to cut small colonies of massive species into two to three polyp fragments known as microfragments.

In ornamental culture, small fragments are generally attached to a ceramic tile or plastic plug for grow out (Fig. 4). They are glued to ceramic tiles. Some plugs are designed to wedge the coral in place without glue. The plugs and tiles are then placed in racks within the culture system.

Both methods offer a convenient way to move and manage many fragments. The attachment substrate is generally left in place for shipment to retailers or reef aquarium hobbyists.

It can take a year or more to establish a new line of ornamental corals from a broodstock colony.

Going to market demands that many small colonies be produced consistently, which requires significant initial investment from the producer. However, once established, a new line is biologically viable as long as it remains in demand and in some cases, producers have been fragmenting a line of corals for many years.

Sexual propagation

For restored populations, the only way to increase genetic diversity is via sexual propagation. The process involves several steps:

1. Growers collect sperm and eggs from corals spawning in the wild, in *in situ* nurseries, or, more recently, in *ex situ* systems.
2. Gametes from genetically distinct colonies are mixed to achieve fertilization.
3. When generated from wild or *in situ* nursery colonies, planula larvae are often transported to *ex situ* facilities.
4. The larvae settle onto biologically conditioned substrates such as ceramic tiles (Fig. 5).
5. The coral is allowed to grow for up to a year.
6. The coral can then be further propagated, transferred to *in situ* nurseries, or planted on reefs.

The ornamental trade relies almost exclusively on asexual fragmentation because it produces coral biomass faster and of a more consistent appearance, which is important in that market.

Figure 5. Four-month-old sexual coral recruits on biologically conditioned ceramic tiles growing at the Florida Aquarium Center for Conservation (Apollo Beach, FL). Each small recruit is a new genetically distinct individual that resulted from settlement and metamorphosis of a planula larva. *Photos courtesy of Joseph Henry.*

Diseases

Coral diseases remain poorly understood. However, all growers must manage diseases and parasites for the corals in their care.

Tissue loss diseases have killed many Caribbean-Atlantic branching corals in the wild and can appear in nurseries. Recently, stony coral tissue loss disease (SCTLD) has severely impacted a specific set of non-branching coral species in Florida and is moving into other areas of the Caribbean.

Restoration nursery managers must take steps to reduce disease outbreaks:

- At the first sign of disease, *in situ* coral restoration nurseries should create a quarantine area away from the main section of the nursery to place corals.
- An option for branching corals is to cut off and remove the diseased parts of the colony. The healthy parts can be left in quarantine areas to determine whether the removal stops the disease's progression.
- One disease treatment is to apply marine epoxy—with or without antibiotics or chemicals mixed in—directly to diseased corals. The approach has achieved varying levels of success.

Although having corals in *ex situ* facilities can make treatment easier, holding animals at high density can worsen the problem.

Ornamental corals can be particularly affected by parasites such as flatworms, nudibranchs, and copepods. Producers use a combination of treatment options:

- Quarantine systems
- Dips or baths for newly acquired corals. To remove parasites, the corals are exposed for brief periods to commercially available chemicals and freshwater.
- Regular therapeutic treatments

Economics and marketing

The economics for restoration and ornamental propagation differs greatly.

Restoration economics: Because native corals are protected and their commercial trade is largely prohibited, most organizations propagating corals for restoration in the United States are nonprofits, governmental agencies, or universities. These groups rely on government grants and contributions from foundations, corporations, and individuals to sustain their operations.

Although restoration organizations do employ full-time staff for nursery operations, they also rely on volunteer labor. Large *in situ* nurseries sometimes partner with snorkel and scuba charter tour companies and become destinations, much like the reefs they work to restore.

Ornamental trade economics: Information on ornamental coral production is difficult to obtain because it is lumped in with other types of aquaculture. The Florida Department of Agriculture and Consumer Services indicates that *ex situ* coral production is a growing segment of marine ornamental aquaculture.

Production practices also make it difficult to determine the true contribution of aquaculture. It can take a year or more to establish a cultured coral line that can sustain production indefinitely at a consistent level. However, some importers obtain large chunks of wild coral from the Indo-Pacific and fragment them into smaller pieces for immediate sale.

Corals cultured at significant scale are usually marketed wholesale to aquarium stores as well as directly to consumers, often through online retailers specializing in the aquarium hobby. Dozens of ornamental coral species and color varieties are available and are often identified with flamboyant names to distinguish them in the marketplace.

Prices differ among coral varieties and are driven by rarity and demand. High-volume cultured corals that are common in the trade might retail for $20 for a small colony. New, rare, or premium varieties can cost upwards of $200 per colony.

Buying cultured coral means that fewer colonies are collected from natural reefs. Further, recent export bans from some major foreign countries that supply ornamental corals have increased the importance of aquaculture in the industry. Because cultured products are more desirable than wild corals, many retailers distinguish these corals from their wild counterparts.

Conclusions

Stony coral aquaculture is an increasingly important tool for reef restoration and a growing segment of the marine ornamental industry. Although the restoration and ornamental realms are distinguished by their economic models and the geographic origin of their species, the basic biology of the animals in culture is identical, and both foster reef sustainability. Corals exist within relatively narrow environmental ranges and while asexual fragmentation has dominated coral aquaculture, technologies for sexual reproduction are developing rapidly and will be important for future restoration efforts.

Coral restoration science is in its infancy, and limited academic research has been dedicated to improving ornamental coral production practices. Further research in these areas should allow continued growth in all segments of coral aquaculture.

The world's reefs face an uncertain future with major challenges, and coral aquaculture can continue to play a positive role in sustaining and recovering reefs and economies.

Suggested reading

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This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2016-38500-25752. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

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USDA United States Department of Agriculture

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The work reported in this publication was supported in part by the Southern Regional Aquaculture Center through Grant No. 2016-38500-25752 from the United States Department of Agriculture, National Institute of Food and Agriculture.