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Coral-Algal Interactions in Coral Reef Recovery

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As anthropogenic stresses to fragile ecosystems increase, the steps required to restore, protect, and preserve these ecosystems deserve the utmost attention. Coral reefs are one of the most fragile ecosystems in need of consideration as 2/3 of worldwide reefs are already dying (NOAA 1999). Reefs commonly experience natural disturbances such as cyclones, waves, currents, tides and hurricanes. However, anthropogenic stresses are increasing degradation rates, especially when coupled with natural disturbance. Some of the stresses damaging reefs include sedimentation from forestry, agriculture, and mining; over-fishing both commercially and for subsistence; eutrophication and pollution; vessel groundings; and global climate change. Restoration efforts are becoming more common, as people are trying to alleviate the major decline in reef health and survival. The importance of the reef ecosystem is becoming more widely known as it provides food, medicine, tourism, building materials, as well as a host of other vital ecological services (South & Skelton 2000).

The survival of any coral reef depends primarily on the coral within that ecosystem due to its multiple functions. Survival is also dependent on the complex and intricate interactions that coral exhibit with the web of organisms that exist on coral reefs. The coral itself represents a unique relationship between a coral polyp and a symbiotic alga. In addition, coral compete with macroalgae for light, nutrients, and space. This paper will discuss specifically the interaction between coral and competing algae and the importance of the interaction in recovering and restoring reef ecosystems around the world.

The Reef Ecosystem

Hard corals are considered to be the most significant invertebrates found in shallow, tropical waters (Snyderman 1989). They provide refuge for fish, large vertebrates, and invertebrates. Coral serve as a primary food source for some herbivorous fish, as well as providing substrate for certain plant and algal species. In addition, coral reef communities protect shoreline from constant wave motion and damaging storms while serving as habitat for the primary food sources (multiple seafood species) for humans. Coral species can be classified as hard (reef-building) or soft. This paper will focus only on the interactions of the Scleractinia corals, or coral that develop hard limestone skeletons in association with algae (Meo 2003) (Figure 1).

Figure 1: Reef building hard coral colonies; Votua Reef, Fiji. (Photo: Kassy Theobald 2003)

These reef building corals form colonies that produce fringing reefs, barrier reefs, or atolls. Fringing reefs actively grow on the edges of land masses. Barrier reefs are found separated from shore by a lagoon with corals growing in the lagoon as well as on the reef structure. Atoll reefs are circular and form as an oceanic island sinks inside a fringing reef, which continues to grow upward as the island sinks (Meo 2003). Reef-building corals exist in water temperatures between 23 and 25 degrees Centigrade, mostly in water shallower than 30 meters. These reefs are primarily found in between the Tropic of Capricorn and the Tropic of Cancer (Cousteau, 1979). In addition, coral reefs require clean, shallow, tropical waters with a normal seawater salinity level and good light penetration (Snyderman, 1989).

As the most biologically productive of all natural communities, the entire reef community contains a myriad of unique organisms (Cousteau 1979). In addition to the six major categories of hard corals: branching, brain, platy, encrusting, mushroom, and star; one can find algae, sponges, echinoderms (starfish, sea cucumbers, sea urchins); octopi, and arthropods (shrimp, crabs, lobster, barnacles, and giant clams) in the reef structure (Figure 2).

Figure 2: Branching Staghorn coral; Fiji. (Photo: Kassy Theobald 2003)

Associated with reefs, vertebrates are extremely diverse, including eels, sharks, rays and skates; butterfly fish, groupers, triggerfish, barracuda, gobies, clownfish, sea snakes, and turtles. These creatures depend on reefs for food, protection, and hunting grounds (Snyderman 1989). The health of the coral itself is vital to the survival of each of these species.

Coral is actually considered an animal: a collection of soft-bodied polyps. Each polyp consists of a tube shaped body with a mouth that is surrounded by tentacles for feeding (Meo 2003). These polyps secrete limestone cups around their tiny bodies, which eventually establish the large, hard structures that become the visible reef structure. Hard coral colonies on average grow between 1-5 meters per 1000 years (Jaap 2000). Corals benefit from coralline red algae found on suitable substrates that aid in cementing coral to the substrate with calcium carbonate (limestone) compounds. Coral also exists in a symbiotic relationship with a microscopic alga called Zooxanthellae (Cousteau 1979). The symbiotic algae photosynthesizes, generating oxygen which they supply to the coral. Zooxanthellae are also responsible for the multiple colors found in all coral. Algae receive nutrients from coral wastes, as well as protection in return (Snyderman 1989).

In addition to the symbiotic microscopic algae, many competitive macroalgae also exist on the coral reefs. Fleshy brown algae, like *Sargassum* and *Turbinaria* can form large beds. These beds thrive on nutrient enriched areas and can completely shade out coral during some seasons. Green algae include organisms such as *Ulva* (sea lettuce) and *Valonia* (sea grapes). These algae can occur in a multitude of shapes and sizes (CRC 2003). Another algae, turf algae, are a commonly occurring species that typically precede coral recruitment in the line of reef succession (McClanahan 1997). Lastly, blue-green algae, also known as cyanobacteria, are common in reefs as a type of "slick." The cyanobacteria also cause the highly publicized "red tides" and blue-grey slime on reefs worldwide.

Disturbances

The natural disturbances of coral reefs alter community structure to restart the succession process. Disturbances such as cyclones, hurricanes, and strong waves, can detach and overturn hard coral, exposing new substrate. Bleaching, when naturally caused by shifts in warm water currents by La Nina and El Nino, can kill coral, also opening new substrate for colonization when cooler water temperatures return. Bleaching involves the expulsion of the symbiotic Zooxanthellae from the polyp due to a breakdown in a biosynthetic pathway between the polyp and algae. The expulsion is caused by warmer water temperatures, even two degrees Centigrade, which cripple the algae's ability to photosynthesize (Meo 2003).

Human induced disturbances also alter community structure and can likewise alter the interactions of the species within the community. Vessel groundings act much like storms and can overturn hard coral structures in large patches of reef. However, groundings can actually flatten corals and change the topography of the reef floor (NOAA 2002). Extensive recreation can also cause human disturbance. Careless snorkeling, SCUBA diving, and standing on reefs causes breakage and death to corals. Bleaching can also be induced by humans. Increases in atmospheric temperatures and higher UV ray penetration due to depleted ozone increases global water temperatures which causes the expulsion of the symbiotic algae in coral.

Human induced degradation reduces the ability of coral and their community to recover from natural and other disturbances (NOAA 2002). Agriculture and forestry harvesting practices create sediment run-off which is captured by rivers flowing out to sea, into the reefs (Szmant 2002). Heavy rainfalls can also wash large sediment loads off exposed hill slopes and fields into the watershed. When sediment reaches the reef, it causes turbidity in the water column, limiting the amount of light available to photosynthesizing organisms, particularly coral. Sediment also prevents coral recruitment by decreasing the quality of the substrate material required for coral attachment when it settles on substrate material.

Over-fishing and harmful fishing practices can also cause lasting degradation. Most commonly over-fished are herbivores who "limit the density and spatial organization of plant communities on reefs" (Glynn 1990). If the number of herbivores decreases significantly, coral can be smothered and overgrown by algae. Harmful fishing practices that continually cause degradation include the use of dynamite, poison, and cyanide (Amino, personal communication 2003). Each of these practices can kill large amounts of herbivorous fish, not to mention the coral itself.

The Coral-Algal Interaction

In an un-impacted reef, the coral-algal interaction, specifically with macroalgae, favors coral dominance (Hunter 2003). The interaction can be characterized by competition for light, direct contact, space competition, and subsequent succession. In degraded reefs, namely those suffering from sedimentation and overfishing, the coral-algal interaction tends to favors algal dominance.

Coral compete with macroalgae for light. Some algal mats can overshadow and crowd coral and cut them off from sunlight and their photosynthetic abilities (Lirman 2001). In low or nutrient poor areas, coral also compete for available nutrients. Direct contact of algae on corals can also cause chronic injury and subsequent death due to constant abrasion. This allows algae to advance on the dead coral patches, with little competition from remaining coral (Lirman 2001). The continued abrasion from algae through wave movement allows bacteria and fungi to invade the coral polyps and kill the organism entirely (Hunter 2003). Perhaps most importantly, coral and algae compete for space. In a healthy reef, coral out-compete macroalgae for space in large part due to herbivory on the algae (Hunter 2003). Grazing fish and sea urchins are the primary predators of most algae who consequently keep algae populations too small to over-colonize coral.

During succession in a healthy coral reef, a bare substrate, usually rock, is colonized by a type of turf algae which succeeds to coralline algae or calcareous algae, and then to the establishment of new coral recruits in addition to some fleshy brown algae (macroalgae) colonization (Hunter 2003, McClanahan 1997). However, in locations of disturbance with widespread degradation, succession can be altered to favor macroalgae dominance as the end result, rather than coral dominance.

On impacted reefs, the normal coral algae interaction is altered. In the Great Barrier Reef off the coast of Australia, near-shore reefs are struggling due to sedimentation degradation. Researchers there have found a correlation between increases in the biomass cover of algae with increases in sedimentation rates. As sedimentation from terrestrial sources increase, algae cover on reefs also increases. Algae tend to out-compete coral in degraded locations such as this (Szmant 2001).

On Caribbean reefs, algal cover has become too high for coral to re-establish themselves. These reefs were originally disturbed by a bleaching event and strong storms, but are also now struggling from herbivore die-off, which arose from over-harvesting of fish species and disease in sea urchins. The reduced herbivory by the sea urchin and the increased open substrate by bleached coral death has allowed the algae to out-compete coral.

Restoration Efforts

Without intervention, the recovery of coral is significantly hindered by its slow growth rate and the stressors of ecosystem health (NOAA 2002). Restoration efforts in disturbed areas depend on the survival of coral recruits, decreased mortality of remaining coral, reduced external stress and

minimal competition from invaders. Restoration of coral in these areas, especially when coupled with persistent anthropogenic disturbances is extremely difficult.

Reef restoration techniques most often address survival of coral recruits, decreased mortality of remaining coral, and some reduced external stress, but have not yet addressed minimizing competition from invaders such as algae. Many countries have began restoration efforts by instituting Marine Protected Areas (MPAs) that exist as human exclusion areas to ease anthropogenic stresses. The primary goal of MPAs is to "rehabilitate depleted economically important marine resources and degraded habitats" (Tawake 2000). In Votua Village, Fiji, the local MPA was designed in response to noted decreases in fish populations and increases in *Sargassum* cover (Amino, personal communication 2003). Votua's hope is to improve the integrity of the reef by banning any fishing, snorkeling, swimming, or diving on the reef for five years.

While there were no widespread efforts in the Votua reef to restore coral directly, other MPAs and restoration sites have used several techniques aimed at improving recruitment and mortality rates of coral. Transplantation is perhaps the most widely used and feasible restoration effort and is commonly used from coral gardens and nurseries. To complete transplants, the coral is often introduced to a disturbed area with artificial substrate structures such as Reef Balls™ and other reef modules, and Bio-rock™.

Coral gardens and nurseries are designed to minimize death of injured corals and to provide donor stock for restoration efforts (NOAA 2000). In the first step, recently broken coral pieces from disturbed areas or branches that have been trimmed from a healthy donor site are cemented to a substrate material in a submerged, protected location. They are typically attached with an epoxy, cement, or hardware to an artificial substrate (Jaap 2000). The coral is nurtured until it is of sufficient size to transplant in a restoration location. Typically, the coral is then attached in the same manner, with cement to another artificial substrate in the restoration site (Epstein et al 2001).

Artificial substrates are designed to provide an attachment site for new coral recruits and for transplanted coral branches. One of the most popular known types of modules are Reef-Balls™ (Figure 3).

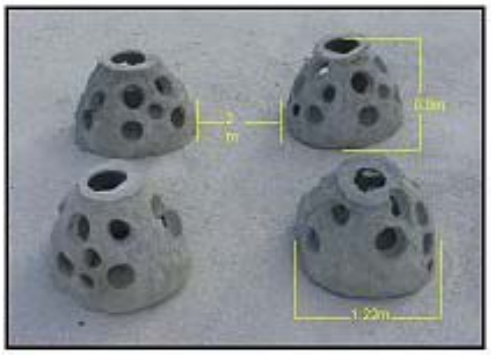

Figure 3: Model representation of a grounding restoration site. Each Reef Ball quad from a individual Reef Ball has 2 m separation from the other Reef Balls in the quad. (Photo :National Coral Reef Institute, www.nova.edu 2000)

Reef Balls can be made of different materials, but usually consist of a type of cement or concrete. They are placed in a restoration site with a configuration tailored to project needs that allows for coral settlement and/or fish recruitment. These mounded structures also have several large round holes to accommodate plugs of transplanted coral from donor sites (NCRI 2000). Other reef modules vary in composition and design, but fulfill the same role for coral recruitment. On a vessel grounding site in the Florida Keys National Marine Sanctuary, modules had to be

constructed to restore topography of the damaged reef floor and also to provide new substrate (NOAA 2002) (Figure 4).

Figure 4: Completed reef module ready for placement. (Photo: Florida Keys National Marine Sanctuary 2002)

A relatively new method, Bio-rock™- mineral accretion is another restoration method employing artificial substrate. This method applies extremely low voltage electrical currents through seawater in a coral nursery type setting. The electrical current, which can be supplied from a solar powered source, causes calcium carbonate (limestone) to crystallize on artificial substrate, typically made of a steel construction mat (Goureau 2000). Mineral accretion is accelerated, which provides a more suitable substrate for transplanted coral. The rate at which coral can grow is also accelerated through constant accretion, thus speeding the rate of restoration efforts as well (Goureau 2000).

Monitoring Efforts

Because coral reef restoration methods are new, monitoring techniques are still being developed. Restoration efforts are visually assessed by line transects surveys, growth measurements, or by a site specific achievement of a restoration goal (i.e. the return of a species). The United State Geological Survey has developed a digital camera system that monitors sedimentation and tidal changes in Hawaiian reefs (Figure 5) (USGS 1999). They also use digital video during line transect surveys to capture visual changes in the reef and to mark reference points for surveying that location again.

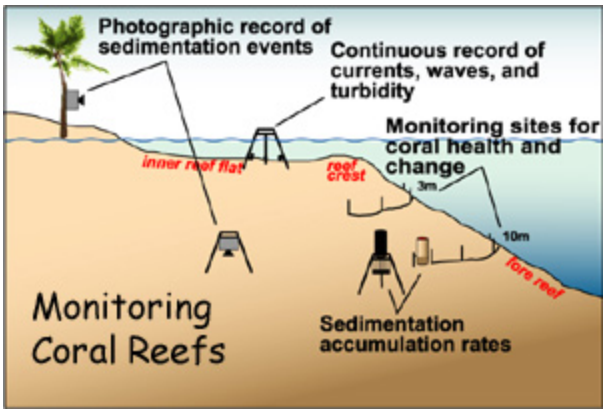

Figure 5: Digital camera system for monitoring reef sediment and tidal changes. (Diagram: United States Geological Survey, http://coralreefs.wr.usgs.gov/hi_refs.html 2002.)

Little evidence as to the success or failure of restoration efforts has been agreed upon due to both the newness of reef restoration and the length of time coral takes to re-establish itself on a degraded site. Marine Protected Areas and restoration techniques currently used can be successful, but those instituting them should take appropriate steps to include stakeholders and local community in the restoration efforts. If communities that depend on the reef daily do not support or understand the restoration, little will be done to change degrading practices to protect and nurture restored coral communities. Community members should also be trained to monitor the restored reef site to incorporate long term monitoring of success or failure.

Evaluation techniques needed to scale success or failure should be further developed so that a large set of baseline data can be used comparatively in future reef restoration. In reference to the coral-algal interaction, the restoration team needs to continue to survey areas in question with line transects to document the coral-algae ratio, percent coral cover, coral recruitment, coral mortality, temperature, water quality and clarity, sedimentation levels, algal types, and valuable indicator species count.

Because algae are a naturally occurring species in the reef ecosystem, success can't be judged on complete exclusion of macroalgae. An appropriate coral-algae ratio would be a good indicator of healthy competition. In addition, as so little is known about how changing environmental factors affect the myriad of algae species on a reef, documenting detailed data including growth form, biochemistry, reproduction, and chlorophyll content, is the only way to understand the interaction between coral and algae. In a changing marine environment, the implications that interaction has on future restoration is necessary for success

Suggestions for Improvements

Improvements in both restoration and monitoring methods should take into consideration the competition interaction between coral and algae to prevent algae from overtaking the substrate site (Epstein et al, 2001). As previously mentioned, restoration efforts need to take into account coral-algal interactions specifically in locations of disturbance and continued degradation to minimize the invasion of disturbance sites by macroalgae. They need to address the biological history of both species, but also the human induced degradation that alter interaction (McCook 2001).

Efforts should be made to confront the long term causes of degradation. Sedimentation caused by land clearing can be addressed by basic practices already in use. Selectively thinning forest and creating buffer zones along adjacent waterways is a practice that has been long-used by

the forest industry. Selective cutting prevents a total clearing of vegetation and compaction, which maintains soil integrity by stabilizing soil. Creating buffer zones allows intact vegetation to catch sediment and excess nutrients that run off logging sites before it reaches waterways that ultimately run into the ocean and reefs. When clearing land for agriculture, strips of vegetation along easily eroded hillsides can be kept to prevent sediment loss. Composted material or other debris kept on the soil during fallow periods also prevents erosion during massive rainfall events. Again, vegetation can stabilize soil and prevent sediment flows.

In addressing fishing pressures, it may be necessary to enforce permitting. Excess takes on fish can drastically reduce herbivory in reef communities. In countries with governmental control of environmental issues, permitting may not be as difficult as with some tropical island nations. Many reefs lie around tropical islands or countries that have tribal laws governing the use of their reefs (Amino, personal communication 2003). In these types of situations, it is necessary to institute environmental education whenever possible because universal widespread governmental permitting is not possible. Working with indigenous groups on how they can limit catches while remaining economically viable is absolutely necessary to preserve reefs in those areas.

Conclusion

The interaction of coral and algae has become an issue that needs to be addressed in coral reef restoration efforts. Anthropogenic stresses coupled with natural and human disturbances impact this interaction, further demonstrating the need to deal with the interaction immediately. Increasing pressure on reefs worldwide promotes the need for advancements in restoration techniques and the monitoring and evaluation of restoration sites.

Literature Cited

Amino, Pita. 2003. Dive Instructor, Internship Coordinator, Mike's Divers, Fiji. Personal interview.

Cousteau, Jacques. 1973. The Ocean World. Abradale Press, Haryn Abrams, Inc. New York, NY;

CRC Reef Research Center, Australia. 2003. Accessed October, 2003. www.reef.crc.org.au.

Epstein, N., R.P.M. Bank, B. Rinkevich. 2001. Strategies for gardening denuded coral reef areas: the applicability of using different types of coral material for reef restoration. Restoration Ecology. 9: 432-442.

Glynn, P.W. 1990. Feeding ecology of selected coral-reef macroconsumers: patterns and effects on coral community structure. Ecosystems of the World . Coral Reefs 25:

Goureau, T. 2000. Global Coral Reef Alliance. Accessed November, 2003. www.globalcoral.org.

Hunter, Cindy. 2003. First report on coral disease in the Hawaiian Islands. 2003.

Waikiki Aquarium, Hawaii. Accessed October, 2003. www.reefnet.org.

Hunter, Cindy. 2003. Ecological success of alien/invasive marine algae in Hawaii. Waikiki Aquarium, Hawaii. Accessed October, 2003. www.reefnet.org.

Jaap, Walter C. 2000. Coral Reef Restoration. Ecological Engineering. 15: 345-364.

Lirman, D. 2001 Competition between macroalgae and corals: effects of herbivore exclusion and increased algal biomass on coral survivalship and growth. Coral Reefs. 19: 392-399

McClanahan,T.R. 1997. Primary succession of coral-reef algae: Differing patterns on fished versus unfished reefs. Journal of Experimental Marine Biology and Ecology. 218: 77-102.

McCook, L.J., J. Jompa, G. Diaz Pulido. 2001. Competition between corals and algae on coral reefs: a review of evidence and mechanisms. Coral Reefs. (19): 392-399.

Meo, S. June, 2003. Lecture notes, University of the South Pacific, Institute of Applied Sciences. Suva, Fiji.

National Coral Reef Institute. 2003. Accessed, November 2003. http://www.nova.edu/ocean/ncri/projects/

National Oceanic and Atmospheric Administration FY 2000 Budget Request Fact Sheet. February, 1999. Coral Reef Restoration. www.noaa.gov.

National Oceanic and Atmospheric Administration. 2002 . Wellwood Grounding. Accessed November, 2003. www.noaa.gov.

Snyderman, Marty. 1989. The Living Ocean. Portland House, Crown Publishers. New York, NY.

South, R. and P. Skelton. 2000. Status of coral reefs in the southwest Pacific: Fiji, Nauru, New Caledonia, Samoa, Solomon Islands, Tuvalu, and Vanuatu. Global Coral Reef Monitoring Network South Pacific Node. University of the South Pacific. Accessed October, 2003. http://www.usp.ac.fj/marine/gcrmn/gcrmn/status.htm

Szmart, A.M. 2001. Coral reef algal community dynamics. Coral Reefs. (19): 299-302.

Szmant, A.M. 2002. Nutrient enrichment on coral reefs: is it a major cause of coral reef decline? Estuaries. (25): 743-766.

United States Geological Survey. 2002. Monitoring change on Hawaii's coral reefs. http://coralreefs.wr.usgs.gov/hi_refs.html