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Environmental Threats to the Symbiotic Relationship of Coral Reefs and Quorum Sensing

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Abstract

The coral reefs are declining in vitality and quantity in all parts of the world. Microbiomes exist symbiotically on the individual coral polyps. With this understanding comes the idea that microbiomes may coordinate survival through their inhabiting microbe colonies in order to sustain the life of the coral polyps. Of particular interest is quorum sensing, a form of bacterial communication known to coordinate gene expression in density-dependent bacteria. The importance of understanding the symbiotic relationship between microbes' use of quorum sensing and the coral it inhabits may offer insight in how microbiological colonies promote reef health and how external toxins alter these molecular processes.

Quorum sensing is a form of bacterial communication known to coordinate gene expression in bacteria dependent on population density. This system might offer insight in better understanding how microbial colonies promote reef health and could help explain why reef health is dependent on the diversity and density of microorganisms and the bacteria, like *Diploria strigosa* and *Montastraea annularis*, that inhabit them. Of particular interest is understanding how gene expression in the microbial colonies is regulated, how that might influence reef health, and how environmental threats affect cell-to-cell communication within a coral bacterial system. Coral reefs are complex and biologically diverse colonies of holobionts, which themselves are whole beings made of smaller sub colonies with diverse microbial processes. Temperature change, pollutants, and human activity all threaten the complex but vital microbial processes within these holobiont colonies as well as the overall biodiversity of the coral reefs (Burke, 2012).

Coral reefs represent a vast collection of microbial colonies that cover over 600,000 square kilometers of the earth's surface (Crossland, Hatcher, & Smith, 1990). They constitute one of the most highly diverse ecosystems in the world, providing a marine habitat to over 30,000 species of organisms (Burke, 2012). These microbial coral colonies are important socially, biologically, and economically as they support the aquatic environment, fisheries, and nurseries and produce income for developing nations. In addition to providing for a diverse marine ecosystem, reefs also provide protection from erosion on coastlines and sand for beaches.

Preserving the biodiversity of the microbial colonies within the coral is vital to promoting a healthy aquatic ecosystem. These colonies help preserve the reef against the damage caused by threats like climate change, fish-farming, human activity and environmental pollutants. The activities of all of these threats have increased over time in positive correlation with the deterioration of the reefs themselves. The importance of the symbiotic relationship between the microbial colonies and coral reefs are not well known but have the potential to become a vital part in determining how to promote reef health and sustain current reefs in poor conditions. Results from climate research by Peters et al (2012) argue that prevention of global temperature increasing over 2 degrees Celsius is unlikely given the meteorological measurements used in their research analyzing global carbon dioxide emissions. This mean that cases of coral beaching and ocean acidification will continue to increase and decimate reefs on a global level.

Coral reefs are colonies of coral, a marine animal in class anthozoa of phylum cnidarian. There are three taxonomic subcategories of coral: hermatypic, ahermatypic, and perforate coral. The most common kinds of coral found in reefs are hermatypic stony coral. The coral reefs are considered to support biodiversity because they provide a habitat to over 300,000 different species of plants, marine and land animals that all use the reefs as their source of nutrients (Brown 1997).

The individual hard coral polyps are typically a few millimeters in diameter. The polyps sit in a cavity called the calyx that is created when the coral secretes calcium carbonate. This process serves to expand the reef structures. There are the walls surrounding the calyx and on the bottom of the calyx is a calciferous ring called the basal plate. The ridges on the coral grow vertically and out of the base of the polyp. Included in their anatomy is the tabulae, which isolates the face of the coral from surrounding calcium carbonate skeleton allowing the upward growth of the coral ("NOAA Coral Reef," 23 A).

Their internal structures consist of a gastrovascular cavity that serves to ingest food and expel waste. Within the gastrovascular cavity is the septa, which functions to support its internal structure. Individual polyps connect through gastrovascular canals which enable them to share nutrients and algae. Within the gastrodermis of reef building coral lies the complex and vital symbiotic relationship between itself and their internal protozoan component zooxanthellae. The coral protects and provides compounds the zooxanthellae needs for photosynthesis and in return, zooxanthellae provides food and nutrients in the coral that allows for the continued secretion of calcium carbonate, which enables reefs to continue to grow. A release of the zooxanthellae due to high temperature change results in a phenomenon called coral bleaching (Brown 1997).

Soft corals, such as gorgonian corals, have a slightly different structure than hard coral. Soft coral, also known as Ahermatypic and Alcyonacea coral, differ from hard coral in that they do not produce a rigid calcium carbonate skeleton. Unlike hard coral, they do not form in reefs although they are commonly found in a coral reef ecosystem. Soft coral are mostly colonial, meaning that a large organism may be made up of several smaller individual polyps. These colonies grow two to four centimeters a year. Instead of secreting solely a calcium carbonate skeleton, they contain sclerites. Schlerites are found in coenchyma, the tissue between polyps, and are made of protein and calcium carbonate. They provide a dense and supportive structure to soft coral ("Noaa Coral Reef," 23 A).

Coral reefs provide a marine habitat that serves as the basis of one of the most biodiverse ecosystems in the world. Not only do they support aquatic life, but they also protect and support the ecosystem of coral islands. In his article "Coral: life's a bleach...and then you die," Rob Painting writes that coral reefs house 25% of the total fish population (Painting, 2011). The fish are attracted to the coral reefs as they are a source of nutrients andprotection from predators. Coral reefs depend on micro bacterial organisms that surround the reef, which are free-living and feed on dissolved organic matter. Coral reefs consume these bacteria that make up most of the biomass of plankton and as a result, they are responsible for approximately 30% of reef production.

Additionally, coral reefs protect shores from the impact of waves, provide food and medicines, and economic benefits to local communities through tourism. This is particularly important to coastline economies in developing countries like Indonesia, who rely on the tourism of their reefs as income. The National Oceanic and Atmosphere Administration put the economic value of coral reefs to be approximately $375 billion dollars each year. This statistic takes into account the services the coral reefs provide including food, tourism, and jobs. With the declining vitality of coral reefs, the prices will only increase ("World Meteorological Organization," 2011).

Bacteria benefit the coral by breaking down waste, fixing nitrogen, and recycling nutrients back to the photosynthetic algal symbionts (e.g. zooxanthellae). Bacteria may also ward off other potentially harmful microbes by producing antibiotics or by occupying the available space. The microbial loop in the oceans' coral reefs is highly dependent on organic particles, bacteria, and consumers of bacteria. A level of microbial substrate produced by the flora and fauna provides a haven for bacterial production and is responsible for 40% of the picoplankton production and 25% of microplankton production. Bacteria are vital to the plankton that provide food for the coral reefs. The main nutrient that prevents bacterial growth is carbon. At a slow rate, the ocean absorbs carbon dioxide from the atmosphere in order to reach equilibrium with the carbon in the atmosphere. A carbon atom will remain in the ocean once dissolved in the ocean and directly affects the reefs. These carbon amounts have increased on a level that cannot be processed by the reefs ("The Ocean Carbon," 2002).

There are existing systems of corals that have been hinted at using a cellular microbial process, known as quorum sensing, to regulate bacterial cell-to-cell communication to aid in reef health. In a study by Hunt, Downum and Mydiarz at the University of Arlington, scientists extracted four kinds of Gorgonian coral samples and used a pseudomonas aeruginosa quorum-sensing-gfp biosensor system that senses long chain acyl homoserine lactones. Two of the four kinds of gorgonian corals Plexaura flexuosa and Briareum*,* had an inhibitory effect on quorum sensing, with a 80% and 90% reduction in signal respectively, which meant that the bacterial colonies within the gorgonian coral systems ceased to communicate. The remaining eunicea laciniata has a 20% signal reduction rate. All of the coral samples showed a dose-response effect. Pseuoplexaura, the last sample, tested stimulated quorum sensing activity in the absence of AHL with a tenfold increase in signal with background fluorescence. The results of this study validated the theory that there are stimulatory and inhibitory compounds in coral reefs that indicate ongoing communication between coral and prokaryotic and interspecies bacterial colonies (Hunt, Downum, & Mydiarz, 2012).

In recent years, the idea of microbial sensing and response systems have been brought to light in the form of cell-to-cell communication and small signaling molecules. Quorum sensing was once believed to be limited to a few obscure examples such as *vibrio fischeri*, the bacteria responsible for the chemical response of bioluminescence. Now, it is becoming increasingly notable in a wide range of microorganisms that bear the ability to sense and respond to the presence of neighboring coral reef microbial colonies. In addition, quorum sensing is a type of bacterial communication known to facilitate virulence, biofilm formation, and antibiotic production. After extensive research, I have concluded that quorum sensing can be applied to the bacterial systems within coral. The microbial colonies shown to be active in Gorgonian coral systems support that theory. Quorum sensing allows these bacterial and coral colonies to coexist harmoniously and to respond to changing environmental conditions and temperature. These colonies use quorum sensing to facilitate defense mechanisms by using various signaling molecules mediating perception and response pathways. The term quorum sensing relies on the production of low molecular mass signaling molecules, an extracellular concentration correlating with population density of the host organism. The signaling molecule can be perceived by cells and allow the whole colony to start a communal action once a certain cell density has been completed.

It is important to research whether these communication systems are present in other coral-associated bacterial colonies besides Gorgonian coral systems and whether these systems are affected by other environmental perturbations. If one understands the symbiotic relationship between coral and microbial colonies that use quorum sensing, it is likely that ecologists and other scientists can better understand how the environmental threats impact the symbiotic relationship between these microbial processes and coral, thus reducing positive gene expression in the coral reefs.

Microorganisms are constantly being bombarded by various environmental threats. These threats include change in pH, nutrient availability, ocean acidification, and temperature. In response, these microorganisms have developed ways to adapt to the fluctuations. An example of these adaptations are the two-component signal transduction phosphorelay mechanisms that allow these coral bacterial colonies to sense and respond to these environmental threats by activation and repression of certain target genes (Croxatto, 2006). These microbial colonies enable the coral systems to support the overall health of the reef.

Other possible environmental threats to the microbial process of quorum sensing are ocean acidification, temperature change, water pollution, sedimentation, coastal development, unsustainable fish farming, ozone depletion, and careless tourism. Ocean acidification is the decrease of pH in the ocean due to the absorbing of excess carbon dioxide from the atmosphere. When carbon dioxide reacts with ocean water, the availability of carbonate ions decreases as well. This process affects the reefs' ability to facilitate quorum sensing within these microbe systems and their ability to expand the carbonate skeleton, thus slowing the growth of the reef and making it more vulnerable to erosion. The prevention of reef growth inhibits appropriate microbe colonies from forming in the reefs. Without the growth of appropriate microbe colonies, the strength of the overall defense mechanisms the coral colonies use against environmental threats decreases.

In addition to ocean acidification, corals are incredibly sensitive to temperature change. The average temperature increase in the ocean has been the main reason for coral bleaching, the microbial process where coral releases zooxanthellae from its gastrodermis signaling environmental distress. In the past century, the ocean temperature has increased by one degree Celsius and increases about one to two degrees per century (Hoegh-Guldberg, 1999). Reef building stony coral are living at their thermal limit due to their sensitivity to rising temperature. Coral bleaching is a sign of their distress and is triggered by a small increase in the water temperature. When coral bleaching occurs, the symbiotic relationship between zooxanthellae and coral is damaged and leads to the detachment of zooxanthellae from its host organism. Coral bleaching is a sign that the microbe colonies within coral have been decimated and their use of quorum sensing has discontinued. Experts expect these sorts of events to increase in frequency and intensity in the next fifty years as sea temperatures rise. This example is one of multiple ways that coral decreases its biodiversity in the overall reef structure.

These environmental threats are damaging to reef health since they not only decrease the biodiversity of the reefs and aquatic organisms that surround reefs by directly damaging the biodiversity, but they also interfere with the symbiosis of the bacteria/microorganisms on the coral which interferes with proper cellular communication, thus also negatively impacting the reefs. They kill the diversity of bacteria, which means that there are not the proper concentrations, density, and diversity of species to promote proper gene expression for quorum sensing. Since they cannot use this mechanism and give off their beneficial byproducts because they do not facilitate mechanisms associated with quorum sensing, the reefs suffer. When the microbial processes within coral are decimated due to environmental threats, their use of quorum sensing seizes, thereby decreasing the overall biodiversity within the reef. The importance of understanding the role of bacterial cell communication in coral reef habitats may lead to ways of understanding the role it plays in life and may lead researchers to ideas relating to sustaining their life given the inevitable variables threatening their survival. Temperature, pollutants, and human direct and indirect contact create a response in the coral by decimating their bacterial cell communication system and therefore decreasing the overall biodiversity of the coral reefs. In order to provide solutions on how to sustain the coral reefs through the coming climate change, one must understand their microbe colonies and their use of quorum sensing. Once scientists and experts have an idea about how quorum sensing and microbe colonies work with coral, ideas such as density manipulation in microbes facilitating quorum sensing may restore balance and overall reef health and prevent coral disease in at-risk areas.

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