

# El Niño's Impact on Eastern Pacific Coral Reef Communities

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## Abstract

The plight of Peruvian fisheries created by El Niño is enormously publicized. Only in recent years have scientists revealed how this oceanographic phenomenon has influenced coral reefs. Although the precise mechanism is unclear, the symbiotic algae dwelling within the fleshy coral tissues called zooxanthellae participate in coral calcification. The coral also uses much of the carbon fixed by these protists. Environmental stresses, such as increased ultraviolet light, turbidity, pollution, drastic salinity alterations, and seawater temperature increases stimulate coral bleaching. Exceptionally warm El Niño waters cause widespread bleaching throughout the Eastern Pacific. Exactly how and why this bleaching occurs remains a mystery, but some studies suggest coral epidermal cells housing this algae are shed into the water thereby clearing the coral of color.

A bleached colony's life expectancy is bleak. During the severe 1982-83 ENSO, Eastern Pacific coral mortality rates ranged from 70-95%. Local and regional coral extinctions were reported. The marine systems suffering substantially were areas normally exposed to either cold upwellings or deep, cool, and stable environments; the corals thriving in shallow, dynamic systems proved to possess stress tolerances. Another observation was the branching corals had greater thermal sensitivity than the boulder corals. This observation could be correlated to the accelerated growth and inferred algal dependence usually associated with the former grouping.

The bleaching and incurring deaths had diverse consequences. El Niño's wake left only empty skeletons for hungry, corallivorous organisms. The new algae proliferating on the barren seascape attracted armies of sea urchins which eroded the reef substrate as they scraped their algal meals. The bioerosion demolished natural wave breakers permitting the full ocean thrust to crash onto the shore. This occurrence caused increased sediments to enter the water, thus the reef framework failed to produce a conducive habitat for coral repopulation. The natural recovery processes might seem slow on a human's time scale, but El Niños of a 1982-83 caliber, which visit every 200 years, could be named the droughts, floods, and fire climaxes of the aquatic realm.

Atmospheric conditions and the world's oceans are an interactive system. This dynamic union, together with the Coriolis effect generated by the Earth's rotation, and the sinking of dense, cool water contributes to the production and maintenance of global currents. In a simplified oceanic scenario, the winds control surface flow; cold dense water descends to the sea floor thereby displacing the existing water to produce upwellings and deep currents. The Coriolis effect is responsible for the vortex patterns observed in individual oceans. Due to the mutable nature of the seasons and factors influencing the oceans, the various aquatic environments may periodically slip into a condition not conducive to the existing regional ecosystem. A specific example of this type of abiotic force devastating a marine community is the 1982-83 El Niño Southern Oscillation (ENSO) impacting the Eastern Pacific Ocean. This review will focus on the warm waters from the El Niño and its ties to coral bleaching. The coral reef's fragile link, supporting the ecological chain along the Eastern Pacific, will be examined.

Normal currents along the equatorial Eastern Pacific consist of the cold California current merging into the warm North Equatorial current flowing westward. The Peru current feeds into the warm South Equatorial current which also pushes west. During an El Niño event, the trade winds subside (Philander, 1985; Graham and White, 1988). Without the atmospheric forces pushing the water to the west, the South Equatorial Current halts or flows *eastward*. The individual El Niño events are followed by the normal cold surface water periods called La Niña. Although wind reversal appears to be a factor in the ENSO, other

unidentified catalysts are likely to be involved. For example, during the 1982-83 El Niño event, the warm waters persisted months after the normal atmospheric pressure zones restabilize.

A second conflict with an exclusive wind/ENSO relationship described by Philander (1985) is that the weak westward blowing wind in 1979 failed to generate El Niño. During the El Niño, atmospheric convection zones (the Intertropical Convergence Zone and the South Pacific Convergence Zone) merge together squeezing the Equatorial Convection Zone eastward from the Western Pacific. As the Pacific heats during this happening, large volumes of water evaporate; due to the thermal retention properties of water, the moist air also warms the atmosphere.

The atmosphere's elevated water content eventually translates into increased rainfall. "Southern Oscillation" is in reference to the increased severity of the Southeast Asian monsoons in an El Niño year. During the first half of 1983, the Galápagos Islands were deluged with nine times the average total annual rainfall (Grove, 1984)! Although this extreme example occurred in the heart of El Niño, El Niño's atmospheric nature leads to an impact on global weather (Philander, 1985).

The direct oceanographic consequences of El Niño are felt on a more regional scale, especially along the Eastern Pacific coast. Focused around the equator, El Niño is notorious for heating the frigid waters off the Peruvian shores. The results can be catastrophic to the fishing industry as the heated water interferes with the upwellings. These abnormal waters replace the natural nutrient and oxygen rich cold waters essential for the indigenous plankton which are, in turn, essential for that coastal ecosystem. Similar damage has also been observed along the Californian kelp forests (Dayton and Tegner, 1984). Examining tropical ecosystems, various algal species experienced die-offs throughout the Galápagos Islands (Grove, 1984). One of the species to suffer, *Blossivilla galapagensis*, was the staple diet for the marine iguana, *Amblyrhynchus cristatus*. As a consequence, the reptiles' mortality rate due to starvation was high. The iguanas either found the surviving species distasteful or undigestible.

A second tropical algae reaction stimulated by the 1982-83 El Niño was found in zooxanthellae: the dinoflagellates forming symbiotic mutualisms within many species of coral, sea anemones, hydrocorals, gorgonians, jellyfish, and giant clams of the genus *Tridacna*. Zooxanthellae represents 5-12% of a coral's biomass (Porter et al, 1989). The loss (either through the algae's death or physical expulsion from invertebrate tissue) of the zooxanthellae and associated pigments was especially noticeable in corals resulting in the form of coral bleaching. Corals experiencing a bleaching event suffered a 39-73% mass decrease when their tissue protein masses, lipids, carbohydrates, and dry weights were compared to healthy corals. In the bleached corals, calcification processes were either drastically dampened or halted. To fully appreciate the interdependency of this animal/protist relationship, one must realize light is the single most important factor to coral growth (Wood, 1983). Although the exact mechanism is unclear, radioactive calcium and carbon tests reveal 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' biochemistry is responsible for coral growth but the algae drives the system and fulfills much of the oxygen demand (Fang et al., 1989). In return, studies on corals (Falkowski, 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 plants and 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 showed that the coral examined (*Stylophora pistillata*) used more than 90% of the carbon fixed by the dinoflagellates despite the light intensity.

A multitude of stressful factors can perturb the coral/zooxanthellae relationship and initiate bleaching. Local bleaching catalyzed by a salinity decrease has been observed near rivers after severe storms (Goreau, 1992). Storms may also wash sediment and pollution into the sea: two additional inducers to local bleaching (Roberts, 1987; Porter et al, 1989). Another source for bleaching potentially having a larger geographic range than the previous agents is ultraviolet light. Intense visible light, having a

wavelength between 700-400nm, apparently does not hinder microalgal proliferation, but the 400-280nm spectral range does have adverse repercussions (Jokiel and York, 1984). Ultraviolet light between 400-300nm can penetrate down to 20m of pure sea water (Lesser and Stochaj, 1990). Lesser and Stochaj were working with a prokaryotic symbiote (*Prochloron* sp.) within a tunicate, *Lissoclinum patella*, but their experiments indicated that the eukaryotic tissue decreased the visible light penetrating the *Prochloron* by 60-80% and the presence of ultraviolet light absorbing pigments. The ultraviolet light seeping through the ozone's hole over Antarctic phytoplankton (diatoms and dinoflagellates) resulted in a decrease of photosynthetic activity (Cullen et al, 1992). Ultraviolet light might play a larger future role on coral bleaching should the ozone layer continue to deteriorate.

All of the precise physiological and biochemical factors involved with coral bleaching remains a mystery. One coral species, *Montastrea annularis*, examined in South Eastern Florida was subjected to bleaching-inducing stimuli (Kleppel et al, 1989). As expected, the corals lost much of their zooxanthellae, but the few algal cells remaining within the polyps contained significantly reduced photosynthetic pigments. Chlorophyll c, peridinin, and dinoxanthin concentrations were 35X, 17X, and 20X lower respectively than the levels found in algae extracted from healthy colonies!

Experiments on *Agaricia lamarcki* indicated an 57% decrease in zooxanthellae density and a 56% chlorophyll reduction in the surviving algal cells (Porter et al, 1989). The identical experiment conducted on *Montastrea annularis* revealed an 86% algae drop and a 48% chlorophyll decrease. The absence of the dinoflagellates and associated pigments resulted in a photosynthetic efficiency of 17-74% compared to normal coral under the same light-saturation conditions. One might speculate the coral's ability to recover from a bleaching event could partially depend on the fitness of the dinoflagellates remaining **and** surviving the ordeal.

A proposed mechanism by which some cnidarians expel their zooxanthellae was discussed by Gates and colleagues (1992). The researchers focused on a Hawaiian sea anemone (*Aiptosia pulchella*) and a coral species (*Pocillopora damicornis*), which suffered enormously throughout the 1982-83 ENSO. Thermal stresses, consisting of either a 16-hour incubation in 32°C seawater or a 12°C chilling for 2.5 hours, precipitated an intercellular adhesion disjoining. The lack of intercellular adhesion was due to dysfunctional ion channels, especially the pathways regulating calcium transport. The result was a disruption in actin and intermediate filaments, especially vimentin and cytokeratin. After the coral cell clusters were released, much of the animal tissue disintegrated yielding free zooxanthellae. Although this cellular disassociation appeared identical in both temperature extremes, only the clusters liberated from the warmer waters were too fragile for electron microscopy examination. This fact suggests these different stresses do not have the same biological effect on the organisms despite the mutual bleaching involvement. In fact, when Steen (1986) conducted his zooxanthellae heterotrophic studies, a cold water bleaching protocol was employed to remove the dinoflagellates from the sea anemones. Not a single animal devoid of the protists was lost and the fragile nature of the heat-released cell clusters (Gates et al, 1992) together imply that the heat-related bleaching process is a more violent and destructive event than cold-induced bleaching.

Any combination of the mentioned strains could produce local or compound a mass coral bleaching, but the apparent root of the extensive bleaching caused by the 1982-83 ENSO was heat. The warming waters of the El Niño washed along the western Panamanian shores in March 1983 (Glynn 1984). During early June of 1983, the water temperature was elevated to 30.8°C in contrast to the normal 29°C. Several weeks later, many coral species began displaying malaise symptoms in their coloration which ranged from a lightened color to a solid cream or white. The bleaching often concluded in death, evident by the bare calciferous skeleton. The deterioration rates varied within a given immediate area based on the coral species' thermal tolerances. For example, hydrocorals [actually a hydrozoan and not a true coral (Wood, 1983)] of the genus *Millepora* was one of the first groups to perish. These hydrocorals are also known as fire coral because of their powerful sting; although people are instructed to avoid handling corals thereby preventing imminent danger to the invertebrates, divers avoid handling fire coral to prevent personal injury. A true coral, genus *Pocillopora*, also possessing a forbidding sting suffered extensive bleaching during and shortly after the fire coral occurrence. Keeping in mind these cnidarians' natural behavior, the significance of the potent organisms' deaths will be explored in later paragraphs.

A general bleaching observation within a local region was that the branching anthozoan, for example, *Pocillopora* sp. and *Acropora* sp. (staghorn coral), appeared more sensitive to elevated ocean temperatures than massive, boulder colonies such as *Porites* sp., *Sardineroseris* sp., and *Pavona* sp. (Brown and Suharsono, 1990; Glynn and Colgan, 1992; Buddemeier and Fautin, 1993). The reason for this distinction is not entirely clear but could be linked to a second generalization: Branching corals grow faster than the boulder coral; the genus *Acropora* contains some of the fastest growing corals (Wood, 1983). One could infer that the zooxanthellae's symbiotic role and photosynthates produced are utilized at a higher rate in the branching species to satisfy an accelerated metabolism. The dinoflagellates' removal from the more dependent branching coral might result in the coral's starvation for either physical nourishment or essential biochemical substances.

The temperature increases were not exclusive to near surface reef systems. Panamanian temperatures from May to September 1983 averaged 29.4° to 30.1°C at a depth of 110m below the surface with three of the highest readings all at 30.5°C (Glynn, 1984). In some instances, a colony experiencing bleaching in deep water did not suffer as greatly as a colony of the identical species found closer to the surface and at a similar temperature. Examining shallow, unstable Atlantic regions, corals generally were not as sensitive to heat and did not bleach as readily as those found in deeper waters (Goreau, 1992). Eastern Pacific corals did not deviate from this observation during El Niño. One could conclude that a genetic element influenced coral endurance. Shallow water corals might either have zooid and/or zooxanthellae alleles resistant to thermal and other near-surface stresses thereby stabilizing the animal/protist relationship. A moderately hostile environment selects for those organisms having that allele. The presence or absence of that genetic element in a deep, continuously cooler habitat would not affect the organism's longevity under normal conditions. Assuming this theory is correct, El Niño's devastating thrust destroyed the colonies lacking the protective gene.

The archaic zooxanthellae nomenclature labeled **all** symbiotic algae as one species (*Symbiodinium microadriaticum*, first described by Freudenthal); the fact that the *Symbiodinium* was found in a wide range of invertebrate species and appeared in a diverse array of shapes and colors was attributed to separate strains of the dinoflagellate (Blank and Trench, 1985). Some of these diversities are not only found in other species; a common Atlantic coral species, *Monastraea annularis*, has such varied coloration that the lighter specimens could be mistakenly thought to be bleached (Knowlton et al., 1992). Upon closer scrutiny of four "strains" extracted from different invertebrate hosts [*Montipora verrucosa* (a Hawaiian hard coral), *Anthopleura elegantissima* (a Californian sea anemone), *Heteractis lucida* (a Jamaican sea anemone), and *Cassiopeia xamachana* (a Caribbean jellyfish)], the protists appeared to be a collection of *individual* species (Blank and Trench, 1985). This conclusion was formulated after finding the zooxanthellae's biochemical elements (isoenzymes, sterols, photosynthetic molecules and affiliated proteins) and their physical attributes (morphology, physiology, and the zooxanthellae's ability to infect hosts) were unique in either concentration or content with respect to the host source. The major finding, which strongly indicated divergent species, was not only varying chromosomal sizes, but different chromosomal *numbers*! These dissimilarities were not a consequence of separate stages within the same algal species' life cycle. Once all of the symbiotes' similarities and differences were studied and organized, Blank and Trench surmised that the dinoflagellates isolated from two species of *Cassiopeia* were actually *Symbiodinium microadriaticum*, but all other hosts tested had a unique species of zooxanthellae. Sexual recombination, the indisputable test distinguishing two unique species, was unable to be performed. This test was normally used to identify free swimming dinoflagellates; however, the fragile nature of the symbiotic zooxanthellae prevented the employment of this decisive technique.

Ambiguities and discrepancies continue to cloud zooxanthellae taxonomy (Blank and Trench, 1988). New methods in molecular genetics should clarify these scientific disputes. The nucleic acids isolated from different dinoflagellates (both free living and symbiotic) were amplified via the polymerase chain reaction (PCR) (Rowan and Powers, 1992). In these genetic identification experiments for determining phylogenies, one generally uses a stable nucleic acid which either is not subjected to recombination or is maternally passed down to the offspring such as ribosomal RNA (rRNA) or chloroplast DNA. The amplified rRNA was sequenced to determine the arrangements of bases; a higher degree of arrangement

similarities suggested a closer interspecies relationship. This experiment showed the members of the genera *Symbiodinium* were closest to a non-symbiotic dinoflagellate of the genus *Gymnodinium*.

Genetic evidence, together with metabolic and physical attributes, could be employed to contrast divergent species if not different genera of any organism including the symbiotic dinoflagellates. Not only are these protocols in molecular biology useful to separate species, genetic studies can be employed for identifying *intraspecies* polymorphisms. If a thermal-tolerance allele is suspected to exist in an organism, the gene's locus could be identified and the algal/coral samples could be tested to see if that genetic element is present. Unfortunately, some of the traditional taxonomists only validate physical traits and disregard DNA and RNA tests. Currently, the quest for intraspecies diversities, such as the ability to withstand elevated temperatures, rests mostly with organismal scaled tests and transplantation experiments.

Glynn and D'Croz (1990) tested the high temperature tolerances of two groups of Western Panamanian corals two years after the 1982-83 ENSO. The *Pocillopora damicornis* samples native to the Gulf of Panama experienced cool upwellings periodically, but the corals collected from the Gulf of Chiriqui failed to receive the deep chilling currents. As a result, the former group of corals subjected to  $29.61^{\circ} \pm 0.03^{\circ}\text{C}$  water temperatures lost more zooxanthellae and tissue protein after five weeks of exposure than the *Pocillopora* from the Gulf of Chiriqui held at  $30.37^{\circ} \pm 0.07^{\circ}\text{C}$ . One may conclude the Chiriqui specimens had adapted to the normally higher seawater temperatures off that gulf whereas no heat related selective pressures influenced the genetic population of the Gulf of Panama corals. As a result, the latter population was crippled by heat.

This pattern of coral heat sensitivity was reflected off the Galápagos Islands' seashores. The Galápagos Islands' reef systems were especially hit hard during the 1982-83 El Niño. The frigid upwellings and meteorological patterns help keep these waters cooler than Panama (Grove, 1984). The warming trend for this island system was apparent by October 1982 (Glynn, 1984). The termination of trade winds resulted in a 20-25cm sea level increase over a four-month period.

The mentioned local extinctions were particularly evident along the Galápagos archipelago (Glynn and deWeerd, 1991). Although the combined cnidarian bleaching across the west coasts of Central and South America ranged between 70-95% of the total community (Glynn, 1984), the Galápagos reefs suffered the full 95% mortality rate. *Pocillopora elegans*, *Pocillopora damicornis*, and *Tubastraea taguseusis* completely vanished from the Galápagos sites. These devastating results were partially formulated because the corals were accustomed to the cool upwellings. Another factor was the construction of its unique reef network. The Galápagos coral reef system is best described as a patch reef; each small reef outcrop consists of one major coral species (Glynn and Colgan, 1992). One might suspect this single major species per patch might have actually generated from several if not a single parental polyp. This polyp budded into a massive colony of which pieces broke, settled on suitable substrate, and propagated new colonies. Both budding and fragmentation are asexual methods of reproduction and the domineering colonies all have an equal genetic structure and resistance abilities.

Although large portions of the Eastern Pacific reefs experienced coral bleaching events, high regional mortalities, and local extinctions (Glynn, 1984; Glynn and deWeerd, 1991), one must realize that tropical Western Pacific corals were also struck by the 1982-83 ENSO. Surface seawater temperatures recorded in the Java Sea (Indonesia) from March to August were  $2^{\circ}$ - $3^{\circ}\text{C}$  higher than in the months later documented from 1984-86 (Brown and Suharsono, 1990). At times, the temperature surpassed  $33^{\circ}\text{C}$  compared to the average  $31.5^{\circ}\text{C}$  seasonal high temperature. Similar to Eastern Pacific mortalities, *Acropora* and *Pocillopora* species were among the first to bleach. The bleaching phenomenon eventually became evident in 70 different coral and hydrocoral species surrounding the Thousand Island study sites. The bleaching and concluding deaths were significantly high (ranging from 84-92% of the previously living reef substrate) but did not peak to the levels witnessed off the Panamanian and Galápagos shores.

Despite El Niño's minimal effects on some of the massive, scleractinian corals, such as *Pavona gigantea* and *Psommocora stellata*, two of the three recorded hydrocorals became extinct throughout the Pacific Ocean's East coast (Glynn and deWeerd, 1991). Prior to the heating event, the fire coral population

contributed 1% of the total live reef corals. In October 1983, only a single 2.0cm branch of *Millipora intricata* was found. Although this species has made a gradual recovery, *M. platyphylla* and an undescribed *Millipora* species have completely vanished from the East; the identity of the latter will probably forever remain a mystery. Part of *M. intricata*'s restoration has been attributed to fragmentation, but much of its comeback was believed to be "sexually derived." *M. platyphylla* continues to inhabit Western Pacific waters, however Glynn and deWeerdts suspected this species' larvae, unlike *M. intricata*, has a brief planktonic life and might not survive a cross-oceanic voyage.

The repercussions produced by the cnidarian thinnings and perishments were felt both at sea and on the mainlands. The corals are a delicate, uniting link in and around tropical waters. One of the corals' major contributions to marine ecosystems is their direct benefit to the residential animals. Many fish and invertebrates feed upon the fleshy polyps. Assuming the heat from the 1982-83 ENSO did not directly affect these animals as it devastated coral colonies, the predators' food resources were drastically reduced. Some of the more adaptive animals or the organisms previously choosing from an extensive menu might have fed on a coral species which was damaged by El Niño. These adaptive animals may redirect their pallets on the corals which survived the higher temperatures. The hardy corals receiving a new predatory focus could suffer their own population declines as a secondary result of El Niño. Such increased predation has been documented in the wake of El Niño (Glynn and Colgan, 1992). If the browsing animal was unable to find another nourishment form, it starved or was forced to migrate. A second feeding development stemming from El Niño events had cast a role exclusively of invertebrates. The notorious crown-of-thorns starfish (*Acanthaster planci*) devours corals causing wide reef damage throughout the Pacific Ocean (Wood, 1983). However, it is not immune to the powerfully stinging nematocysts of the genus *Pocillopora*. The *Pocillopora* formed natural fences around the milder coral heads thereby thwarting the starfish attacks (Glynn and Colgan, 1992). Recalling the previous paragraphs, *Pocillopora* was one of the more thermally sensitive cnidarians. Once this genus bleached and perished, the massive coral colonies were penetrated and consumed.

Not only do other animals browse on coral, many organisms spawn and take refuge amongst the intricate calcitic structures. One might initially believe that the empty coral skeletons could continue to be used for these purposes. However, a number of the reef community members actually live within the coral. For example, the larva of a filter-feeding polychaete known as the Christmas tree worm (*Spirobranchus* sp.) settles on boulder coral, such as *Porites*, and the worm constructs a calcium tube. The tube production coincides with the coral colony's growth so the worm's shell and body are protected as if the coral's skeleton was a concrete bunker. After a bleaching event, the worm's fortress no longer expands and accommodates the polychaete's development. A desperate *Spirobranchus* might produce a tube over the inert skeleton, but this residence is easier to penetrate.

A second problem affecting Christmas tree worms on a dead colony is the coral's inability to repair any wounds. For example, another family of polychaetes actually drills holes through the boulders and may consume parts of the fleshy zooids. By budding and expanding over a perturbed area, a healthy colony could repair the worm damage and moderate injuries inflicted by browsing fish. In dead corals, no repair mechanisms are present; as the boulder head decays, erosion is inevitable.

The chief cause of post El Niño reef erosion was armies of sea urchins (Glynn and Colgan, 1992). After the bleached tissue decomposed from the coral, algae began growing on this clean substrate. As a result, the algae-eating sea urchins scraped their meal swallowing part of the calcium base to which the protists were attached. The echinoderms' drilling abilities transformed the reef seascape into rubble. Not only did this bioerosion ruin the habitat of non-sessile animals, the generated substrate was unsuitable for new coral colonies.

Reef degradation may appear devastating in its aqueous environment, but it also potentially causes trouble on land (Glynn and Colgan, 1992). Barrier and, to some extent, fringing reef structures block the treacherous waves and ocean currents from smashing upon the mainland. The destruction of these reefs allows water to hit the shore initiating terrestrial erosion and possibly flood human habitation on the banks. The increased contaminated run-off and sediment washed from the land often hinder marine life. Particulate matter accumulating on newly developing coral colonies inhibits development if not directly

killing the polyp. Erosion persists without the reef being able to restore itself and the vicious cycle continues.

The severity of the 1982-83 ENSO has made it a classic example of El Niño. This marine catastrophe was the worst El Niño of this century. Examining the reef bed fossil records, El Niño events of this caliber occur about once every 200 years (Glynn and Colgan, 1992). This evidence stems from boulder coral growth studies. One of the oldest corals found in the Eastern Pacific was a 350-year-old *Pavona clavus* colony. This age is not too old compared to the Atlantic corals' lives spanning around 500 years! The Atlantic system may have warming trends, but generally has greater thermal stability than the Eastern Pacific. The dynamic Western American coast is not conducive to a tenacious reef foothold. The Eastern Pacific's chaotic nature could be equated to a drought-prone terrestrial region where only hardy plants are the perpetual residents. Similar to its earthen counterpart, humans are attempting to "reseed" the devastated reefs. Conservatory research conducted by Guzmán (1991) suggests transplanting various coral species to a destroyed reef framework. These colonies would grow and proliferate thereby accelerating the natural recolonization processes and minimize bioerosion. Although the intent of this research is to repair damage inflicted by human activities, it is equally applicable to rebuilding a post-El Niño wasteland. Unfortunately, the transplanted colonies were chipped away from an existing reef system; injury occurs to one coral outcrop to help rebuild a second reef.

A solution to this dilemma is to construct coral greenhouses. This type of facility was successfully constructed in Detroit, Michigan (Perrin, 1993). Perrin was able to cultivate a wide variety of corals within this greenhouse using massive filtration systems and subsidizing the water with trace elements. This type of installation could be used to cultivate indigenous corals in trouble-prone areas. A cross between this greenhouse and Guzmán's restoration program would allow the coral reseeded *without* damaging an existing reef. A second benefit under a controlled greenhouse is a multitude of coral samples could be grown without the threat of extinctions as witnessed in the 1982-83 ENSO.

These arguments pose an ethical question: Should coral reef conservation efforts become implemented? Humans may hold some responsibility to reseed regions devastated by their own activities. However, in the cases of a natural catastrophe, should humans intervene with a natural cycle such as El Niño? As discussed in previous paragraphs, a massive ENSO occurs once every couple of centuries. Perhaps the Eastern Pacific marine ecosystem *requires* this sort of cleansing and rebirth similar to the more frequent fires in the fire climax communities or extensive flooding along a river's flood plains. El Niño events usually do not destroy all forms of marine life; the ENSO might be necessary to control parasites and other undesirable organisms similar to droughts which hinder damaging plant fungi. El Niño is a phenomenon whose origin and consequences are not fully understood. These details must be identified before humans decide they hold more knowledge than the book of nature.

### Works Cited

- Blank, Rudolf J. and Robert K. Trench. 1985. Speciation of symbiotic dinoflagellates. *Science* 220:656-658.
- Blank, Rudolf J. and Robert K. Trench. 1988. Nomenclature of endosymbiotic dinoflagellates. *Taxon* 35:286-294.
- Brown, B. E. and Suharsono. 1990. Damage and recovery of reefs affected by El Niño related seawater warming in the Thousand Islands, Indonesia. *Coral Reefs* 8:163-170.
- Buddemeier, Robert and Daphne G. Fautin. 1993. Coral bleaching as an adaptive mechanism: a testable hypothesis. *BioScience* 43:320-326.
- Cullen, John J., Patrick J. Neale, and Michael P. Lesser. 1992. Biological weighting function for the inhibition of phytoplankton photosynthesis by ultraviolet radiation. *Science* 250:848-850.
- Dayton, P. K. and M. T. Tegner. 1984. Catastrophic storms, El Niño, and patch stability in a southern Californian kelp community. *Science* 224: 283-285.
- Falkowski, Paul D., Zvy Dubinsky, Leonard Muscatine, and James W. Porter. 1984. Light and the bioenergetics of a symbiotic coral. *BioScience* 34:705-709.

- Fang, L.-s., Y.-w. J. Chen, and C.-s. Chen. 1989. Why does the white tip of stony coral grow so fast without zooxanthellae? *Marine Biology* 103:359-363.
- Gates, Ruth D., Garen Baghdasarian, and Leonard Muscatine. 1992. Temperature stress causes host cell detachment in symbiotic cnidarians: implications for coral bleaching. *The Biological Bulletin* 182:324-332.
- Glynn, P. W. and L. D'Croz. 1990. Experimental evidence for high temperature stress as the cause of El Niño-coincident coral mortality. *Coral Reefs* 8:181-191.
- Glynn, P. W. and W. H. de Weerd. 1991. Elimination of two reef-building hydrocorals following the 1982-83 El Niño warming event. *Science* 253:69-71.
- Glynn, Peter W. 1984. Widespread coral mortality and the 1982-83 El Niño warming event. *Environmental Conservation* 11(2):133-146.
- Glynn, Peter W. and Mitchell W. Colgan. 1992. Sporadic disturbances in fluctuating coral reef environments: El Niño and coral reef development in the Eastern Pacific. *American Zoologist* 32(6):707-718.
- Goreau, Thomas J. 1992. Reef and community change in Jamaica: 1951-1991. *American Zoologist* 32(6):683-695.
- Graham, N. E. and W. B. White. 1988. The El Niño cycle: a natural oscillator of the Pacific Ocean-atmospheric system. *Science* 240: 1293-1302.
- Grove, Jack S. 1984. At the heart of El Niño: too warm waters surround the Galápagos Islands. *Oceans* 17:3-8.
- Guzmán, Héctor M. 1991. Restoration of coral reefs in Pacific Costa Rica. *Conservation Biology* 5(2):189-195.
- Jokeil, P.L. and R.H. York. 1984. Importance of ultraviolet radiation in photoinhibition of microalgal growth. *Limnology and Oceanography* 29:192-193.
- Jokiel, P. L. and S. L. Coles. 1990. Response of Hawaiian and other Indo-Pacific reef corals to elevated temperature. *Coral Reefs* 8:155-162.
- Kleppel, G. S., R. E. Dodge, and C. J. Reese. 1989. Changes in pigmentation associated with the bleaching of stony corals. *Limnology and Oceanography* 34:1331-1335.
- Knowlton, Nancy, Ernesto Weil, Lee A. Weigt, and Héctor M. Guzmán. 1992. Sibling species in *Montastraea annularis*, coral bleaching, and the coral climate record. *Science* 255:330-333.
- Lesser, Michael P. and Wayne R. Stochaj. 1990. Photoadaptation and protection against active forms of oxygen in the symbiotic procaryote *Prochloron* sp. and its ascidian host. *Applied and Environmental Microbiology* 58:1530-1535.
- Pearse, V.B. and L. Muscatine. 1971. Role of symbiotic algae in coral calcification. *The Biological Bulletin* 141:350-363.
- Perrin, Richard. 1993. Coral farming in Detroit. *Seascope* 10:2.
- Philander, S. G. H. 1985. El Niño and La Niña. *Journal of Atmospheric Sciences* 42(23):2652-2662.
- Porter, James W., William K. Fitt, and Howard J. Spero. 1989. Bleaching in reef corals: physiological and stable isotopic responses. *Proceedings of the National Academy of Sciences of the United States of America* 86(23):9342-9346.
- Roberts, Leslie. 1991. Greenhouse role in reef stress unproven. *Science* 253:258-259.
- Rowan, Rob and Dennis A. Powers. 1992. Ribosomal RNA sequences and the diversity of symbiotic dinoflagellates (zooxanthellae). *Proceedings of the National Academy of Sciences in the United States of America* 89:3639-3643.
- Steen, M.G. 1986. Evidence for heterotrophy by zooxanthellae in symbiosis with *Arptasia pulchello*. *The Biological Bulletin* 170:267-278.
- Wood, Elizabeth M. 1983. *Corals of the world*. Neptune City, NJ: T.F.H. Publications. 256 pages.

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