A Struggle For Existence: Growth-Limiting Impacts of El Nino Events on Galapagos Coral Reef Systems

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ABSTRACT: Coral reefs are rare in the Galapagos because a number of biotic (biological) and abiotic (physical) factors restrict their growth. The primary limiting factors include: include cold-water currents, predation by corallivores, and oscillating sea surface temperatures due to recurring El Nino events. This paper focuses on the primary and secondary effects of El Nino events, particularly the biological implications for anomalous El Ninos. I will use the intense 1982-83 El Nino as a case study for extreme natural perturbances to Galapagos reefs, look at how the reefs have responded, and touch on the long-term implications El Nino events may have on coral reef survival in this unique archipelago.

INTRODUCTION: Visualize a coral reef. You are probably imagining a scene with abundantly diverse hard and soft coral structures in an astounding array of hues teeming with schools of fish, sharks, and marine invertebrates. Most coral reefs in the Pacific fit this idyllic description. Yet in the Galapagos Islands, 600 miles off the coast of Ecuador,
what lurks below the water’s surface is a far cry from copious coral communities. The few reefs that do exist usually end up fragilely broken and washed upon the shore. Therefore, my paper aims to answer the questions, why are Galapagos reefs ending up on the beach, and, in accordance with Darwin’s theory of natural selection, will they be able to adapt fast enough to cope with environmental pressures like heat stress?

BACKGROUND: Corals had an adverse start in the Galapagos. Coral larvae colonized the eastern Pacific from Indonesia in the Oligocene era around 30 million years ago. Around 18,000 years ago, most of the corals were exposed by low sea levels and died. 2,000-4,000 years ago, coral growth conditions improved allowing coral structures to develop mostly uninterruptedly over this time (Glynn 2004: 191). Coral species in the eastern Pacific were much more diverse in the Early Cenozoic and Cretaceous than in the Late Cenozoic (Bowman 1966: 127). Across the Pacific, Indonesia and Australia have well-developed reefs because of ideal conditions. Recruits settled on barren, basaltic substrates in Galapagos.

Map of number of different coral species around the world. Galapagos are in area of less than 50 species. The Pacific Ocean is a vast matrix isolating Galapagos from biodiverse waters of Indonesia and Australia.

Picture credit: http://www.tatnews.org/emagazine/Green_Fins/Map_globalcoral.gif
Today, corals are considered depauperate, or poorly represented. There are around five known reef structures and they are generally small, thin reef structures of less than 100 m² usually composed of a single species (Colgan 1991: 106). This lack of biodiversity of coral species compounds other selection pressures, because when one species dies off, there are no other species within reasonable range to recolonize. There are around thirteen known reef-building species in the Galapagos, none of which are endemic to the archipelago (Colgan 1991: 105). The three genera of reef-building corals that are found here grow during warm season when warmer waters from the north raise the temperatures to 27-29ºC (Constant 2002: 29). The little reefs that exist are restricted to areas of low upwelling, where they can tolerate the sea surface temperatures of over 25ºC. In the southern islands, reefs found on the northern coasts. In the central region, there is patchy development. In the northern islands, deeper water reefs along southern shores, due to strong swells (Constant 2002: 27).

On top of their adverse colonization to the Galapagos Archipelago, coral experiences a variety of selection pressures, including competition for space (with other corals, but mostly with algae), predation, adverse oceanographic conditions (only growth from July to November when reef development conditions are marginal), and intense physical and biological perturbances, such as El Nino events, which I will now discuss further in this paper (Constant 2002: 29).

HYPOTHESIS: My hypothesis is that with the increasing frequency, magnitude, and duration of El Nino events, reef-building corals in the Galapagos may not be able to adapt fast enough to maintain their slim existence due to their slow generation turnover,
low genetic diversity, and low variation. They have survived this long because they have had enough time in between El Nino events for coral recruits to recolonize. But with the increasing frequency of intense El Ninos such as those of 1983 and 1998 that wipe out entire reefs, corals may not be able to recolonize fast enough or may be simply unable to proliferate because of their geographic isolation from other reefs.

FINDINGS: El Nino/Southern Oscillation (ENSO) events originate in the western Pacific and occur every 3-7 years. Yet more rare, intense El Ninos have been occurring with greater frequency over the past 6,000 years (Podesta 1997: 15758). 12 to 30 of such abnormally intense events have interrupted Galapagos reef building to some extent, with the biggest and longest-lasting interruptions in the past several decades. El Nino events result in decreased upwelling and higher sea surface temperatures. Higher sea surface temperatures are most destructive to coral and cause massive "bleaching," which is the loss of photosynthetic symbiotic algae resulting in a white, deadened skeletal appearance. Species disappearance and reef growth slowing have followed these events.
A case study for looking at the affects on intense El Nino events on the coral reef structures in the Galapagos is the 1982-83 El Nino. It was the strongest event in the past 400-500 years and resulted in over 95% coral mortality in the Galapagos and prolonged warming of 2-3°C above normal lasting for a full year or so after the event (Colgan 1991: 100). The prolonged warming led to widespread coral bleaching. The combined biotic and abiotic factors stressed the reefs almost beyond their ecologic threshold. Slow recovery has followed along with long-term secondary disturbances including the death of most branching corals. Some colonies regenerated but most continue to bioerode. Three species disappeared from their known sites and yet reappeared in new habitats several hundred meters away. A study showed that relatively low rates of larval recruitment have occurred on eastern Pacific coral reefs following the 1982-83 El Nino, suggesting that recovery of reef-building corals is extremely slow (Colgan 1991: 107).
The secondary biological effects of the 1982-83 El Nino have had and continue to leave a destructive wake. The increased sea temperatures eliminated the protective biotic barrier by removing *Pocillopora spp.* that surrounded many bottom areas and thwarted corallivores with nematocysts and crustacean guards. Without a protective biotic barrier, the sea star corallivore, crown of thorns (*Acanthaster planci*), predated heavily on the coral (Glynn 1985: 295).

Sea urchins (*Diadema mexicanum* and *Eucidaris thouarsii*) also did their share of damage by grazing on dead corals, causing erosion of reef framework structures. Internal bioerosion from clinoid sponges, polychaetous annelids, lithophagine bivalves, and like organisms can account for up to a quarter to half of total bioerosion.

The primary and secondary consequences of major El Nino events such as that
from 1982-83 can permanently damage reefs. Persistent biotic disturbances are compounding the slowing reef recovery. The after effects of 1982-83 show that ecologically rare but recurring intense El Nino events can influence the long-term dynamics of Galapagos reef development. One generation of reef growth is not transferred to the next because El Ninos interrupt the continuity of space and time necessary for the formation of substantial reefs (Colgan 1991: 118).

Ecological resilience is a measure of the rate at which an ecosystem returns to a particular state after a perturbation or disturbance. Studies show that corals may survive and recover after mild thermal stress, but typically show reduced growth, calcification, and fecundity and may experience diseases (Hoegh-Guldberg 2007: 1739). As a consequence of the 1982-83 El Nino, Pocillopora colonies died in large numbers resulting in the local extinction of one species (Colgan 2002: 107).

CONCLUSIONS: El Nino events are occurring with greater frequency, increased magnitude, and longer duration, raising sea temperatures more now than in the past 300 years. Since 1983, progressive coral death and erosion has characterized the waters of the Galapagos. Three endemic Galapagos coral species were listed on the 2007 IUCN Red List of Threatened Species, two of which are critically endangered and one is vulnerable.
Adaptation to sporadic thermal stress requires selective mortality of less thermally tolerant individuals. Yet acclimatization in Galapagos corals seems unlikely because intense El Niño events provide an inadequate amount of coral to recolonize, and due to the geographic isolation of the Galapagos, recruitment of better-adapted corals from more biodiverse regions such as the Indo-Pacific is improbable. On the molecular scale, the relatively long generation times and low genetic diversity and low variation of Galapagos coral reefs result in slow rates of adaptation (Hoegh-Guldberg 2007: 1743). Many scientists, including reputable coral researcher Ove Hoegh-Guldberg agree that reef-building corals and their symbiotic algae do not appear to have the capacity to adapt fast enough (genetically) or accumulate (phenotypically) to sporadic thermal stress and other sudden environmental changes (Hoegh-Guldberg 1999: 853). Not only are corals unlikely to adapt, they are unlikely to recover at all. Bioerosion after such extreme El Niño events prevents coral communities from developing substantial reef structures. This inability to adapt and recover could lead to possible extinction whenever the next big El Niño hits.

RECOMMENDATIONS: Further studies on the adaptive potentials of coral and their symbionts are needed in order to assess the relevance of conservation efforts; however, current scientific evidence implies the likelihood of continued reef erosion and further degradation of the coral of the Galapagos due to the increasing frequency, magnitude, and duration of El Niño events. To a notable extent, human activities contribute to the loss of reefs: anthropogenic carbon dioxide emissions contribute to global atmospheric and oceanic warming thus fueling El Niño events. Likewise, fishing activities disturb the natural balance of marine bioeroders to their predators. Yet a longer-term perspective on
natural variability in climate system must be established before anthropogenic changes can be assessed. Without tremendous conservation efforts aiming to curb CO₂ emissions and control detrimental fishing practices, the future of the Galapagos coral reefs look bleak. Thus it appears a Herculean worldwide, concerted effort to reduce our footprint on the environment and learn more about the adaptive potential of coral is needed to promote a healthier future for the reefs of the Galapagos.

REFERENCES:


Glynn, Peter. "El Nino-associated disturbance to coral reefs and post disturbance


