Coral reefs in uncertain seas

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If we were to apply the concepts of inflow, outflow and feedback to natural systems, we would see the old adage, "For every action, there is a reaction" illustrated with clarity. A system in equilibrium that displays the full range of trophic biodiversity within a coral reef for example, thrives within a narrow set of conditions and relies on light, temperature, sedimentation, salinity, and pH. Within nature, all species perform their function within their niches of this trophic cascade. When the cascade is broken, you have a reaction or adaptation, which we call feedback. So, if one or a series of requirements for the health of the system are impacted in a coral reef, for example the feedback loop can lead to coral bleaching and what is called regime shift, where the biodiverse reef slowly dies and is replaced with an algae/urchin stage to sea grass. These extremes represent a warmer, acidic sea.

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Introduction

My work is an extension of a *Synergy-Ocean Stories* collaboration of artists chosen to translate marine research with scientists from the Woods Hole Oceanographic Institution and Oceans at MIT Joint Program, with curatorial assistance from Brown University. In my case, I had the good fortune to work with Dr. Katie Shamberger and Hannah Barkley, Alice Albert, Emily Moberg, and Whitney Bernstein of the WHOI and MIT, who provided insights, visual files, and published papers for review and assimilation on the resilience of the Rock Reef off of the Republic of Palau and global coral reefs. My role as a United Nations Artist for the Oceans and an advocate for the preservation and protection of marine ecosystems and biodiversity is to make the science accessible to the general public in public forums, through publication, and through site specific art installations. My photographically collaged digital panels and soundscapes were exhibited within *Ocean Stories* at the Rotch Library MIT, the Museum of Science-Boston, the New Bedford Art Museum, and were donated to the Sea Lab to inspire future generations of scientists.

The concept of Equilibrium is illustrated by the healthy Kingman coral reef within the Indo-Pacific Line Islands. Kingman reef depicts a kaleidoscopic, biodiverse reef with schools of fish, sharks, and sea turtles (Figure 1). The water is crystal clear. A healthy reef can eventually recover from natural stressors as typhoons and El Nino events. The reefs degrade when natural events are coupled with anthropogenic impacts and climate change effects. Degradation of Fanning Island Reef, Kiritimati and Palmyra Islands from anthropogenic impacts is depicted as a compromised reef in early stages of disease, and bleaching.

Figure 1: Biodiverse coral reef in equilibrium [1].

Transformation at Kiritimati, Christmas Island occurs with the expulsion of temperature sensitive symbiotic coral Zooxanthellae and coral bleaching. Regime shift transforms the reef to an altered state of algae with sea urchins and bare stone (Figure 2). The biodiverse reef is dying. The water is murky, warm, and acidic. The sea floor is littered with trash and waste. There are no fish.

Figure 2: Tropical coral reef degradation [1].

Coral reefs are resilient. Centuries of adaptation to acidic water and warm temperatures can be seen at Papua, New Guinea's volcanic vents, where a monoculture of coral exists with algae, until conditions worsen and the coral corrodes. Then the reef is replaced with temperature tolerant sea grass (Figure 3). This may be a glimpse into the future of our oceans.

Coral reefs are adaptive. Within a centuries old reef unique in all of the world's oceans, there is a reef displaying remarkable biodiversity within acidic and warm water at Rock Reef, Palau, Micronesia (Figure 4). This Rosetta Stone of genetic biodiversity is threatened with pollution and overuse and needs immediate international protection.

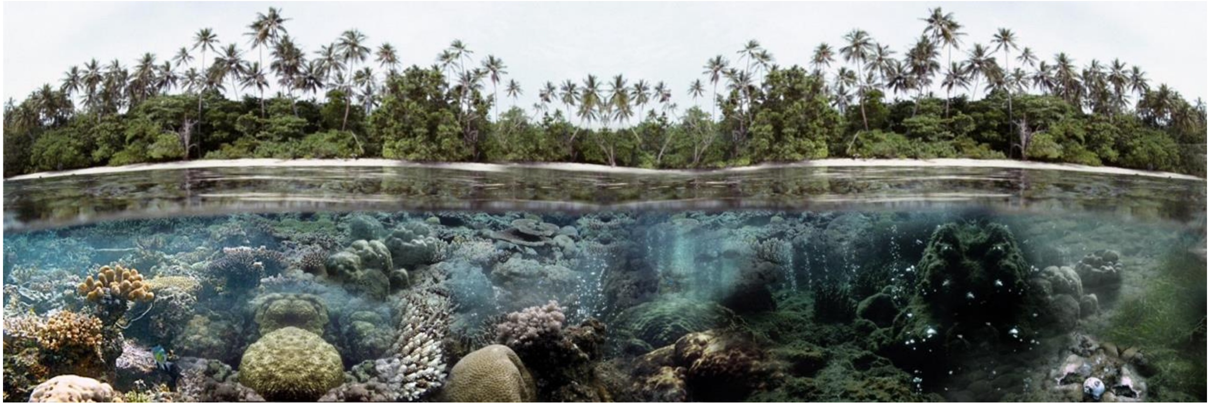

Figure 3: Tropical coral reef acidification [1].

Figure 4: Tropical coral reef resilience [1].

Methodology

Regime shift: When the parameters for equilibrium in the life cycle of coral reefs are exceeded, regime shift occurs (Figure 5).

Tropical coral reef: Parameters for equilibrium

- Location: Kingman Coral Reef, Line Islands, Indo-Pacific, Great Barrier Reef, Australia.
- Soundscape: Rose Atoll, American Samoa.
- Light: Light levels are critical for coral to maintain their symbiotic relationship with the photosynthetic zooxanthellae algae, which give coral their colour. With light penetration corals can survive to a depth of 150 feet (48 m).

Sedimentation: Coral reefs require water clarity to promote photosynthesis of their symbiotic algae and an unsilted coral surface to feed and respire.

- Seawater Temperature: Optimal coral growth occurs between 73-77°F (23-25°C) Coral species can tolerate temperatures between 61-95°F (16-35°C).
- Salinity: Corals can tolerate a narrow range of salinities from 30 to 40 parts per thousand (ppt).
- pH: Coral reefs and the other ecosystems which depend on them require that atmospheric carbon dioxide remain below 350 parts per million (ppm). Pristine seawater has a pH reading of 8 to 8.3 of hydrogen ions present. The coral reefs as we know them are dependent upon a

stable pH level within the oceans. Calcification or the ability of an animal to build a calcium carbonate structure or a shell depends on the saturation state of the surrounding waters.

Biodiversity [2]: Coral reefs are one of the most biodiverse ecosystems on earth. All species play a part in regulating the health of the reef, from predatory sharks to herbivore fish, to scavenging crabs, and filtering shellfish (Figure 6).

Figure 5: Tropical coral reef regime shift [1].

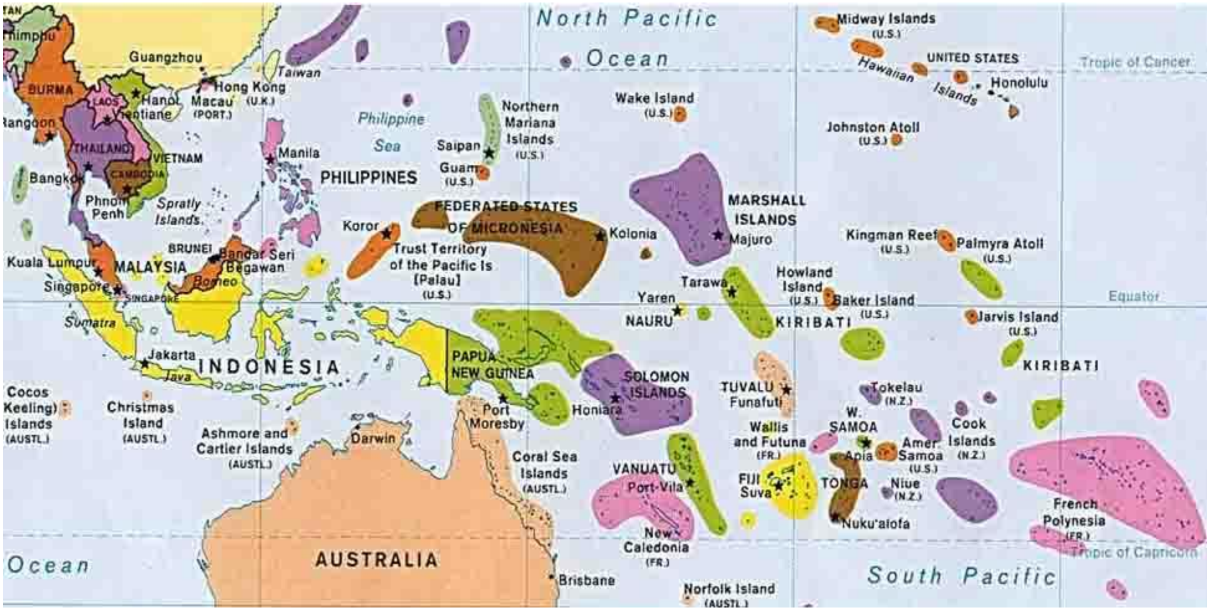

Figure 6: Biodiversity in the Indo-Pacific region [3].

Tropical coral reef: Parameters for degradation

The reefs degrade when natural events are coupled with anthropogenic impacts and climate change effects. Degradation of Fanning Island Reef, Kiritimati and Palmyra Islands from anthropogenic impacts is depicted as a compromised reef in early stages of disease, and bleaching.

- Location: Fanning Island Reef, Kiritimati Island, and Palmyra Island
- Soundscape: Alega Bay, American Samoa Islands

Tropical coral reef: Parameters for transformation

Transformation at Kiritimati, Christmas Island occurs with the expulsion of temperature sensitive symbiotic coral Zooxanthellae and coral bleaching. Regime change transforms the reef to an altered state of algae with sea urchins and bare stone. The biodiverse reef is dying. The water is murky, warm, and acidic. The sea floor is littered with trash and waste. There are no fish.

- Location: Kiritimati, Christmas Island
- Soundscape: Pokai Bay, Oʻahu, Hawaii

Inputs:

- Light: Sedimentation - the quality of light can be affected by turbidity.
- CO_2 - acidification of the water promotes algae growth, which shades the coral.
- Sedimentation: Input: Population growth and urban development cause erosion, pollution, sewerage runoff into the sea.
- Feedback Loop: The input of sedimentation and pollution creates turbidity and explosive algae growth, which inhibits coral growth.

Seawater Temperature:

- Input: Greenhouse gas emission increase
- Feedback Loop: Global warming, rising seawater temperatures cause coral bleaching, death and to regime change to more tolerant species as algae and sea grass.

Salinity:

- Input: Greenhouse gas increase
- Feedback loop: Glacier melting, increased storm events, change of salinity in oceans shall affect coral reefs and related marine species.

pH:

- Input: Atmospheric CO_2 and greenhouse gas emissions
- Feedback Loop: Tropical coral growth rate or calcification decreases as acidity increases, causing a lower pH reading. For every 0.1 decrease in pH there is an approximate 8% decrease in calcification. (Fernand and Brewer (2007) Significance of Changing CO_2 Levels).

Within Oceana's Effects of Ocean Acidification on Corals publication dated June 27, 2023 [4] a dire warning is issued: "*A 20% increase above current carbon dioxide levels, which could occur within the next two decades, could significantly reduce the ability of corals to build their skeletons and some could become functionally extinct within this timeframe.*"

Ocean acidification will have a profound impact on humans including economic loss, coastal protection, tourism impacts and fisheries.

Biodiversity:

- Input: Over-fishing, tourism, aquarium trade
- Feedback Loop: Over fishing has altered the ecological dynamics of marine communities allowing some species to dominate the reefs. For example, shark fining causes an explosion in herbivore and coral eating fish, which damage the reef and upset the balance of nature. Netting the herbivores allows for an algae explosion on the reef, smothering the coral. Fishing practices as dynamite and cyanide used to collect aquarium and souvenir coral and shells also kill the reef and attendant species. Ecotourism with scuba divers touching the corals and dragging anchors damage and kill the living reef.

Tropical coral reef: Parameters for resilience

Coral reefs are resilient. Centuries of adaptation to acidic water and warm temperatures can be seen at Papua, New Guinea's volcanic vents, where a monoculture of coral exists with algae, until conditions worsen and the coral corrodes. Then the reef is replaced with temperature tolerant sea grass. This may be a glimpse into the future of our oceans.

- Location: Normandy and Dobu Islands volcanic seeps, D'Entrecasteau Island group, Milne Bay Province, Papua New Guinea.

Tropical coral reef: Parameters for adaption

Coral reefs are adaptive. Within a reef unique in all of the world's oceans, there is a reef displaying remarkable biodiversity within acidic and warm water at Rock Reef, Palau, Micronesia. This Rosetta Stone of genetic biodiversity is threatened with pollution and overuse and needs immediate international protection.

- Location: Rock Reef, Palau, Micronesia

Tropical coral reef: Policy recommendations

Oceana, Protecting the World's Oceans has summarised the recommendations of scientists, the United Nations, and NGOs as follows to mitigate the effects of climate change on our oceans:

1. Adopt a policy of stabilising atmospheric carbon dioxide at 350 ppm.
2. Pursue Zero net carbon emissions within decades.
3. Promote energy efficient and low carbon fuels.
4. Practice energy conservation, develop efficient cleaner fuels, and promote efficient mass transit.
5. Shift to alternative energy sources.
6. Eliminate subsidies to fossil fuel industries; prohibit burning coal in favour of renewable energy, stop extractions of oil, gas and coal from sensitive locations as the Arctic.
7. Regulate carbon releases.
8. Internalise emissions costs. Regulate shipping and aircraft.

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9. Preserve natural resilience.
10. Protect reefs, which have shown millennial adaptation to volcanic vent warmth and acidity, as bio-reserves to preserve the genetics for the future.
11. Regulate overfishing and pollution.
12. Address climate change.

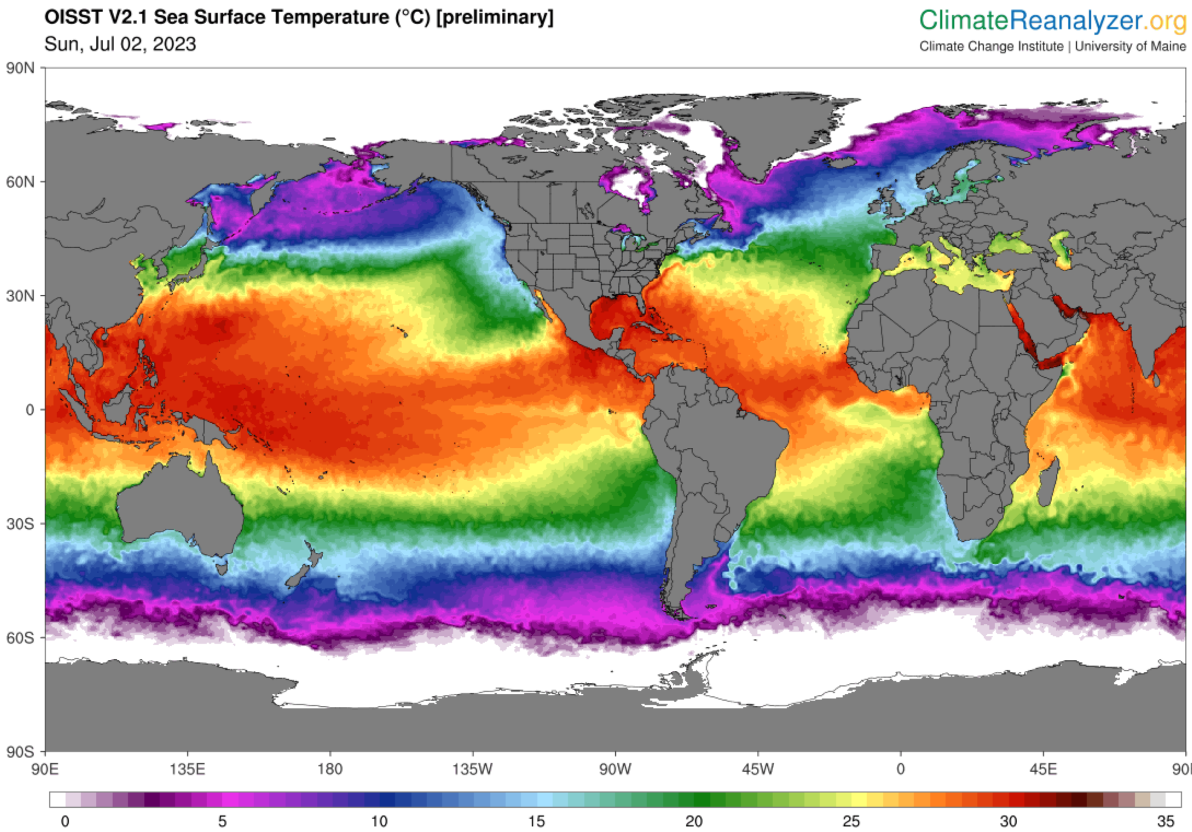

Figure 7: Sea Surface Temperature [5].

Widespread marine heatwaves (MHW) are currently found in the eastern equatorial Pacific, the Northeast Pacific, the Northwest Pacific and the Sea of Japan, the tropical North Atlantic, the Caribbean Sea, the Gulf of Mexico, the Northeast Atlantic from northern Africa to Norway, the Southwest Pacific near New Zealand, and the Southern Indian Ocean, and all sectors (Indian, Pacific, Atlantic) of the Southern Ocean [6].

Conclusions

Changes in ocean water temperature have widespread implications for marine ecosystems functioning in the face of rapid global change. Many of the coral reefs cited within this paper have developed resilience to temperature, acidification, and sedimentation over thousands of years within favourable locations. The ability of tropical coral reefs within the world's oceans to develop resilience through adaptation and mutation in human time is questionable. Colonisation of the world's coral reefs by adapting coral species and their endosymbiotic Zooxanthellae within human time seems improbable. The world's tropical coral reefs may become a monoculture of the most tolerant species in the near term without major policy and management shifts. The pristine coral reefs of the past may be lost to an alternate state of algal-dominated reefs because of development pressures, overfishing, pollution, climate change, and lack of international consensus on a plan of action.

Acknowledgements

In my collaboration, with marine scientists at Woods Hole Oceanographic and MIT, I have vicariously travelled to the most remote islands in the Indo-Pacific to retell a Malthusian story of the coral life cycle in equilibrium, degradation, transformation, acidification, and adaptive resilience over millennial time. Special thanks to Dr. Katie Shamberger and Hannah Barkley, Thanks to Kathrina Fabricius and Laetitia Plaisance of the Australian Institute of Marine Science and to Kevin D. E. Stokesbury, Ph.D. at SMAST, UMASS-Dartmouth for his mentoring to shape the manuscript from a narrative to a research paper.

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