HIGH SCHOOL EDITION
Journal of Student Research

Volume 12 Issue 4 (2023)

The Effects of Climate Change on Hawaii's Coral Reef Ecosystem Over the Past 20 Years

Aaron Joshi[1], Diana Ribeiro Tosato[2] and Magaly Koch[#]

[1]Sage Hill School, USA
[2]Brock University, Brazil
[#]Advisor

ABSTRACT

The Hawaiian Islands are known for their rich marine biodiversity in coral reef ecosystems. However, in the last 20 years, changes in sea surface temperatures, sea levels, carbon dioxide levels, and ocean pH have severely impacted these reef ecosystems. Hawaiian corals can experience heat stress with temperatures as little as 1-2 °C above the average and thermal stress events were prevalent from 2014-2017, causing bleaching and increasing mortality. The increase in sea level in Hawaiian marine ecosystems has caused reefs to "drown" from the lack of sufficient sunlight and thus suffer from bleaching. Coral disease is linked with high temperatures, seen through the common reef-building coral disease white syndrome. Invasive species outbreaks, with *Acanthaster planci* as an example, are also correlated with changes in the climate and reef communities. With the loss of coral, there have been consequences on marine biodiversity in Hawaiian reef ecosystems. Specifically, the three most native coral genera, *porites*, *montipora*, and *pocillopora*, which are the most important species to the reefs, have been declining in population. As a result, higher threat statuses have been observed among turtles, reef fish, and marine mammals that are reliant on their coral reef ecosystems for protection and food sources.

Introduction

Corals are the center of the reef ecosystem, and essential to maintain a balance in biodiversity. Many fish, turtle, and mammal species are dependent on the presence of coral reefs. Corals also help control waves, shelter animals from predators, and prevent erosion. They are also important resources to humans, as they are essential parts of the native fishing and tourism industries (Hagen, 2018). This is why damage to corals is such a big deal; if coral reefs are destroyed, then the whole ecosystem is disrupted.

Anthropogenic climate change has exposed ocean and coastal ecosystems to conditions that are unprecedented, greatly impacting life in marine areas. Climate change not only causes marine heatwaves, sea level rise, and ocean acidification, but also worsens the impacts of habitat degradation, marine pollution, and introduction of invasive species (IPCC Chapter 3, 2022). According to the Intergovernmental Panel of Climate Change (IPCC, 2023), the average ocean temperatures have increased by 0.88 ℃ from pre-industrial levels (1850-1900 to 2011-2020) (IPCC, 2021). Moreover, global mean sea level (GMLS) has risen by 0.20 meters since 1901, and ocean pH has declined over the past few decades (IPCC Chapter 3, 2022).

Climate change has especially impacted coral reef ecosystems. Rising temperatures, rising sea level, and increased ocean acidity all contribute to bleaching of corals. As a result of the overexposure to these stressors, the corals are undergoing bleaching processes and in extreme conditions, dying (Spillman et al., 2011). Coral bleaching, triggered by many factors, especially negative changes in the environmental conditions, occurs when corals release or consume the zooxanthellae (algae) living within their tissue, breaking the symbiotic relationship, and exposing its vulnerable skeleton. Due to temperature increase, ocean acidification, and sea level rise, bleaching events are becoming more frequent (Hagen, 2018).

The effects of climate change can be seen throughout the globe, although some areas are affected more intensely than others, such as Africa, South Asia, and small islands, such as Hawaii (Hare et al., 2011). The Hawaiian Islands have been an object of curiosity for how badly its coral reefs have been affected. The aim of this study was to analyze how climate change has impacted marine biodiversity in Hawaii's coral reef ecosystem for the past 20 years. This study covers the effects of climate change and damages to reefs and biodiversity in reef ecosystems for marine areas off the coast of Hawaii.

Methodology

Study Area

The study area consists of the coasts of the Hawaiian Islands, Hawai'i, Maui, Lana'i, Moloka'i, O'ahu, Kaua'i, Ni'ihau, and Kaho'olawe. Hawaii (6,423 square miles) has an estimated population of 1.43 million, and is located at 19.8987 degrees North, 155.6659 degrees West. Most of the data was gathered from Maui, the Big Island, and Moloka'i.

Figure 1. Map of 7 Hawaiian Islands and coastal regions. Data from UN Biodiversity Lab, 2023

This area was chosen due to its rich biodiversity, and high amount of tourism, which has increased both revenue of the state and damage to the marine environment (Wiener et al., 2009). The Hawaiian government has estimated that 21% of the state's income comes from tourism (State of Hawaii, 2023). According to the Department of Business, Economic Development, and Tourism (DBEDT, 2023), visitor arrivals and expenditure statewide showed an increase from 6,442,020 in 2003 to 10,386,673 visitors in 2019, with each year showing an upward trend. An expenditure of $144,206.63 Million was also calculated from 2009-2019.

The Hawaiian region was also chosen as the study area due to its active climate. Hawaii is a dry region susceptible to effects of climate change. The islands are prone to disasters such as fires (Marris, 2023), volcanic eruptions, and earthquakes (*Hazards | U.S. Geological Survey*, 2023). Recently, in August 2023, fires in Maui were caused from the winds of Hurricane Dora. These fires, despite occurring on land, also cause damage to reef by contaminating the water (Al Jazeera, 2023).

The period that data was taken from is 2003-2023, with a heavy focus on the years 2015-16 because of the El Niño, an ocean surface temperature warming event to above-average temperatures.

Data Collection

Climatic Factors

Geographic information systems (GIS) portals were used to acquire data from the study area in a 20-year interval. NASA Worldview (2023) and Google Earth (2023) were used to compare climatic factors through various layers derived from satellite observations (Aqua Modis, Topex/Poseidon, Jason-1,2, and 3). Sea Surface Temperature (SST) and SST anomalies (irregularly high or low values) during the 2015/16 El Niño were mapped from the Group for High Resolution Sea Surface Temperature (GHRSST) level 4 Multiscale Ultrahigh Resolution (L4, MUR), and SST anomalies (irregularly high or low values). Furthermore, anomalies in Sea Surface Height were mapped from the mean sea surface, derived from data from TOPEX/Poseidon and Jason-1, 2, and 3 satellites. National Oceanic and Atmospheric Administration (NOAA) OceanWatch datasets were used to map the changes in sea surface temperatures in the 5-year period surrounding the El Niño. Vital Signs of the Planet (NASA, 2023) was used to obtain data on global trends of Carbon dioxide, global temperature, ice melting, and sea level rise. The UN Biodiversity Lab (2023) was also used to observe coral reef connectivity. Connectivity refers to the extent to which populations are linked by the exchange of eggs, larval recruits, juveniles, or adults (UN Biodiversity Lab, 2023).

Coral Reefs

Of all the impacts of climate change on corals, bleaching is the most common (Hagen, 2018). Three main climatic factors, SST, Sea Surface Height, and Ocean Acidification were examined and linked with bleaching. Data concerning the direct impacts of these climatic factors on coral reefs themselves was collected through government websites/databases (such as NASA and State of Hawaii), and research papers from Springer Link, PLOS Biology, and other science journals. Direct effects of these climatic factors, such as coral heat stress, reef drowning, and disease, were analyzed through data graphed in other studies (see 3.2 sections 1-3). Climate change relationship with invasive species was also explored, and in this study, the Crown-of-thorns Starfish (COTS), *Acanthaster planci*, was used as an example.

Marine Biodiversity

NOAA coral status reports (2018) and marine life information sites provided in-depth information about the species making up the marine biodiversity of Hawaiian coral reef biomes and affected by the factors above. The coral species that are most prevalent in the study, from the *Porites*, *Montipora*, and *Pocillopora* genera, were chosen to represent the reef ("Coral Species," 2013). Three Species were selected to represent each genus, *Porites pukoensis*, *Montipora flabellata* (Blue rice coral), and *Pocillopora damicornis* (Cauliflower coral). The species were chosen based on The International Union for Conservation of Nature (IUCN) Red List (2023) advanced search for Hawaiian marine species in the order scleractinia, which contains all hard reef building corals. The species were classified based on the threatened level defined by IUCN. They are DD (Data Deficient), LC (Least Concern), NT (Near Threatened), VU (Vulnerable), EN (Endangered), CR (Critically Endangered), EW (Extinct in the Wild), and EX (Extinct). Other details on the Red List assessment page were noted, such as threats, population trends, etc. Fish, turtles, and marine mammals native to Hawaiian reefs were also inspected through the Red List, and their relationships with reefs were examined.

Results

Climate ChangE

According to NASA's global Climate Change site (2023), Carbon dioxide emissions caused by human activity are the main contributor to increasing temperatures. The oceans alone absorb 30% of all anthropogenic carbon emissions (NASA, 2023). Increasing temperatures also contribute to glacier melting, and therefore, rising sea levels. In the past 20 years, global CO_2 levels have risen from 326 to 422 parts per million (ppm), and global sea levels have risen 67mm (Figure 2).

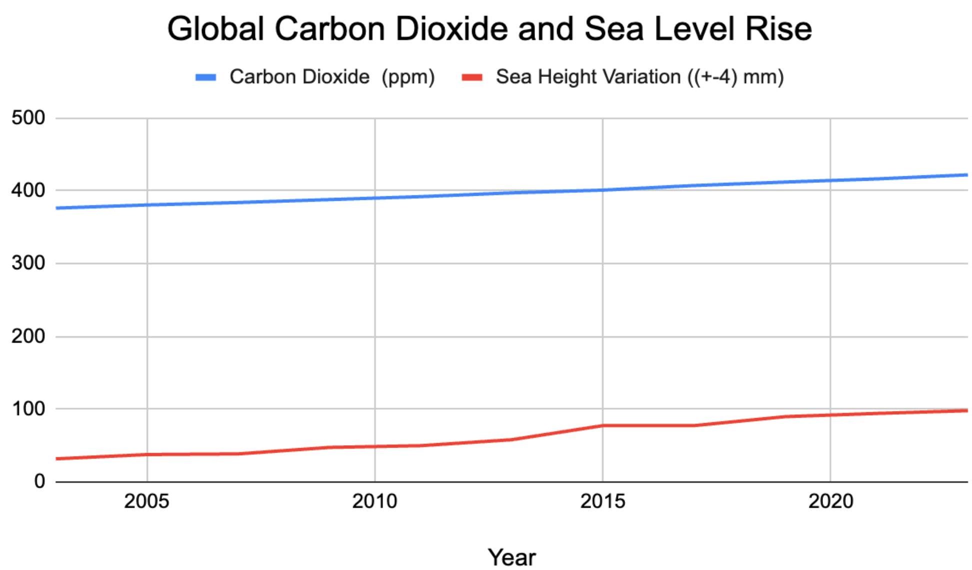

Figure 2. Global carbon dioxide and sea level rise from 2003 to 2023. Data from NASA 2023.

Sea Surface Temperature (SST) and SST Anomalies

Over a 10-year span (2005-2015), SST increased 1℃ (NASA Worldview, 2023). SST anomalies were particularly severe around the 2015 El Niño period. Temperatures rose to 2.5℃ above normal (26-28 ℃) from May to August of 2015. SST anomalies before, during, and after the 2015/16 El Niño are shown in Figure 3, created with NOAA Oceanwatch's Environmental Research Division's Data Access Program (ERDDAP).

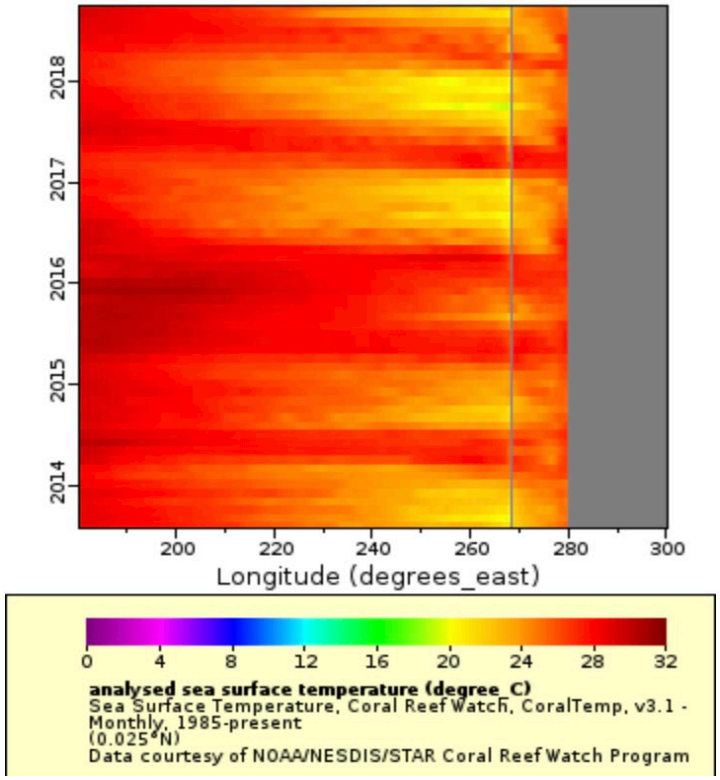

Figure 3. SST around Hawaii from August 2014 to 2018 hovmöller plot. Data from NOAA 2023.

Sea Level

Increasing SST also led to anomalies in sea level. NASA Worldview mapping of Sea Surface Height Anomalies in August 2014, 2015, and 2016 are compared in Figure 4.

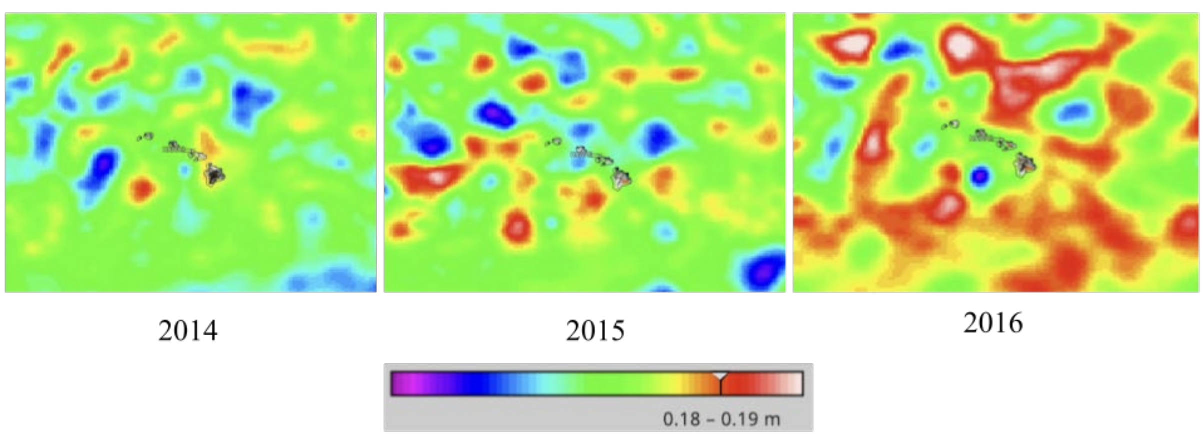

Figure 4. Sea Surface Height Anomalies from August 2014 to 2016. Data from NASA Worldview, 2023.

Ocean Acidification

Increased CO2 absorption by the ocean leads to its acidification, and therefore, a decline in marine pH and reduction of concentration of carbonate ions (building blocks of coral) (NOAA, 2018). This makes the water more acidic and less tolerable for corals.

The average ocean pH in 2016 was 8.1 (US EPA, 2016). The pH of Hawaii's waters has dropped around .04 (from 8.091 to 8.055) since 2003. Figure 5 displays the drop in pH from June 2003 to 2018, with data originating from the Aloha station in pH time series.

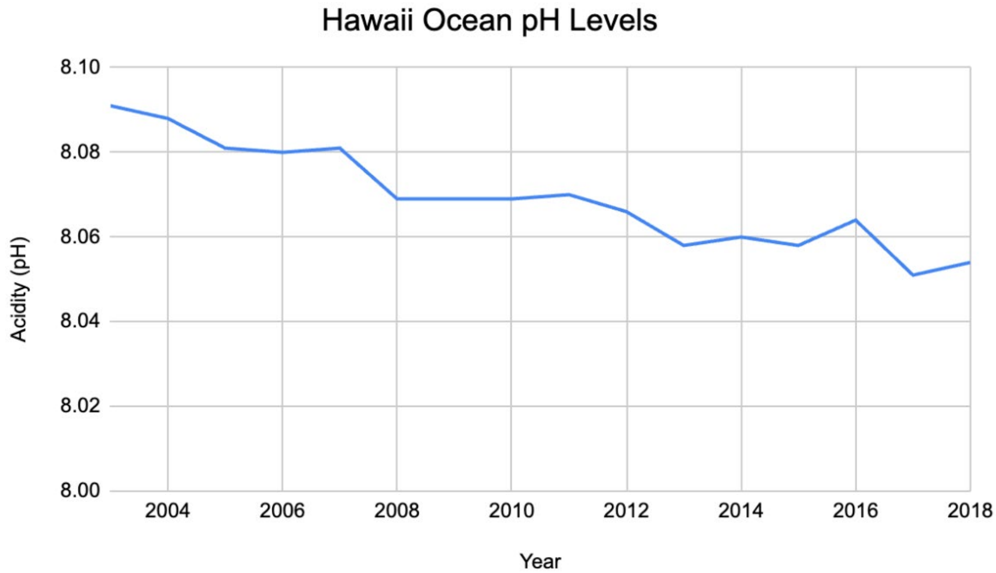

Figure 5. Hawaii Ocean pH level drop from 2003 to 2018. (Decline in Ocean PH, as Shown by Measured PH and PH Calculated from Dissolved Inorganic Carbon Concentrations and Total Alkalinity, at in Situ Temperature at the Aloha Station (Hawaii), and Global Annual Average PH — European Environment Agency, 2020)

Coral Reefs

As a result of temperature stress, sea level rise, and ocean acidification, bleaching events are increasing in severity and frequency, and coral cover (the proportion of seabed covered by coral and crustose coralline algae) is decreasing (NOAA, 2018). Figure 6 shows the decrease in West Hawaiian and Maui coral cover, the proportion of the seabed area occupied by corals, from 2004 to 2016.

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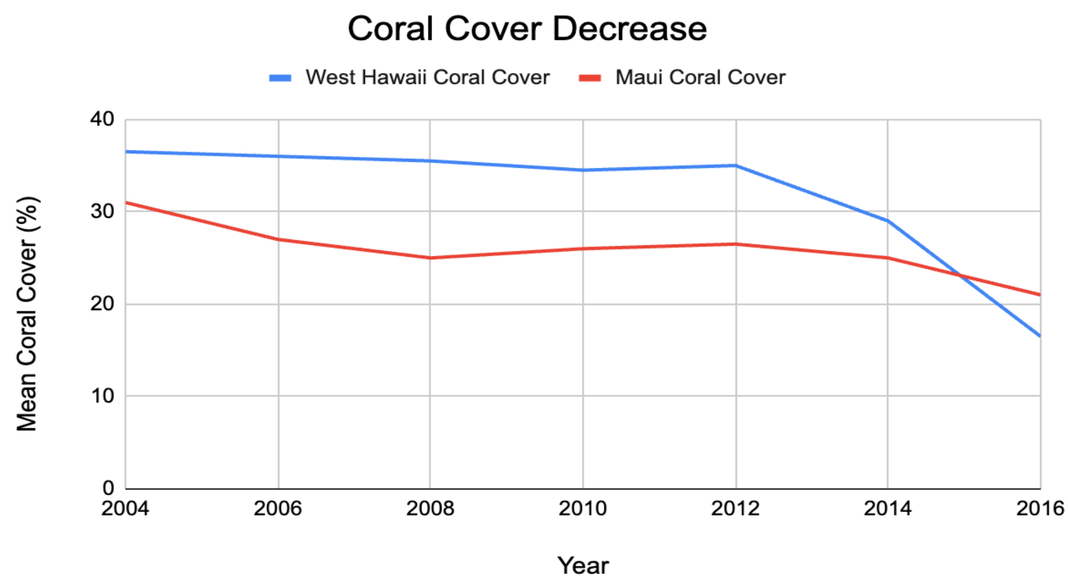

Figure 6. Coral cover decrease in West Hawaii and Maui from 2004 to 2016. Data from NOAA 2018.

The UN Biodiversity lab (2023) dataset displays the level of connectivity between each area containing coral reefs. Coral Reef Connectivity for Hawaii's coast is shown in Figure 7.

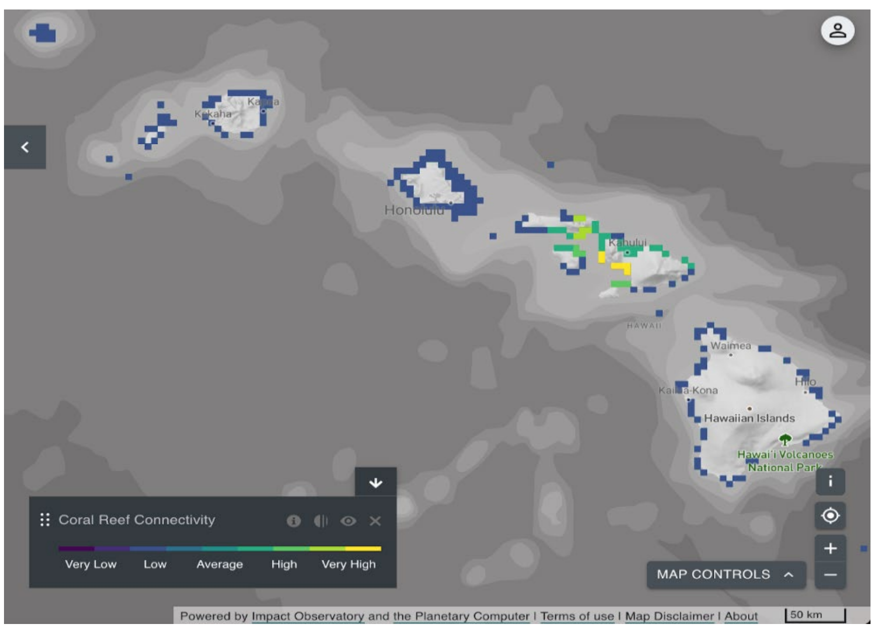

Figure 7. Coral reef connectivity off Hawaiian island coasts in August 2023. Data from UN Biodiversity Lab, 2023

Heat Stress

Heat stress that persists for several weeks, with ambient water temperatures as little as 1–2°C above a coral's tolerance level, has been shown to trigger coral bleaching (Liu et al., 2018). In the past decade alone, consecutive thermal stress events in 2014, 2015, 2016, and 2017 have had global impacts on the structure and functioning of coral reef ecosystems (Hughes et al., 2017). Thermal stress disrupts the partnership between corals and their algal symbionts causing them to lose their color, and in cases of prolonged stress, die. Some coral genera like *Pocillopora* have generally been recorded to be more bleaching susceptible than others, but they are also reef building corals that help drive recovery. Deeper coral reefs have been able to withstand elevated temperatures better than shallower ones (Yadav et al., 2023).

Reef Drowning

Reef drowning occurs when sea levels rise, and depth increases. Shallow reef corals (*Porites*, *Montipora*, *Pocillopora*) are usually found less than 10 meters below ground level (MBGL), and rapid sea level rise results in conditions where shallow-water reef growth cannot be sustained. This is also shown through the results of a Hawaiian coral reef drowning study, where drowning of a coral reef terrace off Kawaihae and Kealakekua bays in West Hawaii was consistent with the timing of Meltwater Pulse 1A (MWP-1A) initiations, or events of rapid sea level rise resulting from the last deglaciation (Sanborn et al., 2017).

Coral Disease

According to a study conducted along 1,500 km of Australia's Great Barrier Reef across 6 years, major outbreaks of the Pacific reef-building coral disease, white syndrome, occurred during warm years, but usually absent during colder years. The results indicate a significant relationship between the frequencies of warm temperature anomalies and white syndrome (Bruno et al., 2007).

Invasive Species

As a result of climate change impacts on reef communities, new communities with different ecological interactions are created. This allows for invasive species, such as *A. planci* (COTS) to invade, especially if top predators are depleted (Mellin et al., 2016). In a study conducted on the Great Barrier Reef, *Acanthaster planci* outbreaks in pacific coastal areas had a greater distribution under higher SST, whereas fewer and smaller outbreaks occurred in cooler parts (Uthicke et al., 2015).

Impacts on Marine Biodiversity

Corals

There are 3 main genera of corals present in the Hawaiian archipelago: *Porites*, *montipora*, and *Pocillopora*. 3 species, representing each of these genera, *Porites pukoensis*, *Montipora flabellata*, and *Pocillopora damicornis*, were examined.

The threat level of these species, according to the IUCN Red List, are displayed in table 1. Currently, *Porites pukoensis* and *Montipora flabellata* are on a decreasing population trend.

Table 1. IUCN Red List Threat Level Status of Hawaiian Coral Species

Coral Species	*Porites pukoensis*	*Montipora flabellata*	*Pocillopora damicornis*
IUCN Red List Status	CR	VU	LC

Turtles

It was found that of the 5 turtle species in Hawaii, 100% are threatened more than the 27% of sharks, 26% of corals, and 17% of marine mammals. The IUCN Red list status of each turtle species (Green Turtle (*Chelonia* *mydas*), Loggerhead Turtle (*Caretta caretta*), Leatherback Turtle (*Dermochelys coriacea*), Hawksbill Turtle (*Eretmochelys imbricata*), and Olive Ridley Turtle (*Lepidochelys olivacea*) is shown in table 2.

Table 2. IUCN Red List Threat Level Status of Hawaiian Turtle Species

Turtle Species	Green Turtle	Loggerhead Turtle	Leatherback Turtle	Hawksbill Turtle	Olive Ridley Turtle
IUCN Red List Status	EN	VU	VU	CR	VU

Reef Fish

Over 400 species of reef fishes inhabit Hawaii's coastal shores, making up a significant amount of the reef ecosystem (Hawaii Division of Aquatic Resources (DAR), 2023). A few threatened fish species (Whitespooted Eagle Ray (*Aetobatus narinari*), Thorny Seahorse (*Hippocapus histrix*), and Whitetip Reef Shark (*Traienodon obesus*)) were examined in table 3, as well as the Yellow Tang (*Zebrasoma flavescens*), which is a small fish and so is not threatened.

Table 3. IUCN Red List Threat Level Status of Hawaiian Fish Species

Reef Fish Species	Yellow Tang	Whitespotted Eagle Ray	Thorny Seahorse	Whitetip Reef Shark
IUCN Red List Status	LC	EN	VU	VU

Marine Mammals

The final group of species examined was marine mammals, with 3 pacific island associated native Hawaiian species, the Hawaiian Monk Seal (*Monachus schauinslandi*), North Pacific Right Whale (*Eubaleana japonica*), and Spinner Dolphin (*Stenella longirostris*). Table 4 shows the threat status of the Hawaiian Monk Seal and other mammals that live further from the reefs, whales, and dolphins.

Table 4. IUCN Red List Threat Level Status of Hawaiian Marine Mammal Species

Marine Mammal Species	Hawaiian Monk Seal	Fin Whale	Spinner Dolphin
IUCN Red List Status	CR	VU	LC

Discussion

The results of this study confirm that the Hawaian coral reefs and marine biodiversity are threatened by the changes in the climatic factors.

According to Takahashi et al. (2023), in a study related to climate factors concerning the Pacific ocean and coasts of Hawaii, since 2013, SST in Hawaii has been higher than the usual state since 2003, reaching a high of 28.5 °C in 2015. SST anomalies reached unprecedented temperatures as well at this point (Takahashi et al., 2021).

Concerning sea level rise, Long et al. (2020) found that record high sea levels (around 10 cm above normal) were recorded in 2017 following the 2015/16 El Niño. However, this sea level rise was also attributed to weak trade winds, which are responsible for sea surface cooling (Long et al., 2020). This factor was not noticed in the data collected from this study, as it was concluded that only melting ice sheets from high temperatures led to an increase in sea surface height.

Furthermore, a book on climate change by Findlay and Turley (2021) explores ocean acidification as a consequence of climate change. It was concluded that because about a third of all global carbon dioxide absorbed by the surface is absorbed into the ocean, the rate at which CO2 is absorbed is too rapid to prevent changes in ocean pH and CO3 2-. PH has increased a global average of 0.1 and pH levels are predicted to drop as much as 0.4 by 2100 and 0.77 by 2300 (Findlay & Turley, 2021). Although the drop in ocean pH has been slow throughout the past decade, rapidly increasing carbon dioxide levels have been observed since 2003 (NASA 2023), which have caused the dramatic decrease in the projections for ocean pH in the future.

The direct impacts of these climatic factors on reefs were also observed in many other research. In data from this paper, anomalies of 2.5 ℃ were mapped, exceeding temperatures known to cause heat stress. According to the Coral Research and Development Accelerator Platform (CORDAP), heat stress results in the deaths of corals or weakens them to the point where they are susceptible to disease ("Threats to Corals," 2022). A study, conducted at the Hawaii Institute of Marine Biology (2022), experimented on corals with 48 hours of heat stress exposure at 32 ℃ to see what would result. It was found that when exposed to these conditions, the dinoflagellates (algae) on corals were scattered and decomposed, leading to separation from the corals after they could not tolerate heat stress, and ultimately causing bleaching. (Al-Hammady et al., 2022). In the plot of SST temperatures during the El Niño from the results of this study, the temperature did indeed hit 32 ℃ in August of 2016, so Hawaii experienced heat stress.

The results of Sanborn et al. (2017) determined that reef drowning is caused by an increase in the depth of water that reduces light availability (along with reduced water quality from ocean acidification) and causes the reefs to "drown" since they cannot receive enough sunlight to perform photosynthesis (Sanborn et al., 2017). Furthermore, a study of coral reef mortality around Singapore (Indian ocean/South China Sea) in response to sea level rise (Law & Huang, 2023) determined that decreasing light availability to corals is the main concern of reef drowning, and there is a correlation between coral depth and mortality. It was found that shallow reef corals 2 to 3 meters below ground level (MBGL) actually showed no signs of reef drowning, but corals over 7 MBGL have declined drastically (Law & Huang, 2023).
Data from 3.2.2 shows that corals of or under 10 MBGL are particularly vulnerable to reef drowning from rising sea levels, so the general range for occurrence of reef drowning is 7 to 10 MBGL.

Results of research done by Bruno et. al. (2007) on coral disease in Australia's Great Barrier Reef in the Pacific was compared to one on coral disease in the Persian Gulf bordering Saudi Arabia. 13 diseases (including white syndrome variants that cause tissue loss) were identified in field surveys, and 6 different corals (including *Porites*) were checked for growth anomalies, diseases, and bleached patches. It was found that the majority of disease prevalence (82.2%) was associated with the extreme temperature ranges and coral stress (Aeby et al., 2020). Despite the difference in region, the other study coincides with findings from 3.2.3. It also confirms that when corals are already in their bleached state from heat stress, they become more susceptible to disease ("Threats to Corals," 2022).

Acanthaster planci is an invasive species to Hawaii that feeds on coral and destroys reefs. 3.2.4 explains how outbreaks of *A planci* were correlated to higher temperatures. However, a different research article points out ocean acidification as a greater factor for invasions of this species (referred to as COTS). A study on COTS found that with decreasing pH in waters, their food source, crustose coralline algae, had its defenses reduced, leading to bolstered growth rates of COTS in their early and juvenile stages (Kamya et al., 2017). Considering that corals are damaged by both high temperatures and acidity, both studies indicate that invasive ability of *A. planci* has increased with the increases in severity of climatic factors.

Impacts of climatic factors and coral reef loss on marine biodiversity were explored as well. A research article providing a model for coral evolution in Hawaii and the Pacific Bhattacharya et al. (2022) deduced that coral reefs are analogous to tropical rainforests in the sense that they house enormous biodiversity and biotic interactions. 80 species of scleractinian (reef building family) corals are native to the 3 dominant genera, *Porites*, *Montipora*, and *Pocillopora* (Bhattacharya et al., 2022). However, despite being essential reef-building corals, a decline in some species has happened (IUCN Red List, 2023). A study putting 5 species of corals, including common Hawaiian native genera *Porites compressa*, *Pocillopora Damicornis*, and *Montipora Capitata*) under high temperature exposure resulted with all corals showing reduced calcification. Additionally, high pCO2 rates were observed with *P. Damicornis*, and mortality was observed with *P. compressa* (Bahr et al., 2016). Just like in the table from 3.3.1, *Porites* corals showed the lowest population sustainability rates, and *Pocillopora* and *Montipora* showed vulnerability to climate change as well.

A research paper on the role of turtles in coral reefs helps to understand why Hawaiian turtle species are significantly threatened. Hawaiian sea turtles have a symbiotic relationship with the corals, as turtles need the reefs for shelter to lay eggs and protection from predators, while corals benefit from grazing activities of the turtles. Therefore, without strong reefs to protect themselves, turtles struggle to survive and reproduce (Goatley et al., 2012). The relationship between corals and turtles explored is reflected in the threat statuses of Hawaiian turtle species in the IUCN Red List.

Another research article found a proportional reduction of fish biodiversity to loss of coral diversity in the Indo-Pacific region, especially in regions with larger background species pools. It was concluded that habitat-specialized/associated fish were at a great risk of extinction in the case of reef loss (Holbrook et al., 2015). Examples of these habitat-specialized fish include certain species of rays and seahorses, such as those in 3.3.3. In addition, it can be deduced from data in 3.3.3 that smaller Hawaiian reef fish seem to be resistant to the damages from corals, although bigger fish such as rays and sharks are more vulnerable.

Although dolphins and whales are present around Hawaii, one marine mammal, solely native to Hawaii and a few nearby pacific islands, the Hawaiian Monk Seal, stands out for being the most threatened, as according to the IUCN Red List (2023), it is critically endangered. Having populations in only a small area around Hawaii, this species only exists in Hawaiian reef ecosystems. The two greatest threats to the Hawaiian Monk Seal are food limitations caused by a decline in food sources. Their diet consists of fish, squids, octopuses, eels, and crustaceans, which need healthy reefs to sustain populations, and shark predation due to a lack of reefs for protection (NOAA Fisheries, 2023). However, Gilmartin & Forcada (2009) found that Hawaiian Monk Seals actually have a very diverse array of food sources (at least 40 species), and the main causes of their endangerment are aggression among the species themselves as a mating tactic and human activity on beaches that prevent females from giving birth to pups in a suitable location (Gilmartin & Forcada, 2009).

Overall, there are several impacts to the Hawaiian coast reef ecosystem caused by climate change. Coral bleaching is one of the most predominant consequences of these changes and it is caused by different factors. First, coral bleach may be caused by heat stress due to the increase in sea surface temperature. Second, the increase in the acidity levels in the ocean water due to the rise in carbon dioxide absorption decreasing ocean's pH also increase coral bleach risks. Additionally, rising sea levels have caused reefs to bleach because of lack of sunlight that directly impacts algae production. The impact on the balance of the reefs also turns this ecosystem into an ideal environment for the arrival of invasive species, such as *Acanthaster Planci*, which feeds on reef building corals and acts as competition against native species. In addition, the changes in the environmental conditions increase the risk of disease outbreaks.

In the Hawaiian Islands, the three most common reef building coral genera, *porites*, *montipora*, and *pocillopora*, are extremely impacted by the climatic factors. Therefore, a large amount of coral cover has been lost. Since many marine species rely on coral resources for survival, the decline in coral reefs affects other populations greatly. Turtles, for example, have a symbiotic relationship with corals, and because of loss of reefs, their species are becoming increasingly threatened. Similarly, rays and seahorses that use corals for habitat and food, are also more vulnerable, as well as several fish species. Finally, a few marine mammals, especially the critically endangered Hawaiian Monk Seal, have their population numbers declined due to the loss of protection and food sources supplied by the reefs.

Conclusion

Hawaiian reef ecosystems are significantly affected by climate change. Climatic factors such as sea surface temperature, sea level, and ocean acidification were found to have negative impacts (heat stress, reef drowning, coral disease, and invasive species outbreaks) on coral reefs. Species native to Hawaiian coral reefs and important to its biodiversity (Corals, Turtles, Reef Fish, and Marine Mammals) are endangered by the loss of coral reef cover. Essentially, climate change has impacted marine biodiversity in Hawaii by creating abnormal and stressing conditions for corals and in turn, causing a decline in the biodiversity of coastal coral reef ecosystems.

Acknowledgments

I would like to thank my advisor for the valuable insight provided to me on this topic.

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