

Interactions Between Environmental and Anthropogenic Stressors Affecting Coral Bleaching and Mortality in Kāneʻohe Bay, Oʻahu

By Zizi Dai

AUTHOR BIO

Zizi Dai is a rising senior at Riverdale Country School in the Bronx, New York with a strong interest in environmental science, public health and scientific research. Her passions for environmental research began through a biotechnology project focused on developing a potential solution to mitigate coral bleaching using biotechnology, which inspired her to pursue further independent research on coral reef conservation. Through her research, Zizi continues hopes to contribute to greater awareness and understanding of the urgent environmental challenges marine ecosystems are facing and the broader consequences of accelerating climate change on our planet.

ABSTRACT

Coral reefs are among the most biologically diverse and ecologically important ecosystems on Earth, yet they're being increasingly threatened by both global climate change and local human activities. This literature review examines how environmental factors, like rising surface water temperatures and algae blooms, interact with anthropogenic factors, like tourism, to influence coral bleaching and mortality in Kāneʻohe Bay, Oʻahu. Twenty five scientific articles and government datasets published between 2015 and 2026 were analyzed, along with historical records of surface water temperature, tourism trends and documented mass bleaching and algae bloom events. Overall, findings suggest that climate-related stressors remain the dominant factor that leads to coral mortality, though local and anthropogenic stressors greatly reduce reef health and resilience. Protecting coral reefs will require both global efforts to mitigate climate change and local management to reduce anthropogenic impacts.

Keywords: Global warming, Kāneʻohe Bay, eutrophication, nutrient run-off, coral reefs, tourism, coral bleaching, biodiversity, long-term stressors, short-term stressors

INTRODUCTION

Coral reefs are among the most biologically diverse and important ecosystems on Earth, supporting thousands of marine species while providing essential services to coastal communities and businesses (US EPA, 2026). Often referred to as the “rainforests of the sea,” coral reefs contribute significantly to local biodiversity, fisheries, shoreline protection, and tourism economies (NOAA, 2019).

Despite the importance of coral reefs to ecosystems all around the world, global warming has increasingly weakened coral resilience, reducing their ability to recover from environmental and anthropogenic disturbances (Quigley et al., 2026). Coral reefs are currently highly vulnerable due to rising ocean water temperatures, ocean acidification, and chronic thermal stress, all of which contribute strongly to coral bleaching and mortality (NOAA, 2023). At the same time, local stressors such as coastal development, nutrient runoff, and tourism continue to degrade coral reefs and amplify the effects of global warming (Bhuyan et al., 2026). Excess nutrients entering coastal waters can trigger algae blooms and eutrophication, which is the over-enrichment of nutrients in a body of water (NOAA, 2017). Excess algae can lead to oxygen depletion and reduced light penetration that leads to further stress on coral communities. While short-term stressors like algae blooms erode reef resilience, long-term stressors, including climate change, increase the likelihood of bleaching events and increase coral mortality rates. These stressors interact synergistically, meaning their combined effects are more harmful than the impact of each stressor alone (Bozec et al., 2015).

Coral bleaching occurs when environmental disturbances, including elevated water temperatures and decreased water quality, stress the symbiotic algae zooxanthellae living within coral tissues. Algae provide coral with food and energy while coral provides algae with a safe environment and home (NOAA, 2026a). As temperatures rise above normal seasonal levels, corals expel the algae, causing them to lose their main source of food and energy. This process also causes the coral to lose their color, turning the coral tissues transparent and exposing their white skeleton. While bleached corals are not dead, the loss of zooxanthellae leaves them extremely vulnerable to disease. Although corals are able to recover from bleaching over time as stressors decrease, persistent heat stress for extended periods of time, normally for eight weeks or more, will lead to coral mortality (Lin et al., 2023). Beyond ecological importance, healthy coral reefs act as a natural buffer zone for coastline communities, absorbing up to 97% of incoming waves and protecting communities from the impact of erosion and destructive storms (MarineBio, 2025). As coral reefs die and their structures deform, coastal communities become increasingly vulnerable to flooding, infrastructure damage and shoreline loss. Continued coral decline would also reduce marine biodiversity, diminish fisheries and threaten small businesses reliant on tourism that are attracted by healthy reef systems. If current warming trends and local stressors continue, widespread reef degradation could become irreversible in many regions, resulting in the loss of essential ecosystem services that support both marine life and human communities.

Reef degradation is further exacerbated by the increasing frequency of algae blooms, defined as rapid increases in the abundance of algae in marine or freshwater environments. While many blooms are harmless, some can become harmful algal blooms (HABs), producing toxins or creating conditions that negatively affect water quality, marine ecosystems, and human health. Nutrient-rich conditions promote algae growth and reduce water quality. Climate change can increase heavy rainfall events, which helps

transport nutrients, sediments, and sewage runoff into coastal waters, creating a more suitable environment for excessive algae growth. Human activity may also contribute to algae blooms. The intentional introduction of invasive smothering seaweed species *Kappaphycus* spp. and *Eucheuma* spp. for aquaculture experiments has further increased pressure on O'ahu's reefs, as these algae species compete with coral colonies for space and sunlight overgrow, hindering reef recovery following bleaching events (Winston et al., 2023). Because coastal tourism can increase nutrient outputs through urban runoff, wastewater, recreational activities and other anthropogenic happenings, it is often thought that higher visitor numbers may lead to conditions that are more favorable for algae blooms (Hawai'i Department of Health, 2025).

One of the most extensively studied reef systems and the largest protected body of water in Hawai'i is Kāne'ohe Bay, located on the island of O'ahu. This reef system has experienced a long history of human disturbance, including urbanization, sewage runoff, and coastal development throughout the twentieth century due to its popularity as a place for vacation and tourism. These impacts caused major declines in coral health and water quality; however, improved wastewater management and conservation efforts led to partial ecological recovery over recent decades (Bahr et al., 2015). Because of its documented history of degradation and recovery, Kāne'ohe Bay serves as an important model for understanding how coral reefs respond to both local and global environmental stressors. This study examines how short-term anthropogenic stressors, particularly tourism related nutrient runoff, amplify long-term climate stressors in Kāne'ohe Bay. By analyzing historical temperature records, tourism trends and ecological studies, this paper hypothesizes that the interaction between local and global stressors accelerates coral degradation and reduces reef resilience over time.

METHODS

This paper reviewed a total of 48 articles, ultimately using 25, that were collected by searching keywords like environmental stressors, anthropogenic impact and elevated sea surface temperatures on Google Scholar, JSTOR ScienceDirect, and more. Only articles published from 2015 to 2026 were used. Historical and recent water temperature data were obtained from the National Oceanic and Atmospheric Administration (NOAA) and PacIOOS observational records. Tourism statistics were acquired from the Hawai'i Tourism Authority and the Hawai'i Department of Business, Economic Development & Tourism. These data points were collected and organized to create trend graphs in Excel and Google Sheets to evaluate correlations between increased tourism, rising ocean temperatures and ecological stresses in Kāne'ohe Bay. Graphs were put into Google Slides after revision to plot points of mass bleaching events, algae blooms and to mark temperatures that stress coral health. AI tools, like ChatGPT, were used in the research process to summarize articles and gain insight on ways to analyze the figures created. All interpretations and analysis of figures and articles used were independently made by the author.

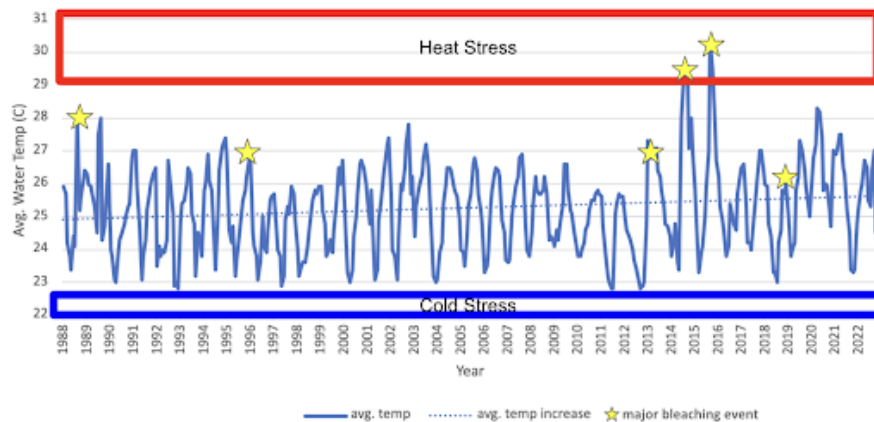
RESULTS

Figure 1 shows average sea surface temperatures in O'ahu from 1988 to 2022. The trendline indicates a gradual increase in surface water temperature over time. Several temperature spikes are visible throughout the dataset, with an upward trend as time goes on. The 1988 bleaching event was associated with El Nino, a phase of the natural climate pattern El Niño-Southern Oscillation (ENSO). This event led

to unnaturally warm waters in the western and central Pacific Ocean, where Hawai'i is located. Both the 1996 and 2019 bleaching events were due to a prolonged exposure to heatwave in the years prior, as temperatures rose to over 27°C in 1994 and 1995. The highest temperatures occurred between 2014 and 2016 due to a marine heatwave known as “The Blob.” These dangerously hot conditions coincided with major coral bleaching events across Hawai'i, including widespread bleaching being reported during August to October 2014 and continued impacts throughout 2015.

Figure 1

Average Sea Surface Temperatures in O'ahu from 1988 to 2022 in Correspondence to Coral Bleaching Events

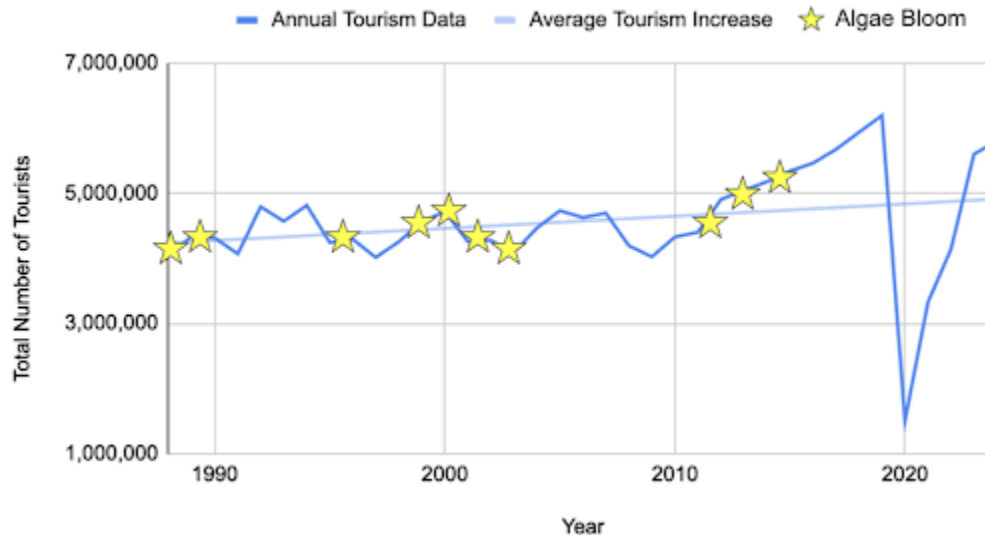


Note. Monthly sea surface temperature trends in O'ahu, Hawaii from 1988 to 2022, ranging roughly from 23°C to 30°C. Yellow star markers indicate documented mass bleaching events.

Figure 2 illustrates tourism trends in O'ahu from 1988 to 2023. Visitor numbers generally increased over the study period, reflecting growing human activity along O'ahu's coastlines. A sharp decline occurred in 2020 due to COVID-19 travel restrictions, followed by a gradual recovery in subsequent years. Despite the decrease in 2020, tourism to O'ahu saw a steady increase starting from 2010 and hitting a record high of 6.1 million tourists in 2019. The data show a general upward trend in tourism over time, with visitor numbers rising from approximately 4 million annually in the late 1980s to over 5.5 million by the late 2010s. A sharp decline occurred in 2020 due to the COVID-19 pandemic and the travel restrictions that came with it, but a gradual recovery followed in subsequent years. This was primarily due to aggressive airline expansion that created millions of more seating on aircrafts and an increased international appeal, particularly from Japan (Hawai'i State Senate, 2020). Additionally, Figure 2 also shows that between 1988 and 2023, 10 major algae blooms happened in O'ahu, none of which directly coincided with a spike in tourism.

Figure 2

Total Number of Tourists Arriving in O'ahu, Hawai'i in Correspondence to Harmful Algae Blooms



DISCUSSION

These results show that rising sea surface temperatures due to climate change amplify the effects of short-term stressors on coral reef ecosystems in Kāneʻohe Bay and throughout Oʻahu. Figure 1 demonstrates a clear increase in surface water temperatures from 1988 to 2022, consistent with broader global warming trends observed across the Pacific Ocean. Several periods of elevated temperature corresponded with documented coral bleaching events, particularly during the 2014 to 2016 marine heatwave known as the Blob. Detected in October of 2013, the Blob was a strong, long-lasting high pressure ridge in the Pacific Ocean that created a mass of water with temperatures warmer than normal. This mass of water was between 4 to 10°F above average and stretched over 1,000 miles wide and up to 300 ft deep between North American and Asia. The Blob raised average water temperatures in Oʻahu from 25.5°C to temperatures as high as 30°C in the summer months, exceeding the thermal stress threshold for most coral species. Thermal stress caused by surface water temperature usually occurs below 18°C and above 28°C (U.S. National Park Services, 2018). The overlap between temperature peaks and documented bleaching events demonstrates a strong relationship between thermal stress and coral reef decline, making sea surface temperature an important indicator of coral health (van Woesik et al., 2022). Exposure to high water temperatures for prolonged periods of time will result in an increased likelihood of coral bleaching, where 8 or more weeks of exposure may lead to fatal bleaching events (NOAA, 2026d). These findings reinforce previous research showing that prolonged exposure to elevated temperatures weakens coral-algal symbioses, causing corals to expel their zooxanthellae and become vulnerable to disease and mortality (Hobson, 2025).

While elevated temperatures alone can trigger bleaching, reefs exposed to additional local stressors may experience more severe and prolonged impacts. Figures 1 and 2 show a connection between algae blooms and surface water temperature, as most major algae blooms happen after spikes in surface

water temperature. Although the data does not establish direct causation, the repeated overlap between these events suggests that warmer conditions may increase coral susceptibility to other environmental pressures like algae blooms. For example, the spike in water temperature in 1989 led to not only a mass bleaching event, but also a two year long algae bloom. Water temperatures continued to rise from the years 2000 to 2003, and although no mass bleaching events occurred during those years, three significant algae blooms happened during that time period. Another three algae blooms and bleaching events occurred during the 2013 Blob heatwave, where the average sea surface temperature reached 30°C. Instances of repeated bleaching events such as these are especially concerning because they reduce the time available for coral recovery between disturbances. As recovery periods shorten, coral cover may gradually decline, leading to long-term changes in reef structure, biodiversity, and proper ecosystem function.

Although the original hypothesis proposed that tourism-related nutrient runoff would amplify coral degradation, the available data from Figures 1 and 2 did not demonstrate a direct relationship between tourism trends and algal bloom occurrence. This finding suggests that tourism alone is not an adequate proxy for all anthropogenic factors that may impact coral health, such as wastewater inputs, urban development, and nutrient runoff. Nevertheless, previous studies suggest that tourism-related coastal development and nutrient runoff may contribute to an increased occurrence of algae blooms. Figure 2 indicates that both tourism and algae bloom frequency increased over the study periods, however this overlap alone does not establish a direct association between the two. While tourism itself does not directly cause coral bleaching or algae bleaching, it can intensify environmental conditions that reduce reef resilience. Tourism in O‘ahu increased substantially during the study period, resulting in increased coastal development, recreational reef use, and nutrient runoff into nearshore waters, all of which may cause physical damage or intensify stress on reef ecosystems already affected by global warming (MarineBio, 2025; McCarrey, 2021). Although research shows that increasing human activity further contributes to reef degradation, tourism trends in Figure 2 do not prove a direct relationship between coral bleaching or tourism and algae bloom occurrences.

Several limitations should be considered when interpreting these findings. First, this study relied heavily on secondary data collected from government agencies, scientific literature, and public databases rather than direct field data collected from Kāne‘ohe Bay. As a result, some environmental responses may not be generalizable to the entire island of Hawai‘i. Additionally, tourism statistics were used as a representation for human impacts on coastal ecosystems, but visitor numbers do not directly measure nutrient runoff, pollution levels, or reef disturbance. Other variables that may also influence coral health, including rainfall patterns and storms, were not included in analysis. Furthermore, while research and graphs showed correlations between temperature spikes, algae blooms, and bleaching events, these relationships cannot conclusively demonstrate causation. Future research should focus more on direct field data collection to generate specialized analyses and reliable conclusions regarding the response of coral reefs to environmental factors in Kane‘ohe Bay.

This research examined the combined impact of environmental and anthropogenic stressors, both short and long-term, on coral reefs in O‘ahu. The findings did not prove a direct relationship between tourism and algae blooms based on information provided through research, as the blooms referenced did not consistently coincide with periods of peak tourism. However, a relationship between surface water

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temperatures and coral bleaching was observed. Analyses showed a correlation between periods of elevated water temperature and major algae blooms, suggesting that rising water temperatures may increase coral vulnerability to algae blooms. If current global water temperatures continue to increase, vital coral reef systems are at risk of irreversible damage. These trends highlight the importance of focused relief efforts to protect both the organisms and communities that rely on reef ecosystems for survival.

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