INTERNATIONAL BACCALAUREATE PROGRAMME
ENVIROMENTAL SYSTEMS AND SOCIETIES
EXTENDED ESSAY

To what extend sea surface temperature changes affect bleaching rates of Great Barrier Reef's between the years 1998-2023 mass bleaching events?

Subject: Environmental Systems and Societies

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1.Introduction

The planet's average temperature rising over time is known as global warming. Even though this pattern of rising temperatures has been ongoing for a while, its pace has accelerated dramatically since the pre-industrial era as a result of human activity, particularly the burning of fossil fuels. With the growth of the human population, so has the amount of fossil fuels used. The combustion of fossil fuels, including coal, oil, and natural gases, triggers the greenhouse effect in Earth's atmosphere. As humans are still going in their directions without investigating what would happen to nature, global warming has become a bigger load to deal with alongside the regression of glaciers.

The extensive impact of global warming is predominantly felt in oceans and seas, given their substantial coverage across the planet and their rich biodiversity. As greenhouse gases increase, oceans absorb the excess heat coming from the atmosphere. This warming event causes ice glaciers to melt, increasing water levels and endangering coastal populations. It can alter temperature patterns to disrupt marine life, like changes in reproduction cycles and the behavior of species. Also, coral reefs, which play a vital part in marine ecosystems, are facing bleaching and degradation as they struggle to adapt to the changing conditions.

Consisting of thousands of reefs, the Great Barrier Reef is located on the coast of Australia, is a natural wonder that has been impacted by humans' numerous times. One of the most significant threats is posed by climate change, driven primarily by the increase in greenhouse gas emissions. Rising sea temperatures, a direct consequence of climate change, have led to the phenomenon of coral bleaching. The corals, under stress from elevated temperatures, expel the symbiotic algae that provide them with nutrients and color. This bleaching weakens the corals, making them more susceptible to diseases and less resilient to other stressors. This study aims to determine whether the sea surface temperature changes around the Great Barrier Reef affect bleaching rates in the mass bleaching events in the years 1998, 2002, 2006, 2016, 2017, 2020, 2022.

2.Background Information

Climate Change and Oceans

"Climate change is widely recognized as the greatest threat to coral reefs worldwide."[1]. While the primary concern for coral reefs has been the rise in sea temperatures due to climate change, the concept of temperature decrease raises a different set of challenges. It's important to note that the overarching trend for the Great Barrier Reef has been an increase in sea temperatures, which has led to coral bleaching and other detrimental effects. But if we consider the speculative case of a sudden and notable drop in water temperature, it might also have detrimental effects on the reef ecosystem. Coral polyps, which are the creatures that make up the structure of the reef, have specific temperature needs for proper growth and health, therefore coral reefs can be very sensitive to temperature swings. A sudden decline in sea level may cause a condition called "cold-water bleaching.". Although it is not as well-known as its warm-water equivalent, cold-water bleaching can happen when corals are exposed to temperatures that are outside their normal range, forcing the symbiotic algae they depend on for sustenance to leave their bodies.

Human Impact:

Alongside the effects of climate change, human activity also degrades coral reefs. The coastal environment is exposed to pollutants, sediments, and nutrients due to runoff from urban growth, deforestation, and agriculture. These contaminants may have a detrimental effect on the quality of the water, resulting in problems like algal blooms and coral illnesses. The fragile equilibrium of the reef ecosystem can be disturbed by an overabundance of excessive nutrients, which encourages the growth of opportunistic species and puts them in direct competition with the corals for available space. Reefs also contribute significantly to the economy through tourism, which creates chances for scientific study and education.

Increased sedimentation and habitat loss are possible outcomes of coastal development, which includes building ports and other coastal infrastructure. Corals can be affected by sediment flow from building sites, which blocks sunlight and stunts their growth. For many marine animals that depend on the reef for food and refuge, the physical disruption caused by coastal development may also result in the loss of vital ecosystems.

<u>Aquatic Life:</u>

The health and biodiversity of the oceans depend heavily on coral reefs. Serving as complex and productive ecosystems, reefs provide a habitat for an immense diversity of marine life, offering shelter, breeding grounds, and food sources for numerous species. Beyond their ecological significance, coral reefs serve as a shield, safeguarding coastlines against storm damage and erosion. "Coral reefs might only occupy 1% of the world's marine environment but they're home to about a quarter of the world's marine species and an important nursery for many fish species."[1]. Around 1500 different types of fish, 400 different kinds of coral, 4,000 different kinds of mollusks, 242 different species of birds, and an enormous variety of crustaceans, marine worms, sponges, anemones, and many other marine lives can all be found in the Great Barrier Reef. The reef offers the most breathtaking underwater scenery on the planet, with almost 2500 distinct reefs of different shapes and sizes. As the world's largest coral reef system, the Great Barrier Reef contributes significantly to global marine biodiversity and supports fisheries that are crucial for human sustenance.

<u>Great Barrier Reef:</u>

As the world's most extensive coral reef ecosystem, the Great Barrier Reef is a globally outstanding and significant entity. The entire ecosystem was inscribed as World Heritage in

1981, encompassing an unbroken latitudinal stretch and spanning over 348,000 square kilometers. The Great Barrier Reef extends 250 kilometers offshore from the low water line along the coast of the mainland consisting of large regions of shallow water near inshore areas, mid- and outer reefs, and seas beneath 2000 meters below the continental shelf.

They are crucial to human well-being as well. “The livelihoods of an estimated 500 million people of coastal areas are reliant on coral reef fishing. They are additionally helpful in preventing erosion and floods along coastlines. Without a doubt, the Great Barrier Reef is the largest coral reef in the world and is arguably the richest region in terms of aquatic diversity. Its immense variety is a reflection of the stability of an ecosystem that has evolved on Australia's northeast continental shelf over millions of years.

Research Question:

How does sea surface temperature changes effect bleaching rates of the Great Barrier Reef between the years 1998-2003 mass bleaching events?

Hypothesis:

The research question and the hypothesis are related because the investigation requires whether the difference in sea surface temperatures would increase or decrease the bleaching rates of the Great Barrier Reef on the years between 1998-2022.

3. Methodology

Variables:

Experimental variable	**Named variable**
Independent	Sea surface temperature (°C)
Dependent	Bleaching ratio (%)

Table 1: Dependent and Independent Variables

Control variable	Why is it controlled?	How was it controlled
Source of Data	To ensure that the data gathered is reliable and has the credibility to draw conclusions after mathematical reasoning.	Using credible sources like Australian Institute of Marine Science and Australian Government Bureau of Meteorology.
Years of data collected	Since all the factors considered are open to change over time and thus could result in inaccurate findings, I have selected a particular period of time to get credible results.	All the data was collected within the year span of 1998-2022.

Table 2: Controlled Variables

List of Apparatus:

Equipment	Quantity	Purpose
Laptop	1	To conduct scientific research
Notebook	1	To record mathematical findings and confirm the outcomes
Internet	1	To use search engines to gather data and statistics from multiple websites
Pen/pencil	1	To document the outcomes

Table 3: List of Apparatus

Procedure:

The investigation involved secondary sources, so this extended essay's exploration of data had to be investigated on a global scale. All the data collected through this process were from sources like Great Barrier Reef Foundation and Australian government website.

1. Choose a location.
2. Determine the biggest cause of the degradation on the chosen location. (bleaching)
3. Find the last mass bleaching events happened in the last 25 years. (1998,2002,2006,2016,2017,2020,2022)
4. Collect data of the Great Barrier Reef bleaching severity percentages
5. Find the average sea surface temperature of the Great Barrier Reef. (28.0°C)

6. Collect data of the sea surface temperature anomalies happened between the years 1998-2022.
7. Take all the collected data into a raw data table.
8. Find the standard error, standard deviation, and mean of the bleaching severity percentages.
9. Create graphs for the bleaching severity percentages and sea surface temperature anomalies calculations for the data to be visually compared and conclusions reached more quickly.
10. Analyze the data and make appropriate conclusions to determine if the hypothesis is supported or rejected.

Justification:

The reason for only investigating the years 1998, 2002, 2006, 2016, 2017, 2020, and 2022 is because these years are considered mass bleaching events in the Great Barrier Reef in the last 25 years. The bleaching events other than these years are minimal and does not have sufficient data.

Risk Assessment:

Since there is a possibility of copying directly of the internet which might result in academic dishonesty, I will make sure there is no chance of plagiarism by including in-text citations wherever I have taken direct quotations from online sources. Since, secondary data is used in this study, the reliability of the websites obtained should be secure enough because all the data was taken from the Australian Institute of marine science.

4. Result and Analysis

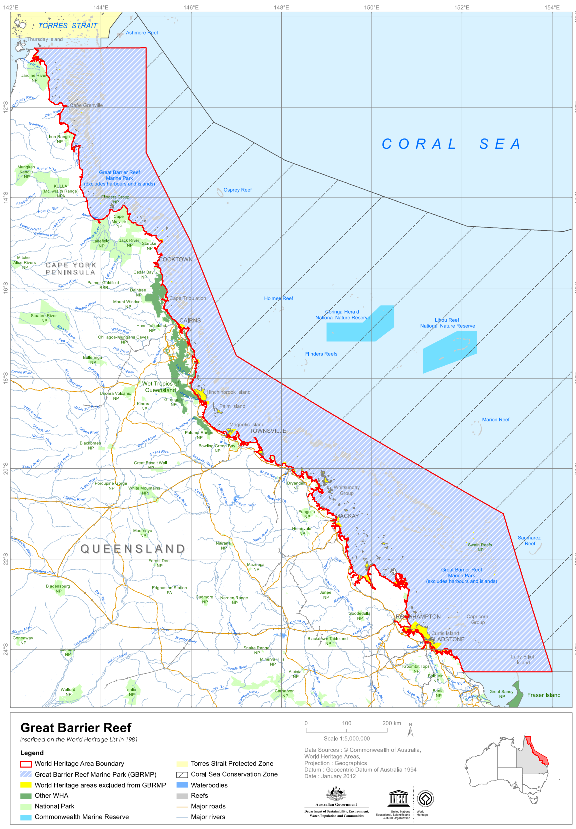


Figure 1: A Photo of the Great Barrier Reef

<u>Bleaching Report in 1998:</u>

Early in 1998, the Great Barrier Reef (GBR) suffered the strongest coral bleaching event ever recorded. In March and April of 1998, extensive aerial surveys covering 654 reefs (or 23% of the reefs on the GBR) revealed that 87% of inshore reefs (or 1% of the coral cover) had some degree of bleaching, whereas 28% of reefs on the offshore (mid- and outer shelf) were in the same condition. Out of all inshore reefs, 67% experienced high levels of bleaching (about 10% of the coral), while 25% had extreme bleaching (about 60% of the coral). About 14% of offshore reefs exhibited significant bleaching, and none showed extreme bleaching.

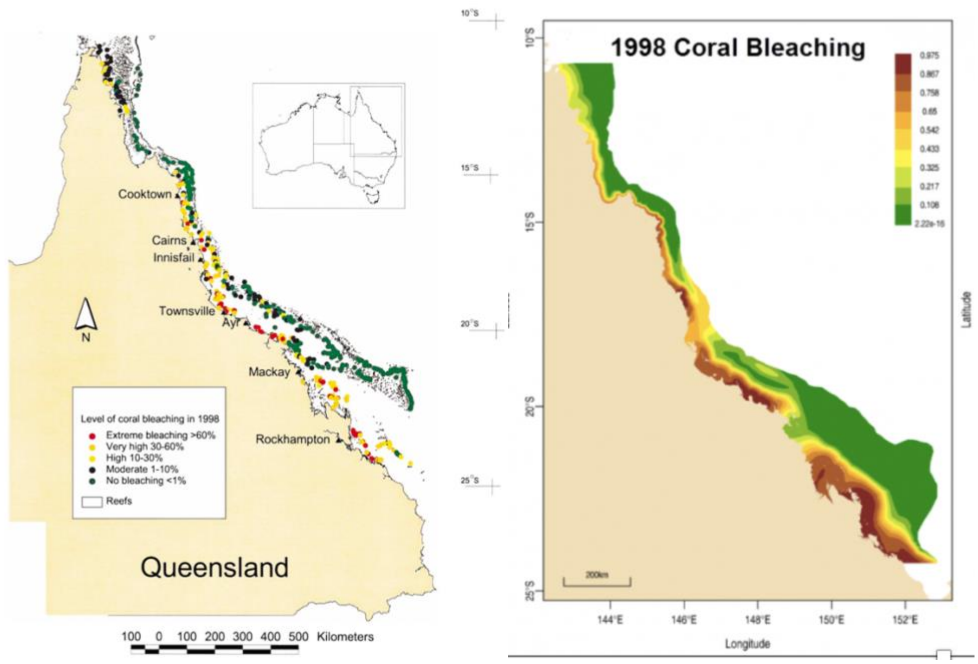


Figure 2: The Arial Survey of the Great Barrier Reef 1998 Mass Bleaching Event

Bleaching report in 2002

Of the 641 reefs surveyed, 54% experienced bleaching during the summer of 2001–2002. Although the 1997–1998 global bleaching episode was not as severe as this one, reef recovery was generally successful, with less than 5% of reefs experiencing high mortality.

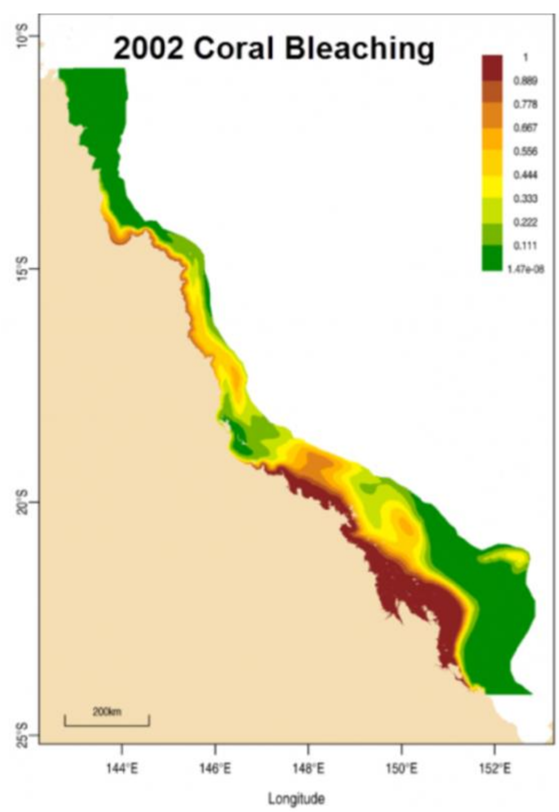


Figure 3: The Arial Survey of the Great Barrier Reef 2002 Mass Bleaching Event

Using the data, the geographical patterns of mass bleaching event throughout the Great Barrier Reef between 1998 and 2002 could be compared. In contrast to around 42% of reefs that bleached to some extent in 1998 with approximately 18% highly bleached, approximately

54% of reefs in 2002 bleached to some amount. “These statistics makes the 2002 event the worst bleaching event on record for the Great Barrier Reef.”[6].

Bleaching report in 2006:

January and February of 2006 experienced a mass bleaching event which was mostly restricted to the southern portion of the Reef. AIMS surveys revealed that, although bleaching was largely confined to the Southern area, the degree of thermal bleaching was worse than in previous years. Up to 98% of the corals on some reefs were bleached, which was a greater degree of bleaching compared to the previous years, resulting in a mortality rate close to 39% on reef flats and 32% on reef slopes.

Table 1. Percentage of hard corals affected by bleaching during the 2005/2006 summer by survey region.

Region	Percent affected
Far Southern	46 per cent
Southern	0.5 per cent
Central	0.75 per cent
Northern	0.5 per cent
Far Northern	1.5 per cent

Figure 4: Severity Percentages of the Great Barrier Reef 2006 Mass Bleaching Event

Bleaching report in 2016:

During 2015-2016, record temperatures triggered an episode of coral bleaching, one of the biggest scale events since mass bleaching was first documented in the 1980s.

In 2016, bleaching was considerably more widespread and severe, affecting numerous coastal, mid-shelf, and offshore reefs, particularly in the northern and, to a lesser degree, the central area.

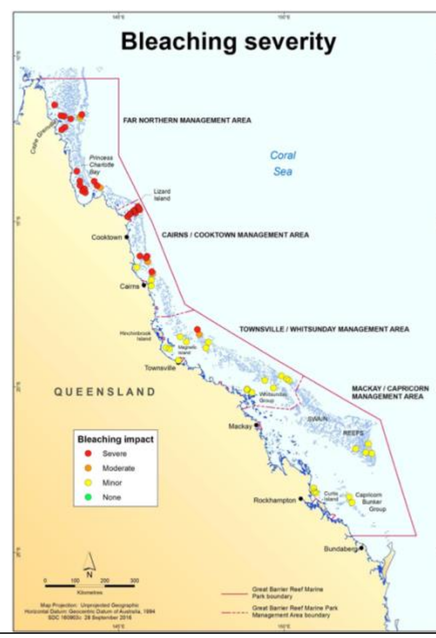


Figure 4: The Arial Survey of the Great Barrier Reef 2016 Mass Bleaching Event

Bleaching report in 2017:

A majority of the Great Barrier Reef was affected by the unprecedented back-to-back bleaching mass bleaching events. The Great Barrier Reef's center and Northern section suffered significant damage in the first few months of 2017. The Southern region remained unharmed.

The AIMS survey in the Northern part of the Great Barrier Reef demonstrates that the reefs lost nearly half of its coral cover due to the two mass bleaching events and two major cyclones(Cyclone Nathan (2015) and Cyclone Debbie (2017)) happened between the years 2014-2017. Reefs in the Central part of the Great Barrier Reef suffered a considerable loss of coral cover as a result coral bleaching and ongoing crown-of-thorns starfish outbreaks.

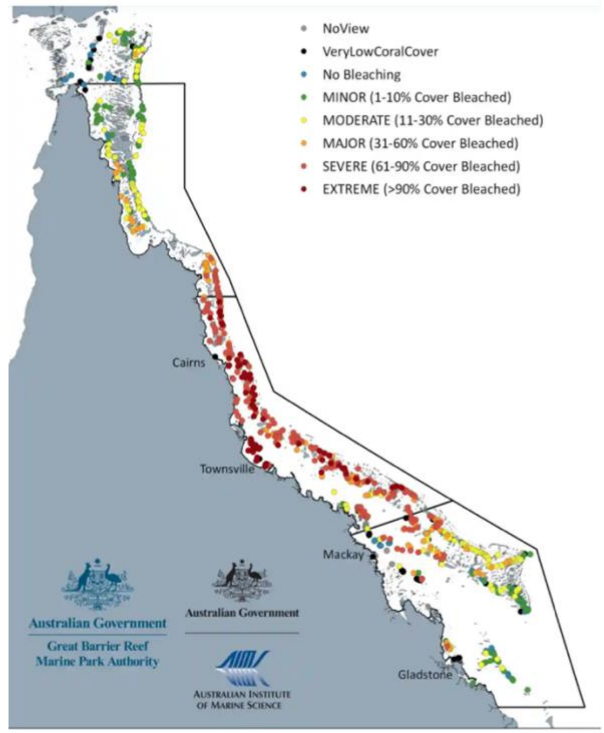
Bleaching report in 2020:

The Great Barrier Reef was exposed to cumulative heat stress over the 2020 summer, to the point where a large portion of the reef experienced mass coral bleaching. Amongst them was the Southern part of the Great Barrier Reef, which had avoided bleaching during the mass bleaching events in 2016 and 2017. The fact that this is the third such occurrence in five years indicates that the Great Barrier Reef is already feeling the effects of climate change.

Bleaching report in 2022:

Coral mortality was minimal during the mass bleaching event of 2022 due to the accumulation of thermal stress. Additionally, outbreaks of crown-of-thorns starfish and Tropical Cyclone Tiffany in January 2022 prevented the rebuilding of many reefs.

On the Northern part of the Great Barrier Reef, mean hard coral cover for the area declined to 32.2% to 40.9%. On the central part, mean hard coral cover for the area declined to 27.6% from 36.5%. Mean hard coral cover for the area on the reefs in the Southern part declined to 29.0% from 39.3% in 2022 but continued to fall within the reasonable intervals despite the repeated outbreaks of crown-of-thorns starfish, which caused parts of the reefs in this area to lose their coral cover.



More than 90% of reefs surveyed along the Great Barrier Reef were affected by coral bleaching in 2022. Photograph: Great Barrier Reef Marine Park Authority

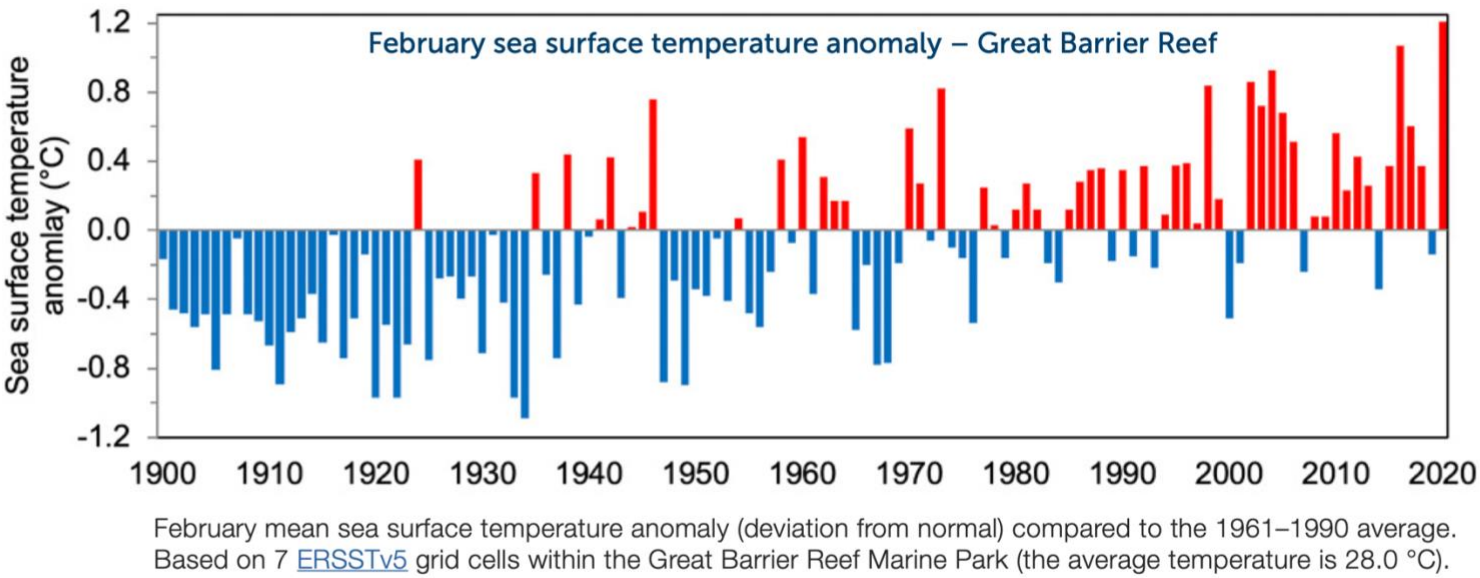
Figure 5: The Arial Survey of the Great Barrier Reef 2022 Mass Bleaching Event

Raw Data:

Great Barrier Reef Bleaching Severity Percentage				
Year	Sea surface temperature changes (°C)	Cairns/Northern Area (%)	Townsville/Central Area (%)	Mackay/Southern Area (%)
1998	0.80	0.20	63.00	68.00
2002	0.80	0.26	81.00	87.42
2006	0.50	2.50	0.75	46.50
2016	1.00	66.00	3.00	0
2017	0.60	81.00	33.00	1.00
2020	1.20	33.00	17.50	8.00
2022	2.00	8.500	8.90	10.30

(The only data that was found about the 2002 mass bleaching event was a comparison between the total percentages of bleaching severity in the years 1998 and 2002 so the data given for the year 2002 were calculated from the percentage comparison of the bleaching severity.)

Table 4: Raw Data Table



Graph 1: Graph of February Sea Surface Temperature Anomalies in the Great Barrier Reef in the last 120 years

<u>Processing Raw Data:</u>

The data was processed with the use of various calculations like mean, standard deviation, standard error, and ANOVA table. This would help in drawing meaningful comparisons and conclusions of the investigation and hence, in the proving of hypothesis.

<u>Calculations:</u>

Sample calculation for the year 1998:

- The mean can be calculated by the following formula:

$$\mathrm{Mean}(x) = \frac{\sum x}{n}$$

$$\frac{0.20 + 63.0 + 68.0}{3} = 43.733$$

- The standard deviation can be calculated by the following formula:

$$\sigma = \sqrt{\frac{\sum (x_i - \mu)^2}{N}}$$

σ = population of the standard deviation
N = the size of the population
x_i = each value of the population
μ = population mean

$$\sqrt{\frac{(0.20-43.733)^2+(63.0-43.733)^2+(68.0-43.733)^2}{3}}=37.783$$

- The standard error can be calculated by the following formula:

$$\frac{\sigma}{\sqrt{n}}$$

$$\frac{37.7837708}{\sqrt{3}}=21.814$$

The processed data for the other years are calculated and written on the following table.

Processed Data:

Great Barrier Reef Bleaching Severity Percentage			
	Mean	Standard Deviation	Standard Error
1998	43,7333333	37,7837708	21,8144702
2002	56,2256667	48,5764638	84,1369034
2006	16,5833333	25,9233646	44,9005846
2016	23	37,2692903	21,5174348
2017	38,3333333	40,2657837	69,7423831
2020	19,5	12,6194295	21,857493
2022	9,23333333	0,94516313	0,54569018

Table 5: Processed Data Table

Anova: Single Factor

SUMMARY

Groups	Count	Sum	Average	Variance
0,80	4	132	33	1412,56
0,80	4	169,477	42,36925	2341,1163
0,50	4	50,25	12,5625	512,68229
1,00	4	70	17,5	1047
0,60	4	115,6	28,9	1436,84
1,20	4	59,7	14,925	189,88916
2,00	4	29,7	7,425	13,675833

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3817,1664	6	636,19440	0,6404245	0,6969202	2,5727116
Within Groups	20861,290	21	993,39480			
Total	24678,457	27				

Table 6: ANOVA Single-Factor Test Results

To determine if there is a statistically significant difference between the group means, the ANOVA test can be implemented. The following states the null hypothesis (H_0) and alternative hypothesis (H_1). Discussion of which hypothesis will be accepted, and which will be rejected will be conducted in the discussion and evaluation section.

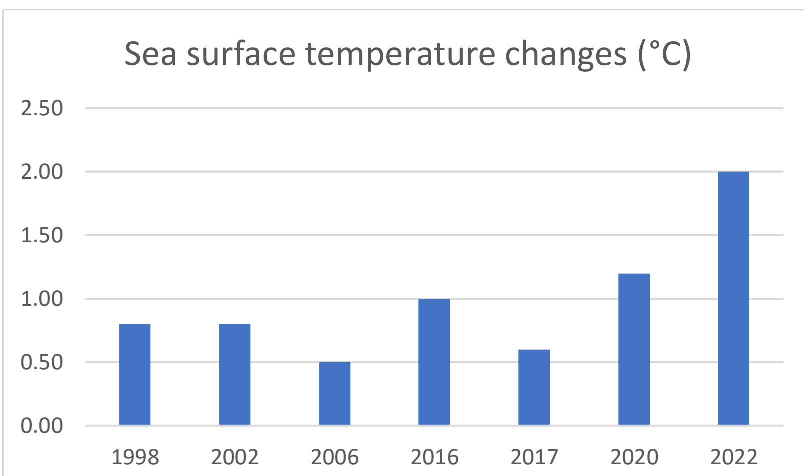
H_0: Bleaching rates in the Great Barrier Reef's mass bleaching events will change due to the changes in sea surface temperatures.

H_1: The change in sea surface temperatures around the Great Barrier Reef will not affect its bleaching rates in the mass bleaching events.

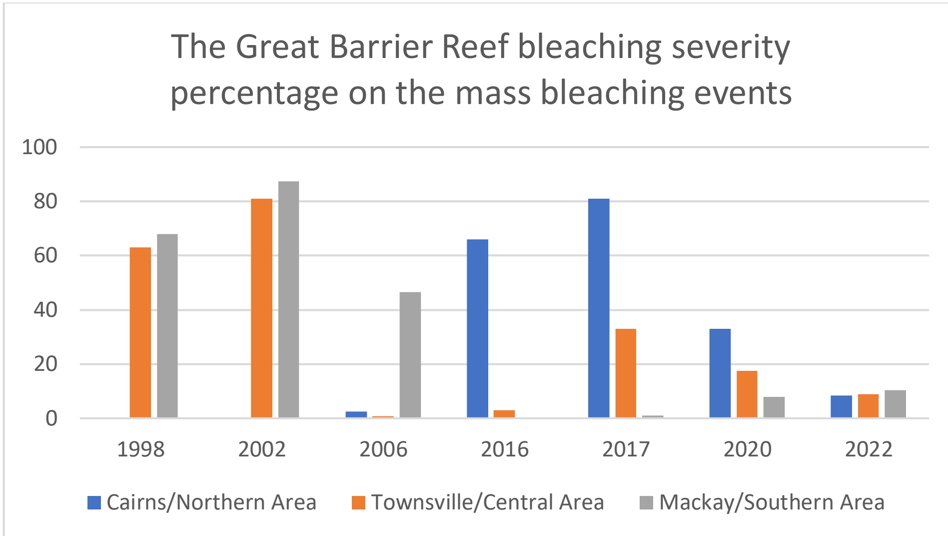
To clearly evaluate and analyze the data, an ANOVA test was conducted. ANOVA test results indicate that the P-value, which is 0,6404245, is higher than α- vale, which is 0.05. This situation indicates that there are significant statistical differences between the bleaching events. As a result, the null hypothesis, "H_0**:** Bleaching rates in the Great Barrier Reef's mass bleaching events will change due to the changes in sea surface temperatures." made for the investigation is rejected and the alternative hypothesis, "H_1: The change in sea surface temperatures around the Great Barrier Reef will not affect its bleaching rates in the mass bleaching events." is accepted.

5. Discussion and Evaluation

This study aims to determine if variations in sea surface temperature surrounding the Great Barrier Reef have an impact on the rate of bleaching during the mass bleaching events occurred in the years between the years 1998-2022. The 7 mass bleaching events used in the investigation took place in the years 1998, 2002, 2006, 2016, 2017, 2020, 2022.



Graph 2: Graph of sea surface temperature changes in the Great Barrier Reef in the last 7 mass bleaching events.



Graph 3: Graph of The Great Barrier Reef bleaching severity percentage on the mass bleaching events.

Using the research made on the topic, it was seen that the reason for these bleaching events were not caused by the sea surface temperature changes, they were caused by the changes around the environment of the Great Barrier Reef.

The mass bleaching event in 1998 was the strongest bleaching for its time, but the anomaly in the sea surface temperature was only 0.80 degrees. 2002 had the same sea surface temperature anomaly yet it is considered the worst bleaching event in the Great Barrier Reef's history to this day. The mass bleaching event in 2006 had the lowest change in sea surface temperatures, which was 0.50 degrees, but it had one the highest bleaching percentages in Southern part of the reef. After that, the Great Barrier Reef did not have a mass bleaching event for nearly 10 years until 2016. In 2016, sea surface temperature was one degree higher than average, and with the addition of Cyclone Nathan in 2015, a mass bleaching event occurred mostly hitting the Northern part of the Great Barrier Reef. 2017 had one of the lowest sea surface temperature anomalies, but still the Southern and central parts of the reef suffered major bleaching. With

Cyclone Debbie happening in 2017, the Great Barrier Reef had faced with two major cyclones and two mass bleaching events in the last 3 years. In 2020, coral reefs were exposed to cumulative heat stress with the sea surface temperature being 1.2 degree higher than average, but still, the bleaching severity rate of the Southern part of the reef had increased significantly for the first time in nearly 14 years. At last, in 2022, the highest sea surface temperature anomaly was seen at 2 degrees above the average temperature. The accumulation of this much heat stress alongside with crown-of-thorns starfish outbreaks and Cyclone Tiffany should have had enormous damage to the coral reefs, but none of the 3 parts of the Great Barrier Reef's bleaching severity percentages exceeded over 10.5%.

Weaknesses:

Weakness	Explanation
The lack of data on the internet	Even though the Great barrier Reef is the biggest coral reef in the world, the data on its bleaching rate is very limited on the internet.
Investigation of a single location	Considering the size of the location, there are many outside affects to its bleaching rates. Investigating a smaller coral reef might have much clear outcomes.
Complexity of the system	The Great Barrier Reef is a massive and complex system, so there are lots of things to consider while only trying look at the sea surface temperatures effect on the bleaching rates.

Table 7: Weaknesses of the Investigation

6. Conclusion

After combining previous research made on the topic to the statistical results taken from the experiment, the investigation came to the fact that the changes in the sea surface temperature around the Great Barrier Reef did not affect the bleaching rates during the mass bleaching events. As explained in the evaluation part, all the years that mass bleaching events occurred, none of the data found throughout the investigation could be linked with the statistical data. The only explanation for why the p-value or standard error were too high is due to the fact that the Great Barrier Reef is too big of an ecosystem. Even by separating to three parts, a statistical outcome could not be provided since there are too many external factors to consider, like cyclones and outbreaks of particular species. Also, even though accumulation of heat stress is one of the leading causes in the Great Barrier Reef, it cannot be kept apart as the only cause of coral bleaching. Just like in many other massive ecosystems around the world, there usually is a natural order of things. When there is a cumulative heat stress in the surface of the ocean, it leads to more intense weather conditions, like cyclones, which can increase nutrient runoff from agricultural areas to coral reefs. The occurrence of this event results in the growth of algae, which is a food resource for species like crown-of-thorns starfish.

Assessment of the long-term health of the Great Barrier Reef

The reefs have demonstrated their ability to recover from disturbances throughout the 25 years of AIMS monitoring, but resilience obviously has its limits. More extreme bleaching events and stronger storms are among the anticipated effects of climate change. Reefs are more severely damaged by more extreme disturbances; therefore, if growth rate stays constant, recuperation will take longer. The duration between acute disturbance occurrences is also getting shorter, and long-term stresses like high turbidity and warm ocean temperatures could hinder the rate of recovery. Due to the recent bleaching's geographic scope, breeding populations of corals have been severely reduced over wide regions, which will decrease the number of potential sources of larvae that could recolonize reefs in the upcoming years.

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