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The Phenomenon of the Greenhouse Effect and Its Effects on Coral Reefs

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ABSTRACT

Coral reefs, vital ecosystems renowned for their biodiversity and economic value, face escalating threats from the intensifying greenhouse effect caused by human activities. This study examines the impacts of rising greenhouse gas concentrations on coral reefs, focusing on coral bleaching and sea level rise. Elevated sea surface temperatures, driven by the greenhouse effect, induce physiological stress in corals, leading to the expulsion of zooxanthellae and subsequent bleaching—impairing photosynthesis and growth. Meanwhile, rising sea levels, resulting from thermal seawater expansion and melting polar ice, risk submerging coral reefs, further degrading their health and ecological functions. These changes threaten marine ecotourism by diminishing the appeal of coral reefs as tourist destinations while undermining biodiversity and coastal protection. The findings highlight the urgent need for sustainable practices and policy interventions to mitigate climate change's effects on coral reef ecosystems and the communities that depend on them.

INTRODUCTION

Coral reefs play a role in protecting against wave damage and erosion on tropical coastlines, making them a very important factor in the livelihoods of millions of people who depend on the productivity of coral reefs **(Wilkinson & Buddemeier, 1994)**. They are one of the most amazing ecosystems on earth that serve as food sources, producers of medicinal chemical compounds, natural wave barriers, and many other benefits. The primary productivity of coral reefs is higher than other ecosystems, such as seagrass ecosystems and tropical forests **(Tuwo & Tresnati, 2020)**. Often referred to as the 'rainforests of the sea', coral reefs occupy less than 0.1% of the seafloor, yet harbor 25% of the world's main species **(Hoegh-Guldberg *et al*., 2017)**.

However, due to catastrophic natural events and careless human activity, coral reefs have been classified as endangered ecosystems **(Riegl *et al.*, 2009)**. One of the main causes of the devastation of coral reef ecosystems is human activity. The concentration of greenhouse gases in the atmosphere has increased due to a number of human activities, including the use of fossil fuels, the use of agricultural chemicals, the burning of forests, and other industrial activities. This has raised Earth's surface temperature and is commonly known as an increase in the greenhouse effect **(Kweku *et al.*, 2018)**. Worldwide, these human-caused causes have resulted in long-term decreases in coral reef biodiversity, abundance, and habitat structure **(Hughes *et al.*, 2018)**. The cumulative effect of this damage has changed the processes and functions of ecosystems by causing a loss in nearshore tropical biodiversity **(Pratchett *et al.*, 2014; Richardson *et al.*, 2018)**.

The rise in sea surface temperature is directly correlated with the increase in Earth's surface temperature. Raising sea surface temperatures is one of the things that contribute to physiological thermal stress, which can lead to coral bleaching and ultimately the destruction of coral reefs **(Richardson *et al.*, 2018)**. According to research, a third of the world's coral reefs will eventually disappear due to ongoing harm to coral reefs **(Plass-Johnson *et al.*, 2015)**. Sea levels have also increased as a result of the melting of ice in the polar regions brought on by an increase in Earth's surface temperature. Sea level has risen by 25cm in the 20th century and is expected to rise by up to 1m by the end of the 21st century. In the event that sea level rise persists for an extended length of time, coral reefs may be submerged.

MATERIALS AND METHODS

1. Methods

This article employs the literature study method, which involves gathering data and theoretical insights from existing references on the research topic **(Sugiyono, 2015)**. The literature review draws upon diverse sources, including books, journal articles, online publications, and instructional materials such as modules or course reports relevant to the study **(Suryanti & Indrayasa, 2021)**.

RESULTS

1. Coral reefs

A coral reef is an ecosystem found in shallow waters that is primarily made up of macroalgae that has been encrusted with calcium carbonate secreted by reef-building corals **(Latuconsina, 2010)**. In tropical and subtropical waters that are warm, shallow, transparent, and low in nutrients, hundreds of thousands of polyps come together to form coral reefs **(Gatusso *et al.*, 2014)**. Coral colony growth is subject to variation based on parameters such as solar exposure, food availability, sedimentation, genetic makeup, wave activity, and current intensity in a body of water **(Grimsditch & Salm, 2006)**.

Because of their rich variety and great primary productivity, coral reefs are frequently compared to as underwater tropical rainforests **(Arisandi *et al*., 2006)**. Though they only make up 0.1% of the ocean floor, coral reefs are crucial for supporting biodiversity, giving fish habitat, and generating an alluring underwater tourist attraction **(Syahrir *et al*., 2015)**.

2. Greenhouse effect

A number of gases, collectively known as greenhouse gases, are found in the atmospheric layer and are helpful in retaining solar heat energy. Earth's temperature is sustained by this greenhouse gas, which keeps the planet warm and livable for people. The term "greenhouse effect" describes this occurrence. The earth's temperature rising as a result of the atmospheric layer being warmer as a result of greenhouse gas accumulation is known as the "greenhouse effect" **(Syahrir *et al*., 2015)**. Some benefits can come from the greenhouse effect. The earth's temperature would not be ideal for human habitation if it weren't for the greenhouse effect **(Wild *et al*., 2011)**.

Nevertheless, the earth's temperature will rise as a result of greenhouse gas concentrations that are too high in the atmosphere **(Mikhaylov *et al*., 2020)**. Anthropogenic activities like industry, agriculture, the use of fossil fuels, urbanization, land conversion, cement production, etc. are major causes of the rise in greenhouse gas concentrations. These activities increase the amount of greenhouse gases in the atmosphere, which trap and reflect back solar heat energy, raising the earth's surface temperature and causing other climate changes **(Pratama & Kunci, 2019)**.

3. Coral bleaching

An increase in the Earth's surface temperature will go hand in hand with an increase in sea surface temperature. There are several marine biotas that will be affected by the increase in sea surface temperature, one of which is coral reefs. One of the impacts of rising sea surface temperatures on coral reefs is coral bleaching. Coral bleaching occurs when corals expel their symbiotic zooxanthellae—algae that provide photosynthetic pigments—due to stress from elevated seawater temperatures. This loss causes the coral colonies to turn pale or white, as their vibrant colors fade without the pigments produced by zooxanthellae **(Utina, 2014)**. In certain cases, there are some coral species that are able to survive and recover from this phenomenon, but in general, corals are unable to recover and lead to coral death **(Dunne *et al*., 2013)**. Coral reefs are one of the marine biotas that are very vulnerable to temperature changes. A small temperature increase of $1^{o}C$ is enough to make this biota experience physiological thermal stress **(Ainsworth & Brown, 2021)**.

4. Sea level rise

Anthropogenic factors are predicted to add an increasing amount of greenhouse gases to the atmosphere, making global warming worse over time. Rising sea levels—one of the many consequences of human-induced climate change—pose a significant threat to coastal ecosystems **(Schuttenberg, 2010)**. This phenomenon is primarily driven by thermal expansion of seawater due to global warming, exacerbated by the greenhouse effect **(Toscano *et al.*, 2002)**. Additionally, rising temperatures accelerate the melting of land ice, glaciers, and polar ice sheets in Greenland and Antarctica, further contributing to sea level rise **(Wadhams *et al.*, 2011; Cazenave & Cozannet, 2014; Meissner, 2017)**. Approximately 10% of the global population resides in low-lying coastal zones (≤10 meters above sea level), making them highly vulnerable to the impacts of rising seas **(Gardner *et al.*, 2013)**.

5. Marine ecotourism

Traveling and visiting natural regions in an environmentally conscious manner that promotes the preservation of the environment and its resources while also improving the well-being of the local population is known as ecotourism **(Jalani, 2012)**. The following ecotourism principles should be addressed in the implementation: minimizing negative environmental effects; generating financial gains for conservation and local welfare; creating a positive impression for both owners and guests; fostering local empowerment; and raising awareness of the nation's socioeconomic, political, and cultural traits **(Anggoro *et al.*, 2019)**. Marine ecotourism involves visitors paying to experience marine and aquatic ecosystems, with revenue often directly supporting conservation efforts through funding protection initiatives, advancing scientific knowledge, and promoting research **(Thorburn *et al.*, 2021)**. Effective ecotourism is characterized by four key principles: proactive environmental stewardship, ecological sustainability, community involvement, and educational value **(Arismiyanti, 2017)**. Sustainable tourism practices aim to operate within the natural environment’s carrying capacity, ensuring long-term resource productivity and ecosystem regeneration **(Hadi *et al.*, 2022)**. The success of marine tourism depends on balancing multiple factors, including environmental preservation, local community well-being, and visitor satisfaction while fostering integration with community development goals **(Arismiyanti, 2017)**.

DISCUSSION

1. The effect of sea temperature's rise on coral bleaching phenomenon

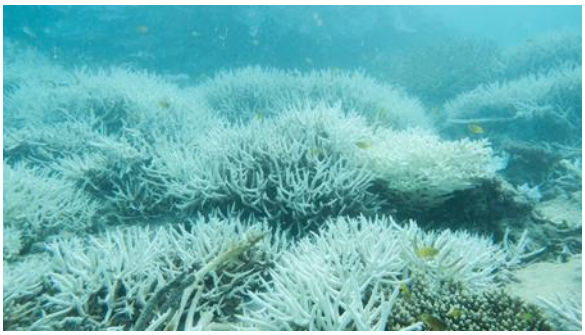

Fig. 1. Effect of sea temperature on coral bleaching **(Hoegh-Guldberg, 2024)**

A key component of human life on Earth is the greenhouse effect **(Mikhayllov *et al.*, 2020)**. Unfortunately, because of human activity, the amount of greenhouse gases in the atmosphere is still rising, trapping more heat energy there. Global temperatures have risen significantly above historical averages as a result of this phenomenon. This affects not only the earth's surface temperature but also the temperature of the sea, which rises concurrently. Undoubtedly, rising water temperatures significantly impact aquatic ecosystems **(Shepherd *et al.*, 2012)**. Many aquatic species exist in regions that are not very hot **(McGranahan *et al.*, 2007)**. Coral reefs, despite surviving in environments that approach their thermal tolerance limits **(Harley *et al.*, 2006)**, are increasingly vulnerable to rising sea temperatures. These marine organisms are highly sensitive to fluctuations in water temperature, with optimal conditions for coral reef vitality ranging between 25–29°C **(Arisandi *et al.*, 2018; Somero, 2020)**. While corals can endure short-term thermal stress from sea surface temperature increases of 1–2°C **(Hughes *et al.*, 2003)**, prolonged exposure triggers the expulsion of zooxanthellae—the photosynthetic algal symbionts critical to coral survival—resulting in bleaching **(Richardson *et al.*, 2018)**. This process disrupts the mutualistic relationship between corals and their zooxanthellae, impairing the algae's photosynthetic capacity and potentially eliminating up to 90% of these symbionts **(Bruno *et al.*, 2001; Selig *et al.*, 2010)**. Consequently, bleached corals experience suppressed photosynthesis and stunted growth **(Arisandi *et al.*, 2018)**, exacerbating reef degradation.

Coral bleaching is a phenomenon that significantly affects marine ecosystems. Because corals are home to various fish species in the marine ecosystem, a loss in coral growth potential may have an impact on places that sustain morphological variety by lowering the resilience of the coral reef community in the waters **(Richardson *et al.*, 2018)**.

2. Effects of sea level rise on coral reefs

Fig. 2. Effect of sea level rise on coral reefs **(Exeter University, 2018)**

A decrease in the geographical range of coral reef habitats can be caused by sea level rise **(Hoegh-Guldberg & Smith, 1989)**. The oceans' natural thermal expansion and the extra water melted from continental ice sheets and glaciers contribute to sea level rise **(Glynn, 1996)**. It is anticipated that by 2100, the average sea level rise since 1870 will have reached 40cm **(Knowlton, 2002)**. However, if ice sheets and glaciers melt more quickly than anticipated, sea levels might rise far more than predicted **(Munday *et al.*, 2008)**.

The reduction in light intensity that can penetrate at specific depths causes a drop in coral accretion rates with depth. Coral reefs located in deeper waters may become submerged as a result of an abrupt rise in sea level. Coral populations may face more deep water if sea levels rise more quickly than coral reefs can reach. At this point, coral reefs may fall because there won't be enough sunlight for corals to photosynthesize **(Church & White, 2006)**. Nonetheless, certain corals can build new reefs on the top slope of the old reef to gain a higher position to combat sea level rise, which allows them to mitigate this issue to a reasonable extent **(Velicogna & Wahr, 2006)**.

Although some coral reefs may be able to keep up with the rate of sea level rise, others may not be able to do so and may not be able to adapt to sea level increase until several thousand years after the sea level stabilizes **(Woodroffe & Webster, 2014)**. In other instances, equatorial sea suction causes coral reefs in the Pacific to undergo a drop-in sea level, which leads to coral reef drowning **(Blanchon, 2011)**. The equatorial sea is drawn out of the region to fill the void left by the fore bulge collapsing around glaciated areas, causing a relative sea level drop in the remote regions of the Indo-Pacific coral reef zone **(Rannad, 2024)**.

3. Impacts of global warming on marine ecotourism and coral reefs

Fig. 3. Impact of marine ecotourism in coral reefs **(The Nature Conservancy, 2017)**

Activities related to marine ecotourism can be carried out on coral reefs in a variety of ways. Here are a few of them: Snorkeling and diving: These pursuits provide visitors a close-up look at the stunning coral reefs and associated marine life. While snorkeling is done at the water's surface, diving is typically done at deeper depths. Coral Bleaching: The rising temperatures of the ocean due to global warming cause coral to bleach. This makes coral reefs less visually appealing to tourists and may result in fewer visits **(Rannad, 2024)**. Decreased Biodiversity: Damaged reefs provide less habitat for different marine species, which lowers the amount of biodiversity that tourists can experience **(World Bank, 2024)**.

Marine ecotourism offers educational tours that teach visitors about coral reef conservation through guided tours, workshops, and interactive talks **(Lukyani, 2022)**. Many programs incorporate research and conservation activities, allowing tourists to participate in coral replanting projects or scientific data collection **(Lukyani *et al.*, 2022)**. Low-impact water activities like kayaking and paddleboarding enable reef exploration while minimizing ecological disturbance, while glass-bottom boat tours provide access for non-swimmers to observe marine ecosystems. Underwater photography has become popular both for its artistic value and as a tool for conservation education, helping raise awareness about reef biodiversity. In select locations, surfing on reef-generated waves serves as another sustainable tourism activity. However, improperly managed tourism can damage fragile reef ecosystems through physical impacts like diving-related contact or boat anchor damage, exacerbating existing stressors from climate change **(Richardson, 2018; Lukyani, 2022)**. These activities must be carefully balanced with conservation efforts to protect vulnerable marine environments.

CONCLUSION

Coral reefs, as vital marine ecosystems, face significant threats from the intensifying greenhouse effect caused by human activities such as the burning of fossil fuels, deforestation, and industrial processes. These activities contribute to rising greenhouse gas concentrations, which elevate Earth's surface temperature, leading to detrimental impacts on coral reefs. Notably, increased sea surface temperatures result in

coral bleaching—a process where corals lose their symbiotic algae, hindering photosynthesis and growth, and ultimately causing coral mortality. Additionally, sea level rises due to melting polar ice caps and thermal expansion further jeopardizes coral reefs by reducing light availability, essential for coral survival.

These ecological changes not only threaten the biodiversity and productivity of coral reefs but also impact coastal communities reliant on them for protection, food, and tourism income. Marine ecotourism, while offering opportunities to promote awareness and conservation, must be carefully managed to mitigate further damage to these fragile ecosystems. This study highlights the urgent need for global action to mitigate climate change and implement sustainable practices to preserve coral reefs and their invaluable ecosystem services for future generations.

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