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Analysis of Coral Reef Cover in Nias Regency, North Sumatra

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Abstract
Marine and fisheries resources in the waters of Nias Regency are one of the sectors that drive the community's economy, especially in coastal areas. Coral reefs are one of the marine ecosystems in Nias Regency that have high ecological and economic value. This research aims to evaluate the environmental conditions of coral reefs in the Nias Regency Water Area, especially in the seascape tourism zone around the waters of Onolimbu Island and Musi Island as research locations. The research was conducted from March to May 2023 in the coastal waters of Nias Regency to collect ecological and socio-economic data. Coral cover analysis was carried out using underwater photo methods and classified based on condition categories set by the Ministry of Environment. The condition of coral reefs at this research location is in the damaged to moderate category (23.47-45.13%) with an average abundance of 31.54% and is included in the medium category. The percentage of coral reef life form types consists of Dead Coral Algae (DCA) (34.86%), Hard Coral (31.81%), Sands (15.73%), Recent Dead Coral (5.84%), and the rest are Rubble, Other Biota, and Rock. Coral Reefs, Coral Cover, Nias Regency

Keywords: Coral Reefs, Coral Cover, Nias Regency, Environment, Ecology

INTRODUCTION

Coral reef ecosystems play a vital role in supporting marine life. One of their most critical ecological functions is coastal protection. Coral reefs growing in tidal zones significantly reduce the energy of incoming waves, thereby preventing coastal erosion and contributing to the formation of sandy beaches. In addition, coral reefs serve as critical habitats by providing food, shelter, and breeding grounds for various marine organisms. They also play a role in maintaining the biodiversity and sustainability of aquatic ecosystems, ensuring the survival of commercial and non-commercial species vital to oceanic food webs (Hein et al., 2021).

Ranjan et al. (2023) emphasized that the destruction of coral reefs caused by human activities is rooted in multiple interconnected socio-political and economic factors. These include poor policy implementation, weak management systems, ineffective legal frameworks and law enforcement, and low public awareness of coral reefs' ecological and economic importance. Moreover, poverty, uncontrolled exploitation, and a lack of capacity in environmental governance also contribute to coral reef degradation (Fudjaja et al., 2020). The open-access nature of many reef areas and unsustainable market demands and cultural practices further intensify the pressures on these fragile ecosystems.

Over the past several decades, coral reef ecosystems have experienced significant declines in health and coverage due to a combination of global and local stressors (Eddy et al., 2021). Globally, coral reef cover has decreased by approximately 50% since the 1950s, a trend attributed to rising sea temperatures, ocean acidification, overfishing, and pollution (Davis et al., 2021). For instance, the Great Barrier Reef has substantially reduced coral cover, declining from 28.0% in 1985 to 13.8% in 2012, primarily due to tropical cyclones, crown-of-thorns starfish predation, and coral bleaching. Local anthropogenic activities further exacerbate the degradation of coral reefs. In Vietnam, for example, only 1% of coral reefs remain healthy, with the majority affected by climate change, pollution, and overfishing. Similarly, in Hawaii, nitrogen-rich sewage from cesspools and septic tanks promotes algal overgrowth, which, coupled with the decline of herbivorous fish like parrotfish due to overfishing, leads to coral smothering and decreased resilience.

Naturally, coral reefs have high resilience to any disturbance and have survived for hundreds of millions of years. However, the negative impact of human presence on Earth in the last two centuries has caused the resilience of coral reefs to existing disturbances to become smaller (Hochberg & Gierach, 2021). This phenomenon is also thought to occur in the waters of Nias Regency, which has contributed significantly to creating severe pressure on the decline in resilience of coral reefs. The decreasing resilience of coral reefs is a significant disruption and shock to the marine tourism sector, as is the case in Australia's Great Barrier Reef, and this problem also occurs at the research location (Walpole & Hadwen, 2022).

Marine and fisheries resources in Nias Regency are one of the sectors driving the community's economy, especially in coastal areas. Some people in the area earn their living from marine products as fishermen. Coastal regions and small islands with their diversity of resources make them one of the development targets in the marine and fisheries sector, as well as an orientation for future national development planning policies. In line with this policy, the Nias Regency Government in the Nias Regency Regional Spatial Planning (RTRW) places the coastal area as one of the areas for future regional economic growth. Coral reefs are one of the marine ecosystems in North Nias with high ecological and monetary value. These environmental values include a habitat, a place to find food, a place to nurture and grow, and a spawning place for various marine biota. The essential economic value of coral reefs is as a place to catch multiple types of marine biota for consumption and different kinds of ornamental fish, construction materials, and jewelry, and as an attractive tourist and recreational area (Dalimunthe et al., 2023).

The urgency of evaluating coral reef conditions in Nias Regency stems from the increasing rate of degradation experienced by reefs globally and regionally. Coral reefs are biodiversity hotspots and provide vital ecosystem services such as coastal protection, fisheries support, and tourism opportunities. However, these ecosystems are under significant threat due to intensified human activities and climate-induced stressors. In Nias Regency, where the community is closely dependent on marine and coastal resources for their livelihoods, especially in fisheries and tourism, coral reef degradation threatens socio-economic stability and environmental

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sustainability. Moreover, the strategic positioning of the region as a future marine economic development area under the RTRW makes it imperative to ensure the sustainability of its aquatic ecosystems.

Despite the recognized importance of coral reefs in the region, there is a lack of up-to-date, comprehensive scientific data that reflects the current status of coral reef ecosystems in Nias Regency. This research seeks to fill that gap by providing an ecological assessment of the current limited or fragmented coral reef cover and health.

RESEARCH METHODS

Location of Research

The research will be carried out from March to May 2023, at the lead ore mining company (PbS/Galena) PT. Thanks to Bhinneka Perkasa, which administratively includes mines in the Kanagarian Tanjung Balit area, Pangkalan Koto Baru District, Limapuluh Kota Regency, West Sumatra Province. The research is conducted in the Nias Regency Water Area, located in northern Sumatra, Indonesia. Nias Regency is known for its rich marine biodiversity and significant coastal and island ecosystems, which include coral reefs, seagrass beds, and mangrove forests. The region's waters are home to various aquatic species that depend on the coral reef ecosystem for shelter, breeding, and feeding.

Tools and Materials

The equipment used for collecting ecological data in the field in this research consisted of a rubber boat, transect (50 m), quadrat transect (50x50 cm), Global Positioning System (GPS), underwater digital camera, underwater stationery and diving equipment with using Self Contained Underwater Buoyancy Apparatus (SCUBA) and equipment for collecting water parameter data. Meanwhile, to collect socio-economic and institutional data using a questionnaire.

Data Collection Techniques

The data collection for this research was conducted at four stations in the Nias Regency Water Area, which are located in the seascape tourism zone: Onolimbu Island 1, Onolimbu Island 2, Musi Island 1, and Musi Island 2. The collection process measures biophysical indicators such as water quality, coral cover percentage, abundance of megabenthos, abundance of coral fish, and the growth of young coral (saplings).

a) Water quality

Water quality data were collected at each station, with measurements taken three times during the research period. The variables measured included:

- Temperature (°C) using a thermometer.
- Salinity (‰) measured with a refractometer.
- Depth (m) recorded using a deep gauge.
- Brightness (m) measured with a Secchi disc.

These measurements were taken in situ at each observation station to monitor water quality and its potential impact on the coral reef ecosystem.

b) Coral cover percentage

The coral cover percentage was measured using the Underwater Photo Transect (UPT) method while diving using SCUBA equipment. The procedure for data collection is as follows:

1) Station Setup
The station is named for new locations, and coordinates are recorded using GPS. The transect coordinates from records are confirmed if the area has been previously monitored.

2) Transect Line Deployment
The diver deploys a 70-meter transect line parallel to the coastline at approximately 5 meters depth. The position of the transect line is marked by two iron stakes and buoys to aid in the identification of the transect's starting point.

3) Underwater Photography
Photographs are taken of the reef habitat surrounding the transect. The photographer uses a digital underwater camera (e.g., CANON G15 or higher) to capture images at perpendicular angles to the substrate. The area captured in each photo must cover at least 2552 cm^2, which is achieved by maintaining a 60 cm distance between the camera and the substrate.

4) Photographic Sequence
The photo-taking sequence begins at the left side of the transect (closer to land), starting at the first meter, and continues to the right side (further from land) as the transect is followed.

5) Photograph Management
A frame of iron measuring 58 cm by 44 cm ensures consistency in photo coverage. The photos are systematically numbered for ease of data management.

Once all photos are taken, the photographs are analyzed using the CPCe (Coral Point Count with Excel) software. Random point sampling is applied to each image, with 30 points per frame selected for analysis. This method allows the estimation of the percentage cover of coral species, other biota, and substrates across the transect line.

Data Analysis Techniques

The analysis of coral cover percentage was performed using the following steps:

a) Photo Analysis
Each photograph from the transect is analyzed by the CPCe software, which randomly selects 30 points for evaluating the substrate and biota. This analysis provides the percentage cover of coral and other reef components.

b) Coral Condition Categorization
Based on the percentage of coral cover obtained from the photo analysis, the condition of the coral reef is classified according to the guidelines set in the Decree of the Minister of Environment Number 4 of 2001. The classification categories are as follows:

Table 1. Coral Condition Categories

Coral Reef Condition Category	Coral Cover Percentage Hard Life
Very Good	≥ 75 %
Good	50 - < 75 %
Currently	25 % -< 50 %
Damaged	< 25 %

RESULTS AND DISCUSSION

Water Quality

Dissolved oxygen (Dissolve Oxygen) is one of the main components for aquatic biota. Dissolved oxygen levels in the sea surface layer generally range between 5.7 - 8.5 mg/l. Low oxygen levels in these waters are closely related to high turbidity. They may also be caused by the increasing activity of microorganisms in decomposing organic substances into inorganic substances using dissolved oxygen. Besides being useful for respiration, the dissolved oxygen content in water can also be used as an indicator of water quality. Dissolved oxygen levels measured at the research location averaged 8.5 mg/l.

The degree of acidity of waters is one of the chemical parameters that is quite important in monitoring the stability of waters. In general, sea water has a pH value range of 7.5 – 8.5, which tends to be alkaline, but under certain conditions, the value can be lower than seven so that it becomes acidic. The results of measuring the pH value in the marine waters of Nias Regency show that the pH value is in the range of 7.2 – 8.3, this indicates that the pH quality of the waters in the marine waters of Nias Regency is still within the normal interval value as per Quality Standards Based on Minister of Environment Decree number 51 of 2004 (For Marine Biota), namely 7-8.5. The appropriate degree of acidity or pH value will help corals to speed up the calcification process. The calcification process is a process that forms the lime substance $CaCO_3$ to enlarge coral reefs. At the research location, the average pH was 8.3. This value also follows the standard value, namely the pH value suitable for living marine biota.

Based on the results of temperature measurements, the highest temperature was located at Station 2, Onolimbu Island, 29.5 0C, and the lowest temperature was at Stations 1 and 3, namely Onolimbu Island and Musi Island, 29.2 0C. The average temperature at the research location as a whole is 29.3 0C. The temperature in the waters around Onolimbu Island and Musi Island and their surroundings is by the quality standards for marine biota (coral), namely 28 - 30 0C (Kepmen of Environment, 2004). Good temperatures can increase the rate of growth and reproduction in coral animals. Temperatures that are not optimal can result in a bleaching process in coral because it can inhibit zooxanthella from photosynthesis, resulting in reduced nutrition in coral and death of coral animals.

Salinity in the study area has an average of 30‰. The salinity found on Onolimbu Island and Musi Island does not significantly differ in value. The standard quality standard for seawater salinity for marine biota (coral) is 33 - 34 ‰. Corals have different tolerance levels for each species; the average tolerance of corals to water salinity ranges from 25-40‰ (Veron, 2000). Coral reefs can generally adapt to fluctuating salinity, but are typically more suited to stable and natural salinity suited to marine habitats. Low salinity values can cause coral stress by disrupting the homeostatic control process, which causes a decrease in zooxanthellae and chlorophyll concentrations, thereby inhibiting growth and reproduction, and resulting in the most severe impact, namely coral bleaching.

Coral Reef Cover Presentation

The condition of coral reefs in the Nias Regency marine conservation area is in the damaged to moderate category (23.47-45.13%), so that the average abundance is 31.54% in the medium category, according to the Decree of the Minister of Environment Number 4 of 2001. Percentage The highest coral cover was found at Onolimbu_02 station, namely 45.13% and was in the medium category, then followed by the Onolimbu-01 station area (32.23%) in the medium cover category, Musi_02 Island (25.34%) in the medium cover category, and finally Musi_01 station with the lowest coral cover and is in the low category (23.47%). Coral reef cover aims to determine the status of the coral reef cover area category. The coral identification results are presented in the following image.

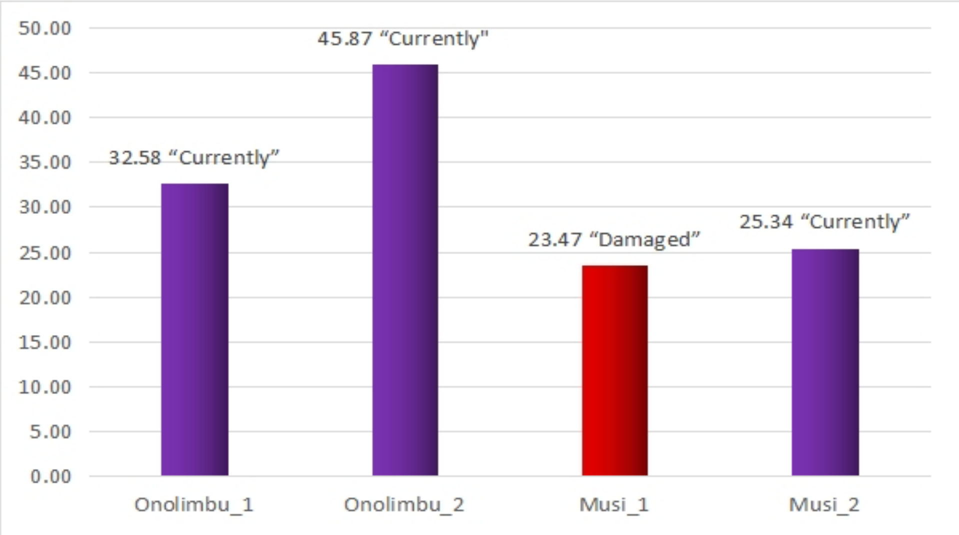

Figure 1. Percentage of Coral Reef Cover at Research Locations in Nias Regency Waters

Based on the 2015 Final Report on the Survey and Mapping of Potential Marine and Fisheries Resources in Nias Regency, it is stated that in general, the type of coral in Nias Regency is a small island fringing reef type, where the average percent of live coral cover in these waters is 60.82%. This area is generally included in the good coral reef category (50 – 75%). This data was taken based on the results of satellite image interpretation, and coral reefs in Nias Regency are spread around small islands in this water area. Coral reef ecosystems are vulnerable to damage, mainly caused by environmental factors in the surrounding waters. Coral reef ecosystem damage can be seen from physical and physiological damage. Physical damage to coral includes destroyed coral colonies, broken branches, and colonies lifted from the substrate.

Meanwhile, physiological damage to coral includes changes in coral color that fade or even turn white, or bleaching. Fading color changes in coral occur due to reduced concentrations of zooxanthellae photosynthetic pigments in coral polyps. Coral polyps that detach from the host cause the coral to lose most of its color pigments and soft tissue. This is because zooxanthellae, which contribute pigment to coral, are released along with the coral polyps.

Coral bleaching occurs when corals experience stress on a large spatial scale. It also results from prolonged exposure to warmer sea surface temperatures. The intensity and frequency of coral bleaching are expected to increase due to the continuous rise in sea surface temperature driven by global climate change. Observations indicate that the degradation of coral reef ecosystems in the waters of Onolimbu Island and Musi Island is also caused by environmentally harmful fishing practices, such as using potassium, overfishing, and coral mining. In addition, natural factors significantly contribute to the decline in coral cover. The complex coral genus that dominates is Porites, which has a massive (solid) growth form. Porites corals can survive in various environmental conditions, including areas with high sedimentation and fluctuations in salinity. They can also live in diverse habitats like rocky substrates, sandy bottoms, and coral rubble.

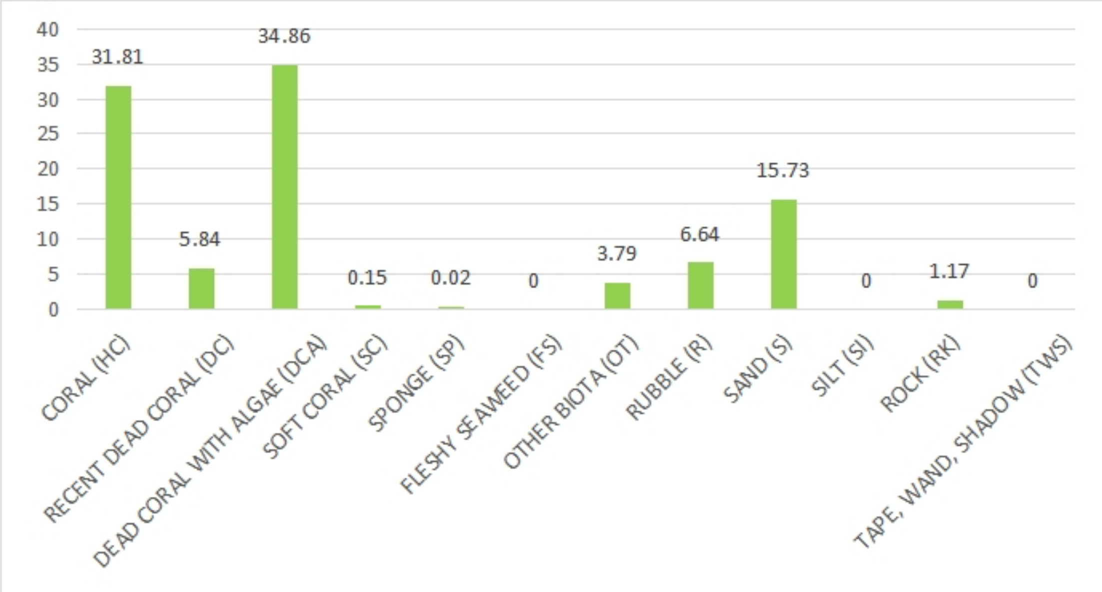

Figure 2. Percentage of Coral Reef Life Form Types at Research Locations

The percentage of coral reef life form types consists of Dead Coral Algae (DCA) (34.86%), Hard Coral (31.81%), Sands (15.73%), Recent Dead Coral (5.84%), and the rest are Rubble, Other Biota, and Rock as seen in Figure 3. This data shows that Dead Coral Algae is the highest type compared to the others. This can happen due to the effects of global warming, resulting in coral bleaching. The bleaching event on corals is a real event that puts pressure on the environment of coral reefs (coral bleaching). One of the environmental conditions that is taken into consideration is the increase in sea surface temperature during the El Nino phenomenon which last occurred in 2015 to 2016, this is a phenomenon the strongest ever recorded coefficient of change in sea water temperature is often associated with global warming, which affects coral animals, including fauna with low resistance to temperature changes ranging from 1°C to 1.5°C.

The impact of bleaching leads to low coral recruitment, resulting in a slow recovery process in affected areas because most new coral juveniles die. Another impact of bleaching is a significant decrease in fish abundance, indicating that only large (adult) fish remain while small fish, including juveniles, are rarely found. A high sand substrate makes it difficult for attached corals to recruit, as sand is easily disturbed by currents and offers less support for coral survival than solid substrates. Solid substrates with high stability facilitate coral recruitment. Additionally, coral death creates space for algae to grow as competitors to coral reefs, thereby increasing the percentage of algae.

Assessment of Water Quality Parameters and Their Impact on Coral Health in Nias Regency Waters

Water quality plays a critical role in determining the health and sustainability of coral reef ecosystems. This study's measured parameters, such as dissolved oxygen (DO), pH, temperature, and salinity, were generally within acceptable limits based on the Minister of Environment Decree No. 51/2004. The average DO level was 8.5 mg/l, which indicates high oxygen availability essential for marine biota. Similarly, the pH level was stable at around 8.3, supporting calcification processes in corals.

Despite suitable DO and pH levels, salinity values in the area were slightly lower than the optimal standard for coral reefs. The average salinity was 30‰, while the ideal range is 33–34‰. This lower salinity may cause stress in corals, impacting their ability to maintain homeostasis and contributing to bleaching events. Similar findings were reported by Paulino et al. (2020), where coral health was negatively influenced by freshwater runoff and salinity fluctuations.

The sea surface temperature at the research site averaged 29.3°C, which falls within the recommended range (28–30°C). However, the proximity to the upper thermal limit suggests vulnerability to thermal stress. Prolonged exposure to temperatures above this range can inhibit zooxanthellae's photosynthesis, resulting in coral bleaching. During the global bleaching event, Research Foo & Asner (2020) also found that sustained sea surface temperature increases are the primary cause of mass coral mortality worldwide.

Coral Reef Cover Degradation and Bleaching Phenomena in Nias Regency

The coral reef cover in Nias Regency is currently categorized as moderate to poor, with an average live coral cover of 31.54%. This figure is significantly lower than the 60.82% reported in the 2015 regional survey. The highest cover observed in this study was 45.13% at Onolimbu_02 Station, while the lowest was 23.47% at Musi_01. The declining trend in coral cover suggests a continued degradation of reef ecosystems, potentially driven by natural and human-induced stressors. Dominant coral life forms included Porites species, known for their resilience in fluctuating salinity and sedimentation. However, Dead Coral Algae (DCA), the most abundant category (34.86%), indicates previous coral mortality, likely resulting from bleaching.

Siringoringo et al. (2022) Identified a similar pattern in Central Tapanuli, North Sumatra, where coral mortality post-bleaching was marked by increased DCA and reduced recruitment of new coral polyps. The 2015–2016 El Niño event is believed to have contributed to large-scale bleaching in Nias, consistent with global coral reef responses to temperature anomalies. Bleaching reduces coral pigmentation and leads to polyp detachment, preventing recovery due to the lack of solid substrate for new coral settlement. This line emphasizes that prolonged heat stress reduces reproductive capacity in corals, hampering ecosystem recovery.

Additionally, destructive fishing practices such as potassium poisoning and coral mining have exacerbated the damage in the research area. Combined with sedimentation and competition from algae, these stressors result in low coral recruitment and fish population shifts. Similar observations were made Ford et al. (2020) where reef damage directly correlated with local human activities. Restoration efforts should, therefore, integrate ecological monitoring with community-based marine resource management.

CONCLUSION

The condition of coral reefs in the Nias Regency marine conservation area falls within the damaged to moderate category, with live coral cover ranging from 23.47% to 45.13%, averaging at 31.54%, which is classified as medium. The dominant complex coral genus consistently observed over the past three years is *Porites*, a massive (solid) lifeform known for resisting environmental stress. However, coral recruitment has been negatively impacted by several anthropogenic factors, including the use of potassium for fishing, overfishing, and mining. To support coral reef recovery, it is recommended that stricter enforcement of marine conservation regulations be implemented alongside community education programs on sustainable fishing practices. Moreover, initiating coral transplantation and artificial reef programs, particularly using resilient genera like *Porites,* could help accelerate ecosystem regeneration and enhance biodiversity in degraded reef areas.

REFERENCE LIST

Dalimunthe, H. I., Husaini, H., Manurung, V. R., Yudhiwinata, M. A., Harahap, M. P., Pahlevy, M. A., Adisusilo, M. N., Abdillah, M. F., Hanif, A., Florencia, S., Sazida, H., Tambunan, D., Abshar, M. T., Manurung, F., & Waruwu, B. K. (2023). Upaya Rehabilitasi Ekosistem Terumbu Karang Terdampak Tumpahan Minyak Di Desa Faekhuna, Kecamatan Afulu, Kabupaten Nias Utara. Jurnal Abdi Insani, 10(3), 1555–1568. https://doi.org/10.29303/abdiinsani.v10i3.1066

Davis, K. L., Colefax, A. P., Tucker, J. P., Kelaher, B. P., & Santos, I. R. (2021). Global coral reef ecosystems exhibit declining calcification and increasing primary productivity. Communications Earth and Environment, 2(1), 1–10. https://doi.org/10.1038/s43247-021-00168-w

Eddy, T. D., Lam, V. W. Y., Reygondeau, G., Cisneros-Montemayor, A. M., Greer, K., Palomares, M. L. D., Bruno, J. F., Ota, Y., & Cheung, W. W. L. (2021). Global decline in capacity of coral reefs to provide ecosystem services. One Earth, 4(9), 1278–1285. https://doi.org/10.1016/j.oneear.2021.08.016

Foo, S. A., & Asner, G. P. (2020). Sea surface temperature in coral reef restoration outcomes. Environmental Research Letters, 15(7), 1–8. https://doi.org/10.1088/1748-9326/ab7dfa

Ford, A. K., Jouffray, J. B., Norström, A. V., Moore, B. R., Nugues, M. M., Williams, G. J., Bejarano, S., Magron, F., Wild, C., & Ferse, S. C. A. (2020). Local Human Impacts Disrupt Relationships Between Benthic Reef Assemblages and Environmental Predictors. Frontiers in Marine Science, 7(1), 1–14. https://doi.org/10.3389/fmars.2020.571115

Fudjaja, L., Viantika, N. M., Rani, C., Nurdin, N., Priosambodo, D., & Tenriawaru, A. N. (2020). Anthropogenic activity and the destruction of coral reefs in the waters of small islands. IOP Conference Series: Earth and Environmental Science, 575(1), 1–9. https://doi.org/10.1088/1755-1315/575/1/012057

Hein, M. Y., Vardi, T., Shaver, E. C., Pioch, S., Boström-Einarsson, L., Ahmed, M., Grimsditch, G., & McLeod, I. M. (2021). Perspectives on the Use of Coral Reef Restoration as a Strategy to Support and Improve Reef Ecosystem Services. Frontiers in Marine Science, 8(1), 1–13.

https://doi.org/10.3389/fmars.2021.618303

Hochberg, E. J., & Gierach, M. M. (2021). Missing the Reef for the Corals: Unexpected Trends Between Coral Reef Condition and the Environment at the Ecosystem Scale. Frontiers in Marine Science, 8(1), 1–10. https://doi.org/10.3389/fmars.2021.727038

Leinbach, S. E., Speare, K. E., Rossin, A. M., Holstein, D. M., & Strader, M. E. (2021). Energetic and reproductive costs of coral recovery in divergent bleaching responses. Scientific Reports, 11(1), 1–10. https://doi.org/10.1038/s41598-021-02807-w

Paulino, G. V. B., Félix, C. R., Silvan, C. G., Andersen, G. L., & Landell, M. F. (2020). Bacterial community and environmental factors associated to rivers runoff and their possible impacts on coral reef conservation. Marine Pollution Bulletin, 156(1), 1–11. https://doi.org/10.1016/j.marpolbul.2020.111233

Ranjan, D., Chandravanshi, S., Verma, P., Singh, M. B., Verma, D. K., Maurya, P., Upadhyay, A. K., Raghunath, Tiwari, A. K., & Sahu, K. K. (2023). Effects of Coral Reef Destruction on Humans and the Environment. International Journal of Environment and Climate Change, 13(10), 716–725. https://doi.org/10.9734/ijecc/2023/v13i102708

Siringoringo, R. M., Abrar, M., Sari, N. W. P., Putra, R. D., Hukom, F. D., Sianturi, O. R., Sutiadi, R., & Arbianto, B. (2022). Coral reefs recovery post bleaching event in Central Tapanuli, North Sumatra. IOP Conference Series: Earth and Environmental Science, 1033(1), 1–10. https://doi.org/10.1088/1755-1315/1033/1/012044

Skinner, C., Cobain, M. R. D., Zhu, Y., Wyatt, A. S. J., & Polunin, N. V. C. (2022). Progress and direction in the use of stable isotopes to understand complex coral reef ecosystems: A review. In Oceanography and Marine Biology: An Annual Review, Volume 60. https://doi.org/10.1201/9781003288602-8

Walpole, L. C., & Hadwen, W. L. (2022). Extreme events, loss, and grief, an evaluation of the evolving management of climate change threats on the Great Barrier Reef. Ecology and Society, 27(1), 1–16. https://doi.org/10.5751/ES-12964-270137