BIODIVERSITAS
Volume 26, Number 3, March 2025
Pages: 1384-1394

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d260339

Analysis of the factors contributing to the degradation of coral reefs and marine biota at Pasir Putih Beach, Prigi Bay, Trenggalek District, East Java, Indonesia

RAHMANTA SETIAHADI[1], MARHENY LUKITASARI[2,♥], NURUL KUSUMA DEWI[2], SUMANI[3], CATUR RETNANINGDYAH[4], MUKHTASOR[5]

[1]Department Agrotechnology, Faculty of Agriculture, Universitas Merdeka Madiun. Jl. Serayu No.79, Taman, Madiun 63133, East Java, Indonesia
[2]Department of Biology Education, Faculty of Teacher Training and Education, Universitas PGRI Madiun. Jl. Setiabudi Timur 85, Kartoharjo, Madiun 63138, East Java, Indonesia. Tel.: +62-351-462986, Fax.: +62-351-459400, ♥email: lukitasari@unipma.ac.id
[3]Departement of English Education, Faculty of Teacher Training and Education, Universitas PGRI Madiun. Jl. Setiabudi Timur 85, Kartoharjo, Madiun 63138, East Java, Indonesia
[4]Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Brawijaya. Jl. Veteran, Malang 65145, East Java, Indonesia
[5]Department of Biology, Faculty of Science and Data Analytics, Sepuluh Nopember Institute of Technology. Jl. Arief Rahman Hakim, Kampus ITS Sukolilo, Surabaya 60111, East Java, Indonesia

Manuscript received: 11 October 2024. Revision accepted: 17 March 2025.

Abstract. *Setiahadi R, Lukitasari M, Dewi NK, Sumani, Retnaningdyah C, Mukhtasor. 2025. Analysis of the factors contributing to the degradation of coral reefs and marine biota at Pasir Putih Beach, Prigi Bay, Trenggalek District, East Java, Indonesia. Biodiversitas 26: 1384-1394.* The deterioration of coral reefs and marine ecosystems poses a significant challenge that needs to be addressed to maintain sustainable marine ecotourism management. Both natural processes and human activities contribute to the decline of coral reef ecosystems. This study seeks to examine the factors causing damage to coral reefs and marine life along the Karanggongso Coast, East Java Province, Indonesia. The research utilized a survey method combined with a descriptive analytical approach. Coral reef surveys were conducted using the Line Intersept Transect (LIT) technique, while sedimentation and land cover changes were assessed using grab samplers, Google Earth maps, and Rupa Bumi Indonesia (RBI) maps. Beach physical condition observations provided material for descriptive analysis, and coral reef and sedimentation data were used to create indicative maps. The overlay of indicative maps and descriptive analysis results were employed in the spatial analysis of factors destroying coastal ecosystems. The study findings revealed the Physical Condition of the Waters, with indicators including temperature (28.7°C), salinity (35%), dissolved oxygen (13.2 Ppm), pH (7.73), and brightness (4.5m). While these conditions remain favorable, extensive sedimentation has reduced the Percentage of Coral Reef Cover to below 24.9%. Analysis of sedimentation from land use change indicates that significant areas of forest and shrubland have been converted to agricultural land, settlements, tourist facilities, and several shrimp ponds, leading to erosion and sedimentation. The size of the sediment grains in the water reflects the predominant sand content at each station, with values ranging from 99.19% to 99.63%.

Keywords: Ecotourism, education, factors driving coral reef degradation, marine biota

INTRODUCTION

The development strategy for coastal areas in Trenggalek District is stipulated in regional regulation 15 of 2012 concerning the Spatial Plan of Trenggalek District, East Java, Indonesia for 2012-2032 (Bappedalitbang Trenggalek District 2024). While coastal regions offer development opportunities, they also require preservation through planned resource management and rational land use (Watt-Pringle et al. 2023), including areas like Pasir Putih Beach in Karanggongso Village, Trenggalek District.

Coastal ecosystems are highly productive and diverse, supporting various economically valuable activities (Lee et al. 2019). However, rapid population growth and increased economic activities in these areas lead to social issues and environmental challenges (Lara-Pulido et al. 2021; Giyanto et al. 2023). To address threats to biodiversity and ecosystem management in coastal regions, sustainable spatial planning is necessary, considering geographical and socio-cultural factors such as demographics, population distribution, and other strategic aspects (Vidayanti and Retnaningdyah 2024). The aim of this spatial organization is to promote sustainable development that incorporates educational (Sukri et al. 2023), economic, socio-cultural, and environmental elements, while ensuring equitable development (Glaser et al. 2018).

Coastal waters and marine resources exhibit a unique diversity that necessitates comprehensive area management (Hidayat et al. 2023). Research has shown that there are functional ecological connections among coastal ecosystems, as well as between coastal and highland areas and the open ocean (Giyanto et al. 2023; Cahyani and Nugroho 2024). For instance, alterations in one coastal ecosystem, such as mangroves, will eventually impact other ecosystems (Gudka et al. 2023; Cahyani and Nugroho 2024; Sartori 2024). Furthermore, coastal forests and coral reefs have the capacity to act as carbon sinks, similar to community forests, thereby mitigating the effects of

climate change (Wirabuana et al. 2020; Sartori 2024). Coral reefs play a crucial role in supporting the local economy. The socioeconomic benefits that communities derive from coral reef ecosystems can be evaluated not only in monetary terms but also through qualitative assessments (Sabbagh and Hickey 2020; Isdianto et al. 2024). These qualitative evaluations can enhance our understanding of the vital role coral reefs play in people's everyday lives (Delevaux et al. 2018; Mujahidah et al. 2023).

Pasir Putih Beach, situated within the 'Pegunungan Seribu' Geo-park landscape, is highly susceptible to climate change impacts. Consequently, it is essential to develop climate change mitigation strategies to prevent the destruction of coral reef ecosystems, which are vital for sustaining the income sources of coastal communities (Sari et al. 2021). Coral reef damage can result from both natural and human-induced factors (Graham et al. 2020).

Karanggongso's Pasir Putih Beach in Trenggalek District is a conservation area with the potential to become an underwater tourist destination due to its coral reefs and diverse marine life. However, these ecosystems are currently facing severe degradation caused by sedimentation, alterations in land cover, and harmful practices by fishermen and visitors. The sedimentation is a result of the Southern Cross Roads (SCR) construction and changes in land cover within nearby watersheds. The primary challenge for ecotourism in this region is the deterioration of coral reefs and marine ecosystems due to sedimentation and coastal land cover destruction. To date, no comprehensive solution has been developed through a collaborative process involving all stakeholders to create a management model for ecotourism areas that adapts to changes in physical conditions and aquatic ecosystems.

An alternative method for addressing conflicts in ideas and authority within natural resource management is the deliberative approach (Setiahadi et al. 2017). This process offers all parties an equal chance to identify existing problems and create solutions (Setiahadi et al. 2019). To enhance problem-solving strategies, policy monitoring implementation must incorporate the deliberative process (Setiahadi et al. 2020). Developing such strategies through deliberation requires stakeholder collaboration.

This study examines how natural and human factors affect coral reefs and marine life degradation. The study results were used to develop marine ecotourism objects on Pasir Putih Beach. The findings will contribute to an integrated ecotourism planning strategy developed through deliberation. This approach seeks to align the interests of all stakeholders, particularly in the socio-economic, marine conservation, and ecotourism management subsystems, with the Trenggalek District's development plans.

MATERIALS AND METHODS

Study area

The study was carried out in the Pasir Putih Beach area of Karanggongso village, located within Prigi Bay, Trenggalek District, East Java Province, Indonesia. The geographical coordinates of the research site are between 111043'08" and 111060'80" East Longitude (EL), and 8°14'43" and 8°24'00" South Latitude (SL). Figure 1 displays a map illustrating the location of the research area. The area of Karanggongso beach used for research is 1.5 km^2.

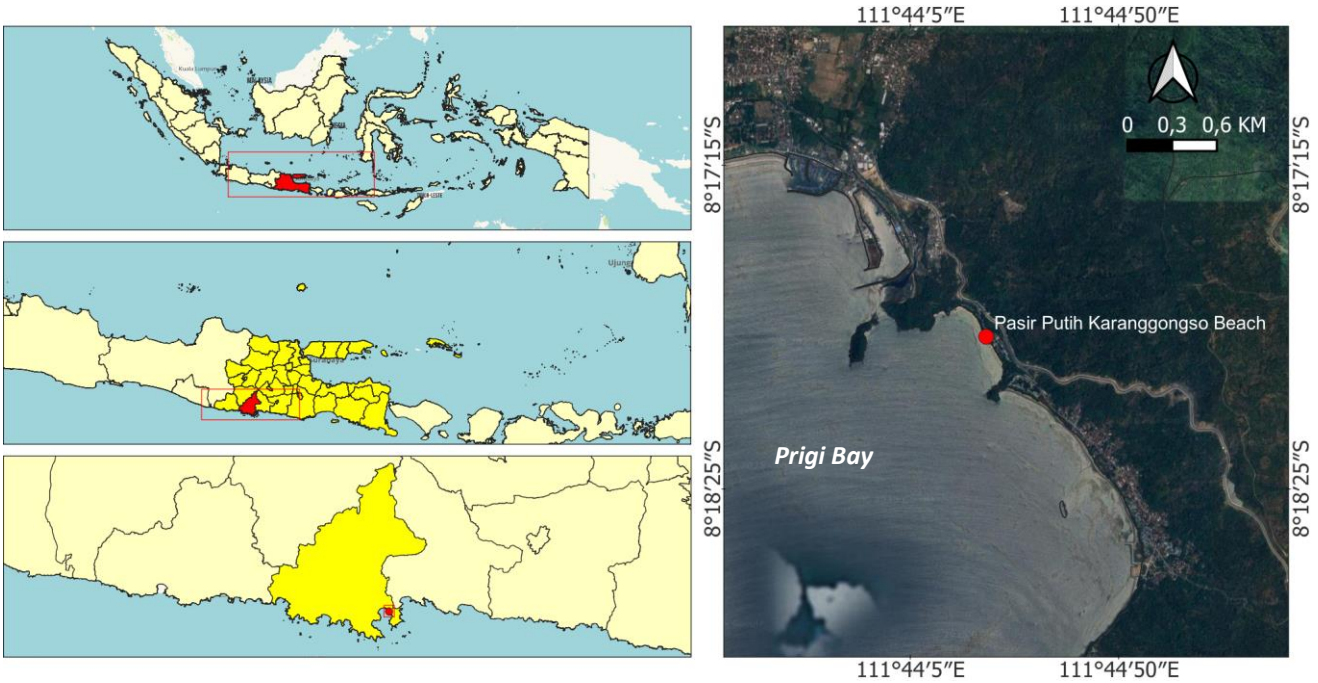

Figure 1. Maps of location research in the Pasir Putih Beach, Prigi Bay, Trenggalek District, East Java Province, Indonesia

Procedure

The research began with an examination of natural elements, gathering both primary and secondary information on the aquatic and coral reef environments. The assessment of physical conditions involved measuring seawater salinity, clarity, and temperature. Coral reef health was evaluated using the Line Intercept Transect (LIT) technique to obtain data on reef composition and coverage (Tuwo and Tresnati 2021). These datasets would be used to create a coral reef map depicting current conditions at the time of the study. The investigation of human factors focused on analyzing sedimentation resulting from changes in land cover and conservation efforts by tourism management. To support this analysis, sedimentation areas were mapped using cartographic tools and drone technology (Tuwo and Tresnati 2021). The findings from the water condition survey were examined using a descriptive approach, while coral reef status and sedimentation extent were analyzed through indicative map creation. The combination of indicative map overlays and descriptive analysis facilitated the spatial examination of factors contributing to material damage. Figure 2 illustrates the research and analysis steps for identifying the causes of coral reef and marine life degradation at Pasir Putih Beach.

Data collection and analysis

The study employs a survey method, which is one of the techniques utilized in Participatory Action Research (PAR). PAR has not been extensively applied to investigate the causes of ecosystem degradation due to the complexities involved in verifying and balancing facts related to sustainable management issues (Hendrastiti et al. 2024). The survey aims to gather both primary and secondary data concerning natural/environmental factors and human factors. At designated observation plot points, physical water conditions such as salinity, clarity, and seawater temperature are measured using transects and sampling with 5 repetitions.

Coral reef assessments are conducted using a 50 m transect aligned with the coastline (Tiu and Abelson 2023; Komala et al. 2024). Sedimentation data is obtained through sediment grain analysis and in-depth interviews with tourist attraction managers. Respondents are selected through purposive sampling. An indicative map of the area is created using Google Earth maps, Rupa Bumi Indonesia (RBI) maps, and drone-assisted ground checks. Padding points for transect placement are established at each location using the Line Intercept Transect technique and sediment grain testing. Coral lifeforms intersecting the transect are documented and photographed for subsequent identification based on condition and taxonomy (Sartori 2024).

Using the LIT method, a single point is selected at each site to establish the transect location (Wang et al. 2024). The coral lifeforms intersecting the transect are documented, captured in photographs, and classified based on their state and taxonomic group (Cahyani and Nugroho 2024; Patty et al. 2024). This collected information allows for the determination of coral cover percentage, lifeform prevalence, lifeform diversity, and the proportions of dead and living corals. The analysis of the data involves calculating the overall percentage of coral reef coverage using the Cox (1967) method:

$$\text{Percent Cover } (\%) = \frac{\text{Total Lenght Categori}}{\text{Lenght Transect Line}} \text{ X } 100$$

Determination of mortality index value based on the formula (Hill and Wilkinson 2004):

$$Mortality\ Index\ (IM) = \frac{IM}{KM + KH}$$

Where,
IM : Mortality Index
KM : Dead Coral Cover Percentage
KH : Live Coral Cover Percentage

To determine the condition of coral reef cover based on the percentage of live coral reef cover, the criteria of Gomes and Yap (1984) are used, as listed in Table 1 (Hill and Wilkinson 2004).

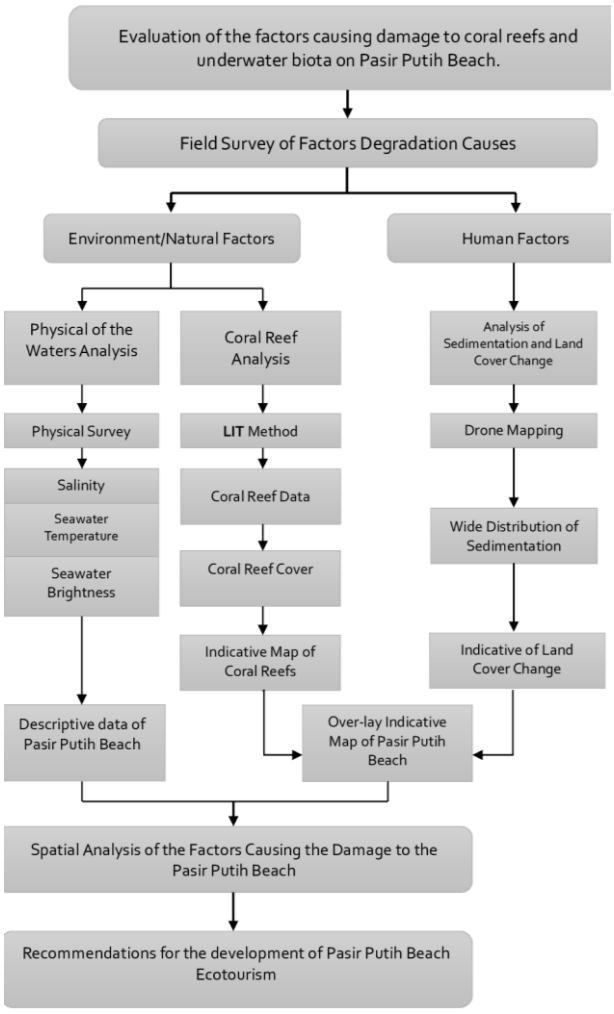

Figure 2. Research procedure of analysis of causes factors of the degradation of coral reefs and marine biota on Pasir Putih Beach, Trenggalek, East Java, Indonesia

Table 1. Criteria for a percentage of live coral reef cover

Parameter	Standard criteria for coral reef damage (%)		
Percentage of living coral reef cover area	Damage	Bad	0-24,9
		Middle	25-49.9
	Good	Good	49.9-74.9
		Very Good	75-100

The main data for examining sediment particles is the fundamental sediment obtained from the coastal waters of Karanggongso's Pasir Putih Beach. Supplementary information for this research includes maps from Google Earth and RBI provided by the Geospatial Information Agency. Using the purposive sampling method, bottom sediment rate data was gathered at 5 coastal locations using a grab sampler. The sedimentation rate information was processed by calculating dry volume, while surface sediment data underwent granulometry analysis to determine sediment types. A grab sampler was employed to collect primary data. secondary data was acquired from https://earth.google.com/web for Google Earth and https://tanahair.indonesia.go.id/ for RBI maps. Satellite imagery from 2006, 2011, 2017, 2021, and 2023 was utilized. Information systems conduct digital, visual, and geographic analyses of the imagery to assess its appearance.

RESULTS AND DISCUSSION

Results

Physical condition of coastal waters

To evaluate ecological parameters at each observation site, environmental variables are monitored. Table 2 presents the findings from the environmental parameter observations conducted during the study. At Pasir Putih Beach, the water temperature measures 28.0-30.1°C, which is conducive to coral reef ecosystems. While coral reefs thrive best in waters ranging from 23-25°C, they can endure temperatures up to 36-40°C (Mcquaid 2021). The observed average seawater temperature falls within the acceptable range set by the Ministry of Environment Decree No. 51/2004, which specifies 28-30°C for coral reefs and seagrass beds and 28-32°C for mangrove forests.

Along with temperature, salinity plays a crucial role in coral reef survival. Salinity acts as a limiting factor, with corals only able to thrive within specific ranges. The measured salinity at the beach is 34-35%, aligning with the ideal range of 30-35% for coral growth (Ding et al. 2022). Consequently, corals are scarce in areas with large river estuaries, high rainfall, or excessive salt content. Salinity extremes can impede coral growth rates, with the extent of this impact varying based on each coral species' tolerance to salinity fluctuations (Oetama et al. 2024).

The synergistic impact of elevated temperature and reduced salinity on coral bleaching and zooxanthellae was observed. When corals were subjected to the maximum temperature (33°C) and minimum salinity (10 psu), extensive bleaching (50-90%) occurred, accompanied by increased symbiont concentrations in the surrounding water (Patthanasiri et al. 2022).

The Dissolved Oxygen (DO) concentration of 10.0-13.5 ppm is optimal for coral reef development, indicating that Pasir Putih Beach waters are likely free from industrial contamination. This high oxygen level is attributed to phytoplankton and aquatic plant photosynthesis, facilitated by adequate sunlight. Additionally, in coastal regions, the upwelling of nutrient-rich bottom water enhances phytoplankton photosynthesis, further contributing to elevated DO levels (Bettencourt et al. 2020). Algae demonstrated significantly higher tolerance to extremely low oxygen levels (2-4 mg L^{-1}) compared to corals. While corals could withstand reduced oxygen concentrations, they had a specific threshold determined by exposure duration and concentration. Surpassing this limit resulted in rapid coral tissue loss and death. Hypoxia may play a crucial role, or in some instances be the primary cause, of coral tissue degradation during coral-algae interactions (Haas et al. 2014).

The acidity level (pH) of 7.1-7.8 falls within the acceptable range of 6-9 for various purposes (Ding et al. 2022). This pH value in the waters surrounding Pasir Putih Beach is ideal for coral reef growth. Typically, marine water pH ranges from 7.0 to 8.5 (Khusnah et al. 2019). Ocean Acidification (OA) poses a significant threat to coral reef ecosystems by reducing the availability of carbonate ions necessary for coral skeleton formation. Coral skeletal growth involves two distinct processes: extension (upward growth) and densification (lateral thickening). Skeletal density is directly affected by changes in seawater carbonate ion concentration and thus, by OA, while extension is not (Mollica et al. 2018). Mollica et al. (2018) introduce a numerical model of Porites skeletal growth that connects skeletal density to the external seawater environment through its influence on coral calcifying fluid chemistry. They validate this model using existing coral skeletal datasets from six Porites species across five reef sites and employ this framework to forecast the impact of 21st century OA on Porites skeletal density throughout the global tropics. Their model predicts that OA alone will lead to a decline of up to 20.3±5.4% in the skeletal density of reef-building Porites corals.

Immediate measures to combat ocean acidification are required at both global and local levels, including CO_2 mitigation and ecosystem protection, adaptation, and restoration. The diverse legal, economic, and social contexts, coupled with the intricate connections between threats to coral reef ecosystems, necessitate that governmental and stakeholder efforts to safeguard specific coral reef systems be tailored to the unique circumstances and priorities of the communities relying on those systems, while considering relevant national, regional, or global commitments (Allemand and Osborn 2019).

The water quality parameters evaluated are brightness and depth, which are closely interrelated as brightness diminishes with increasing water depth. Greater brightness values in water bodies indicate higher light penetration. Sunlight intensity plays a crucial role for coral reefs and

their symbiotic organisms (zooxanthellae). At Pasir Putih Beach in Karanggongso, the water brightness measures approximately 2.2-4.7 m.

Percentage of coral reef cover

The percentage of coral cover at Pasir Putih Beach at a depth of 5 m is presented in the following Table 3. The environmental conditions of a habitat determine the prevalent coral species found there. Each coral reef ecosystem is characterized by a particular type of coral that thrives in those specific conditions. In the flat regions of coral reefs, smaller corals are typically dominated by massive, submassive, and branching varieties (Ceccarelli et al. 2022). Figure 3 illustrates the coral reef coverage percentages at Pasar Putih Beach in Karanggongso.

The coral reef is situated in close proximity to the shore, featuring a broad sandy area and relatively gentle water movement. Based on observations at the location, coral community structure includes Coral Branching (CB), Coral Foliose (CF), Coral Massive (CM), Coral Mushroom (CMR), and Coral Submassive (CS). The overall health of the coral is favorable, as evidenced by the substantial presence of CB and CF. CF is a prevalent variety that readily adjusts to aquatic environments characterized by waves, turbidity, and sedimentation (Riegl and Piller 1999; Graham et al. 2020). Riegl and Piller (1999) stated that foliated corals in regions with strong currents can generate micro-currents within their structures, passively aiding in sediment removal from colony surfaces. CM observed at Pasir Putih Beach primarily takes the form of spherical shapes or solid, hard chunks. Despite the relatively calm currents, coral massive exhibits satisfactory growth at the study site. However, the massive coral growth form typically thrives better in environments with stronger currents. Mushroom coral is found solitary shaped like a mushroom and comes from the species. Indications used that an area is experiencing damage to its coral reefs are the cover of rubble and the presence of algae.

Rubble is a form of irregular coral fractures that can be caused by natural disasters, the use of explosives to find fish, coral mining for building materials, anchor dumping, and other destructive human activities. Algae is one of life for coral reefs, algae will be very difficult to live and grow on good coral reefs (Samuel et al. 2023). The study location revealed a Dead Coral Algae (DCA) percentage of 11,24%. This comparatively high proportion of dead coral is believed to result from the substantial amount of sediment transported by water currents. Sedimentation can have lethal consequences for coral reefs, as burial impedes growth rates. The abrasive effect of sediment particles hinders zooxanthellae photosynthesis, reduces coral abundance and diversity, diminishes the percentage of live coral cover, and impedes coral reef recovery. Sedimentation is one of the limiting factors for coral life. Suspended and deposited sediment have negative effects on the coral community. The rate of sedimentation can lead to low coral cover, low growth rate and low recruitment (Limmon and Marasabessy 2019). Sediments affect corals in numerous ways including smothering, abrasion, shading, and inhibition of coral recruitment. Sediment delivery resulting in deposition and water quality deterioration can cause degradation at the spatial scale of corals or entire reefs (Rogers and Ramos-Scharrón 2022).

Satellite imagery analysis and extensive interviews reveal that sedimentation poses the greatest threat to coral reefs near Pasir Putih Beach. Activities such as deforestation, road construction, and non-terraced agricultural expansion contribute to increased sediment in surface runoff, which ultimately reaches rivers and settles in coastal and marine areas. Human actions that disregard environmental sustainability, even those occurring far upstream, can harm coastal and marine ecosystems. Fine and coarse suspended sediment particles negatively affect coastal and marine life through three primary mechanisms. Firstly, sediment covers or clogs the respiratory systems of marine organisms, particularly benthic species like coral, seagrass, and algae, leading to asphyxiation. Secondly, increased water turbidity from sedimentation reduces light penetration, impacting light-dependent organisms and benthic communities reliant on sunlight for photosynthesis. Thirdly, sediment from agricultural areas rich in nitrogen and phosphate can trigger eutrophication, with phosphate typically found in higher concentrations in sediment from fertilized soil due to its strong binding to soil particles.

Table 2. Environmental parameters observed at Pasir Putih Beach, Trenggalek, East Java, Indonesia

Parameter	Value	QS
Salinity (%)	34-35	33-34
Temperature (^{0}C)	28.0-30.1	28-32
Dissolved oxygen (ppm)	10.0-13.5	>5
pH	7.1-7.8	7-8.5
Brightness (m)	2.2-4.7	NA
Current speed (m/s)	0.9-3.9	NA

Source: Primary data processed (2024). Note: QS: Quality Standard based on Appendix III of KepMen LH No 51 2004; NA: Not Available

Table 3. Percentage of coral reef cover

Types of coral reefs	Genus	Percentage (%)
Coral Branching (CB)	*Porites*	19.40
Coral Foliose (CF)	*Montipora*	13.22
Corak Massive (CM)	*Favites*, *Favua* and *Goniastrea*	5.22
Coral Mushroom (CMR)	*Herpolitha* and *Fungia*	1.46
Coral Submassive (CS)	*Pocillopora*	8.52
Dead Coral Algae (DCA)	-	11.24
Rubble (RB)	-	18.74
Rock	-	11.84
Silt (S)	-	9.5
Water (W)	-	0.86

Source: Primary data processed (2024)

The characteristics of bottom materials, including size, shape, and composition, play a significant role in sedimentation and erosion along stable coastlines. Key factors influencing sediments include composition, size, grain distribution, shape, porosity, and settling speed, with grain size distribution being particularly important. The study site's sediments consisted of sandy clay fractions and loamy sands, with fine particles dominating the water's bottom. The calm nature of ocean currents in the area allows suspended particles to settle more rapidly.

The aforementioned alterations took place in 2006, 2011, 2017, 2021, and 2023, resulting in increased turbidity and harm to coral ecosystems. Coastal conditions are monitored along the shoreline. Interviews with local inhabitants revealed evidence of sediment accumulation. Shorelines with white sand exhibit indications of new sediment buildup extending seaward. The beach face slope, typically situated 5-8 meters from the coast and approximately 10 meters deep, is diminishing. This slope's sediment suggests material transport from land to shore through erosion and surface runoff, with deposition occurring beyond the beach crest. Karanggongso's Pasir Putih Beach experiences mixed tides with a single dominant pattern. Typically, tidal currents move shoreward during high tide and retreat to the bay during low tide.

Land erosion issues are also addressed in research by (Limmon and Marasabessy 2019), which notes exacerbation by rainfall, vegetation, organic matter, and human activities. Another study by Jones et al. (2020), proposes that sediments directly falling onto coral reefs and other organisms, or suspended in the water column, may reduce light availability necessary for photosynthesis, growth, and coral calcium formation. The outcomes of laboratory analysis on sedimentation samples indicate the average grain size at each collection site, as illustrated in Table 4.

Examination of water samples revealed a predominant sand composition at each location, with percentages ranging from 99.19% to 99.63% (Table 4). Web-based map analysis indicated alterations in coastal water conditions, showing an expansion of sedimentation areas across numerous regions of Karanggongso's Pasir Putih Beach. Sediment properties, including grain size, hue, and mineral content, influence sedimentation or suspension processes and light absorption capacity (Tuttle and Donahue 2022). Sediment particles exceeding 2 mm in size typically sink to the ocean floor and may contribute to coral reef erosion during periods of high wave activity (Serrano-Moreno 2024). Conversely, fine particles (<0.063 mm) often remain suspended, diminishing light penetration. The presence of minute sediment particles in coral environments can enhance bacterial activity (Tuttle et al. 2020). This may result in coral exposure to dissolved substances such as heavy metals and other pollutants, including pesticides adhering to clay minerals.

Table 4. Results of the type of sediment grain size at the observation point at Pasir Putih Beach of Karanggongso, Trenggalek, East Java, Indonesia

Observation points	Content (%)			Sediment name	Grain size (mm)
	Sand	Silt	Clay		
1	99.19	0.73	0.07	Sand	0.435
2	99.63	0.32	0.03	Sand	0.417
3	99.34	0.60	0.05	Sand	0.425
4	95.45	4.06	0.47	Sand	0.329
5	99.36	0.58	0.05	Sand	0.435

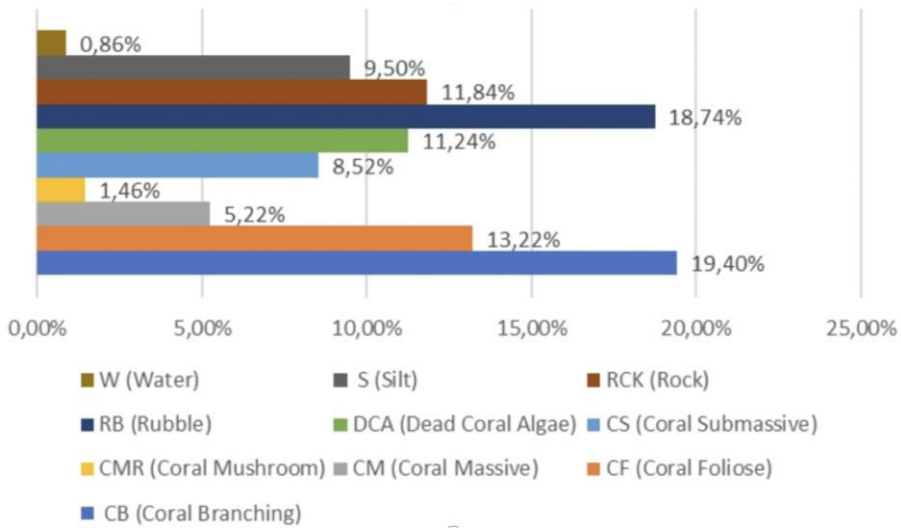

Figure 3. Coral reef cover at Pasar Putih Beach of Karanggongso, Trenggalek, East Java, Indonesia

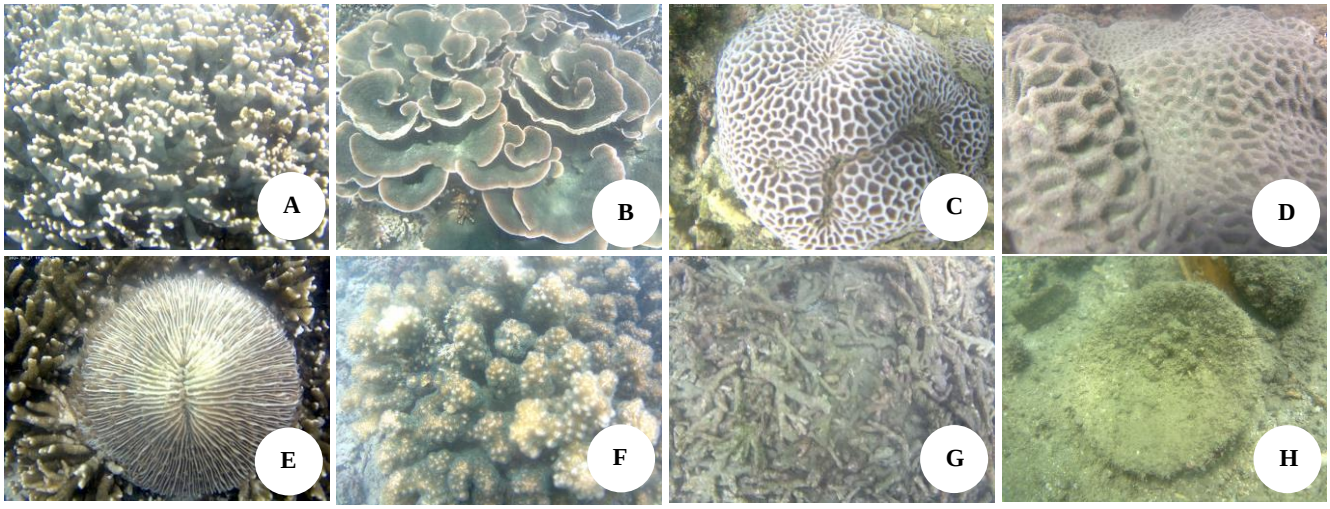

Figure 4. Some coral reefs of Pasir Putih Beach, Karanggongso, Trenggalek District, East Java, Indonesia. A. Coral Branching (*Porites*); B. Coral Foliose (*Montipora*); C. Coral Massive (*Goniastrea*); D. Coral Massive (*Favites*); E. Coral Mushroom (*Fungia*); F. Coral Submassive (*Pocillopora*); G. Rubble; H. Dead Coral with Algae (DCA)

The characteristics of sediment play a crucial role in sedimentation, erosion, and coastal stability. Key factors influencing these processes include sediment composition, grain size distribution, particle shape, porosity, and settling velocity. Among these, grain size distribution is considered the most critical. The analysis of sediment grain size at Pasir Putih Beach adheres to the classification system outlined in the shore protection manual (Limmon and Marasabessy 2019).

Although some research suggests that coral species may react differently to settled or suspended sediment, a definitive sequence of responses to sediment accumulation or reduced water clarity has not been established (Tuttle and Donahue 2022). The susceptibility or resilience of coral reef species to sediment varies depending on factors such as reef location, proximity to the shore, depth, wave exposure, and other environmental conditions. Nevertheless, a substantial decrease in coral populations could indicate significant environmental changes, particularly deteriorating water quality (Tuttle et al. 2020).

In 2006, 2011, 2017, 2021, and 2023, alterations occurred that resulted in increased turbidity and harm to coral reefs. Coastal conditions are monitored along the shoreline. Interviews with local inhabitants indicated ongoing sedimentation. The white sandy coastline exhibits signs of new sediment accumulation towards the ocean. The beach face slope, typically situated 5-8 meters from the shore with a depth of about 10 meters, is diminishing. This slope's sediment indicates material transported from land to coast through erosion via run-off and over-top processes, leading to precipitation. Karanggongso's Pasir Putih Beach experiences mixed tides with a single dominant type. Generally, tidal currents move inland along the coast during high tide and return to the bay at low tide.

Water conditions can naturally fluctuate over time, aligning with environmental changes. Clarity levels shift due to alterations in land cover, causing erosion and sedimentation. Predictions for the sedimentation area along Pasir Putih Beach, where sampling occurred, suggest a trend of expansion. This is supported by visual interpretation of Google Earth imagery (Figure 4). To complement the study of factors damaging coral reef ecosystems and marine life, land use changes were analyzed. This examination involved observing satellite imagery to identify land cover changes during 2006-2011 (Figure 5), 2017-2021 (Figure 6), and 2023 (Figure 7).

Discussion

Research has identified key environmental factors that significantly impact coral biology, including temperature, salinity, nutrient levels, oxygen content, and pH (Freeman et al. 2013; Giyanto et al. 2023). Coral growth and metabolic processes are particularly influenced by the surrounding water's temperature and salinity, as well as the duration of feeding periods (Graham et al. 2020). Despite covering merely 0.1% of the ocean floor, coral reefs thrive under specific environmental conditions. These include tropical seas with shallow, warm (but not excessively hot) water, ample sunlight for zooxanthellae algae photosynthesis, and clear water. Turbidity, caused by suspended particles, hinders coral growth by absorbing radiant energy and impeding filter-feeding, which is why corals are typically absent near river mouths) (Dao et al. 2021). Coral reefs generally flourish at depths between 0 and 25 meters, but cannot develop between 50 and 70 meters (Mcquaid 2021). In these ecosystems, light intensity is crucial for zooxanthellae photosynthesis, which provides corals with nutrition. The compensation point for corals occurs at a depth where light intensity diminishes to 15-20% of surface levels.

Recent research has highlighted oxygen as a critical, potentially limiting factor in reef environments, as evidenced by mass mortality events linked to low oxygen levels. Both natural and human-induced factors cause oxygen fluctuations on coral reefs at various scales. These variations restrict key processes like productivity, respiration, and calcification, and often influence interactions between corals and their competitors,

pathogens, and mutualists. Furthermore, oxygen frequently mediates the apparent effects of temperature, eutrophication, acidification, and other stressors on corals. Consequently, oxygen variation's impact is visible in numerous patterns, including reef biodiversity, coral bleaching, colony morphology, and fish behaviour (Nelson and Altieri 2019). Environmental conditions and depth play a significant role in shaping the structure and composition of coral reefs. A study conducted in the Pramuka Island area of Seribu Islands, north of Jakarta, Indonesia, aimed to investigate how location and depth affect coral reef formations. At a depth of 3 m, hard coral coverage was generally higher than at 10 m in both study sites on Pramuka Island, with the exception of the northern area. The coral mortality index showed variation, ranging from 0.39 to 0.98. The western part of Pramuka Island exhibited the lowest average number of families, genera, and life forms. Significant differences were observed between sites in terms of hard coral cover percentage, coral mortality index, and mean numbers of families, genera, and life forms. Depth differences primarily affected the percentage of coral cover and the average number of life forms. Various factors limit coral development and growth (Fahlevy et al. 2017).

Figure 5. Interpretation of visual changes Maps of Google Earth in 2006-2011 in Pasir Putih Beach of Karanggongso, Trenggalek District, East Java, Indonesia

Figure 6. Interpretation of visual changes Maps of Google Earth in 2017-2021 in Pasir Putih Beach of Karanggongso, Trenggalek District, East Java, Indonesia

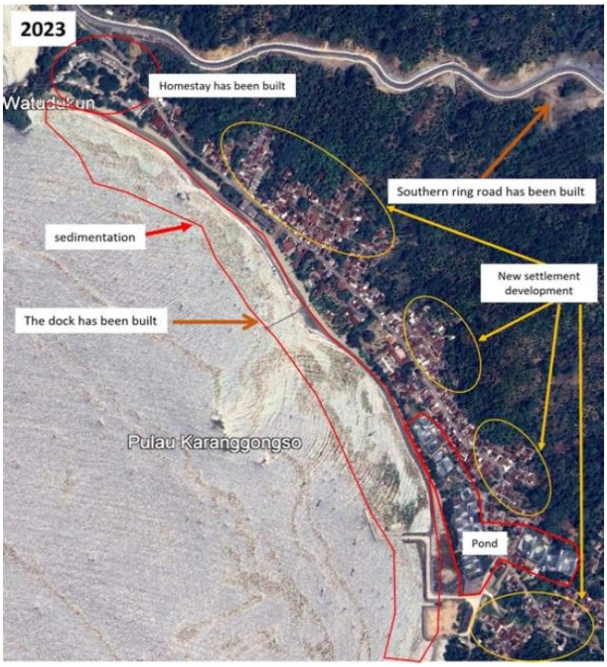

Figure 7. Interpretation of visual changes Maps of Google Earth in 2023 in Pasir Putih Beach of Karanggongso, Trenggalek District, East Java, Indonesia

In the Pasir Putih Beach of Karanggongso waters, the measured current is relatively mild, approximately one m/s. Current velocity influences nutrient transport within marine environments. The significance of currents in coral reef ecosystems is crucial. Corals require currents for microplankton food supply, removal of material deposits, and oxygen delivery from the open sea (Ding et al. 2022). Consequently, current circulation is vital for energy transfer processes. Coral growth tends to be more robust in areas with continuous water movement from currents and waves compared to calm, sheltered locations. Sedimentation poses a threat to coral growth, as coral polyps become susceptible to sediment or sand coverage due to insufficient sediment removal from the coral surface.

Satellite imagery analysis and interview data suggest that sedimentation poses the primary threat to coral reefs near Karanggongso's Pasir Putih Beach. Activities contributing to soil erosion, including deforestation, the construction of Southern Cross Road, and non-terraced agricultural land clearing, can elevate sediment levels in surface runoff. This sediment ultimately reaches coastal and marine areas via river systems. Environmental neglect in human activities, even those occurring hundreds to thousands of kilometers upstream, can result in damage to coastal and marine ecosystems. Fine and coarse suspended sediment particles can adversely affect coastal and oceanic biota. According to Tuttle et al. (2020), coastal development and runoff-induced sedimentation directly impact coral recruitment, growth, mortality, and the ecosystem services provided by coral reefs. Rogers and Ramos-Scharrón (2022) claimed that sedimentation can impede coral reef growth and potentially lead to coral death.

The impact generally occurs through three mechanisms. Initially, marine organisms, particularly those residing at the bottom of water bodies (benthos) like coral animals, seagrasses, and seaweeds, are covered by sediment materials or have their respiratory systems enveloped. This leads to breathing difficulties and eventual death from oxygen deprivation (asphyxia). Sedimentation also increases water turbidity, which hinders light penetration and disrupts light-dependent organisms. This effect extends to basic communities relying on light for photosynthesis. Lastly, sediment from agricultural areas rich in nitrogen and phosphate can trigger eutrophication. Phosphate typically binds strongly to soil particles, resulting in higher concentrations in fertilized soil sediments.

Reskiwati et al. (2022) examined how depth and slope gradient influence the vertical distribution of hard coral growth forms and genera at three locations on Bunaken Island. The study utilized the Line Intercept Transect (LIT) method, dragging it vertically at depths between 3-15 meters. Findings revealed two distinct slope types: steep and gentle. The slope variations corresponded to different coral growth forms, with encrusting forms predominating on 90° slopes, while massive growth forms dominated 55° and 43° slopes. The study also found that depth characteristics did not affect hard coral genera but impacted colony numbers and sizes. Both colony quantity and size decreased as depth increased.

Ecosystems in coastal regions can suffer damage from unregulated land use alterations. These changes are often tied to population expansion and economic survival, naturally resulting from societal socio-economic shifts. This encompasses modifications to both productive and non-productive lands, involving the conversion of specific functions to others (Rogers and Ramos-Scharrón 2022). The scarcity of available land is exacerbated when areas designated for particular purposes are repurposed for different activities. Environmental impacts become significant when land is utilized for commercial endeavors such as tourism (Woodroffe et al. 2023).

Land use transformations are evident in the conversion of forests and shrublands into agricultural areas, residential zones, tourist facilities, and shrimp farms. These alterations diminish coastal vegetation and reduce the soil's capacity to absorb rainfall. Consequently, run-off transports soil to the shoreline, leading to erosion and sedimentation in coastal areas. The Pasir Putih Beach of Karanggongso is geographically situated near the southern crossroad development project on Java island. The region is physically influenced by the forest cover conditions in the surrounding Karts mountains and the seasonally varying oceanographic dynamics of Prigi Bay. An empirical calculation approach, based on sediment characteristics and their impact on coastline conditions, revealed a sedimentation process occurring along the coastal area.

The land use changes observed from 2017 to 2021 mirror the pattern seen from 2006 to 2011. Typically, these changes involve the transformation of vegetated areas like forests and shrublands into parts of the Southern Highway, settlements, or tourist attractions. However, this pattern shows minimal change from 2021 to 2023. Over the four-

year period, these land-use alterations have significantly impacted coastal sedimentation levels.

The transformation of coastlines results from the interplay between coastal conditions and the effects of both natural and human-induced factors. The Pasir Putih Beach in Karanggongso is situated near the southern crossroad development project on Java Island. This area is influenced by the forest cover in the surrounding Karts mountains and the seasonal oceanographic dynamics of Prigi Bay. An empirical analysis of erosion and sedimentation processes, based on sediment characteristics and their impact on shoreline conditions, indicated a predominant sedimentation process along the coastal region.

Theoretically, the significant variations in coastline changes are linked to the shoreline's morphology and wave characteristics, which are dependent on wind direction and intensity. The extended coastline features several tributary streams that transport eroded material from inland. The generally calm coastal currents, combined with wave diffraction, intensify the sedimentation process. Eroded material from upstream is transported parallel to the shore through littoral drift, leading to sedimentation in specific areas. Observed land use modifications affect coastal water conditions, subsequently impacting coral reefs and marine biota. Figure 5 shows minimal changes in land conversion for settlements and tourist attractions, as well as limited forest area transformation for road construction. In contrast, Figures 6 and 7 depict significant changes from densely vegetated areas to settlements, tourist facilities, and the construction of the Southern Cross Road.

Evidence indicates significant land-use transformations, including the conversion of forests, bushes, and shrubs into agricultural areas, urban developments, and transportation infrastructure. These alterations diminish vegetation in water catchment zones and reduce the capacity to retain rainwater. Consequently, erosion occurs, transporting soil particles into streams and coastal waters. The once clear and bright waters have become turbid, resulting in a decline in living coral reef coverage. This demonstrates that both natural processes and human activities contribute to the degradation of the ecosystem and marine life at Pasir Putih Beach.

The research concludes that the damage to coral reef ecosystems and marine life on Pasir Putih Beach is caused by erosion and sedimentation. Although this process occurs naturally, human-induced land cover change accelerates ecosystem destruction. Coastline instability and damage to coastal ecosystems can cause disruption of coastal sediment dynamics. The results of this study show that the physical condition of the waters remains ideal for coral reef growth. Nonetheless, the percentage of coral reef cover has decreased as a result of extensive sedimentation. The results of sedimentation analysis from land use change prove that most of the forest and shrub areas have been converted into agricultural land, settlements, tourist attractions, and some shrimp ponds, which cause erosion and sedimentation. As evidence of massive sedimentation, it was found that the size of sediment grains in the water showed the dominant sand content at each station.

ACKNOWLEDGEMENTS

The researchers extend sincere gratitude to the DRPM of Kemendikbud Ristek, Indonesia, for providing the KATALIS 2024 research grant. Also, thanks to the Trenggalek District, Indonesia, local village authorities, and residents near the study site for permitting the research to take place. Additionally, the authors acknowledge the valuable input from unnamed reviewers, which helped enhance the article's quality.

REFERENCES

Allemand D, Osborn D. 2019. Ocean acidification impacts on coral reefs: From sciences to solutions. Reg Stud Mar Sci 28: 100558. DOI: 10.1016/j.rsma.2019.100558.

Bappedalitbang Trenggalek District. 2024. Trenggalek dalam Angka. Bappedalitbang, East Java. [Indonesian]

Bettencourt JH, Rossi V, Renault L, Haynes P, Morel Y, Garçon V. 2020. Effects of upwelling duration and phytoplankton growth regime on dissolved-oxygen levels in an idealized Iberian Peninsula upwelling system. Nonlinear Process Geophys 27 (2): 277-294. DOI: 10.5194/npg-27-277-2020.

Cahyani IY, Nugroho AF. 2024. Biodiversity of coral reefs and reef fishes in Pasir Putih Situbondo. BIO Web Conf 89 (01001): 1-13. DOI: 10.1051/bioconf/20248901001.

Ceccarelli DM, Lestari AP, Rudyanto, White AT. 2022. Emerging marine protected areas of eastern Indonesia: Coral reef trends and priorities for management. Mar Policy 141: 105091. DOI: 10.1016/j.marpol.2022.105091.

Dao HN, Vu HT, Kay S, Sailley S. 2021. Impact of seawater temperature on coral reefs in the context of climate change. A case study of Cu Lao Cham - Hoi An biosphere reserve. Front Mar Sci 8: 1-10. DOI: 10.3389/fmars.2021.704682.

Delevaux JMS, Winter KB, Jupiter SD, Blaich-vaughan M, Stamoulis KA, Bremer LL, Burnett K, Garrod P, Troller JL, Ticktin T. 2018. Linking land and sea through collaborative research to inform contemporary applications of traditional resource management in Hawai'i. Sustainability 10 (3147): 1-19. DOI: 10.3390/su10093147.

Ding DS, Patel AK, Singhania RR, Chen CW, Dong CD. 2022. Effects of temperature and salinity on growth, metabolism and digestive enzymes synthesis of *Goniopora columna*. Biology 11 (3): 436. DOI: 10.3390/biology11030436.

Fahlevy K, Khodijah S, Nasrullah IA, Fathihatunnisa R, Subhan B, Madduppa H. 2017. Site and depth influence on coral reef structure and composition in Seribu Islands, Jakarta. Aceh J Anim Sci 2 (1): 28-38. DOI: 10.13170/ajas.2.1.8212.

Freeman LA, Kleypas JA, Miller AJ. 2013. Coral reef habitat response to climate change scenarios. Plos One 8 (12): 1-14. DOI: 10.1371/journal.pone.0082404.

Giyanto G, Rikoh MS, Muhammad A, Hermanto B, Tri AH, Rizkie SU, Wayan NPS, Ode AL. 2023. The reef health index for coral reefs management in Indonesia. BIO Web Conf 70: 03002. DOI: 10.1051/bioconf/20237003002.

Glaser M, Gorris P, Ferreira BP, Breckwoldt A. 2018. Analysing ecosystem user perceptions of the governance interactions surrounding a Brazilian near shore coral reef. Sustainability 10 (5): 1464. DOI: 10.3390/su10051464.

Graham NAJ, Robinson JPW, Smith SE, Govinden R, Gendron G, Wilson SK. 2020. Changing role of coral reef marine reserves in a warming climate. Nat Commun 11 (1): 1-8. DOI: 10.1038/s41467-020-15863-z.

Gudka M, Obura D, Treml EA, Nicholson E. 2023. Strengthening resilience potential assessments for coral reef management. Methods Ecol Evol 15 (4): 612-627. DOI: 10.1111/2041-210X.14303.

Haas AF, Smith JE, Thompson M, Deheyn DD. 2014. Effects of reduced dissolved oxygen concentrations on physiology and fluorescence of hermatypic corals and benthic algae. PeerJ 2014 (1): 1-19. DOI: 10.7717/peerj.235.

Hendrastiti TK, Setiahadi R, Kusujiarti S, Pratiwi D, Safrudi HI. 2024. Essential ecosystem area policies as a means to promote participatory and inclusive conservation in forest landscape governance: Centering

perspectives of marginalized women in Taman Kili-Kili, Indonesia. For Soc 8 (1): 140-153. DOI: 10.24259/fs.v8i1.28312.
Hidayat SA, Ayuningtias A, Cahyaningrum YM, Astrida N, Kusumo S. 2023. Temporal study of coral reef health in Kepulauan Seribu Marine National Park. IOP Conf Ser Earth Environ Sci 1260 (1): 012015. DOI: 10.1088/1755-1315/1260/1/012015.
Hill J, Wilkinson C. 2004. Methods for Ecological Monitoring of Coral Reefs. Australian Institute of Marine Science, Australian.
Isdianto A, Gibran K, Yamindago ADE, Hikmah S, Sari J, Yanuar ADIT, Setyoningrum D, Setyanto A, Hidayah LNUR, Marsela K, Haykal MF, Fathah AL, Putri BM, Luthfi OM, Pratiwi DWIC. 2024. Environmental determinants of reef fish community structure in Sempu Strait, East Java, Indonesia. Biodiversitas 25 (12): 4781-4789. DOI: 10.13057/biodiv/d251214.
Jones R, Giofre N, Luter HM, Neoh TL, Fisher R, Duckworth A. 2020. Responses of corals to chronic turbidity. Sci Rep 10 (1): 1-13. DOI: 10.1038/s41598-020-61712-w.
Khusnah A, Retnaningdyah C, Kurniawan N. 2019. Community structure of coral reef at Pasir Putih Beach in Situbondo East Java, Indonesia. J Indones Tour Dev Stud 7 (1): 32-38. DOI: 10.21776/ub.jitode.2019.07.01.05.
Komala R, Noer MI, Miarsyah M, Widyartini DS, Handayani. 2024. Assess the level of damage to the coral reef ecosystem based on substrate coverage on Bira Island, Kepulauan Seribu, Indonesia. Biodiversitas 25 (3): 971-977. DOI: 10.13057/biodiv/d250309.
Lara-Pulido JA, Mojica Á, Bruner A, Guevara-Sanginés A, Simon C, Vásquez-Lavin F, González-Baca C, Infanzón MJ. 2021. A business case for marine protected areas: Economic valuation of the reef attributes of cozumel island. Sustainability 13 (8): 1-18. DOI: 10.3390/su13084307.
Lee CH, Chen YJ, Chen CW. 2019. Assessment of the economic value of ecological conservation of the Kenting coral reef. Sustainability 11 (20): 1-17. DOI: 10.3390/su11205869.
Limmon GV, Marasabessy AM. 2019. Impacts of sedimentation on coral reefs in Inner Ambon Bay, Indonesia. IOP Conf Ser Earth Environ Sci 339 (1): 012035. DOI: 10.1088/1755-1315/339/1/012035.
Mcquaid CD. 2021. Oceanography and Marine Biology, CRC Press, London.
Mollica NR, Guo W, Cohen AL, Huang KF, Foster GL, Donald HK, Solow AR. 2018. Ocean acidification affects coral growth by reducing skeletal density. Proc Natl Acad Sci U S Am 115 (8): 1754-1759. DOI: 10.1073/pnas.1712806115.
Mujahidah K, Ramadani A, Hasan V, Yanti S. 2023. Zeolite-microfragmenting media: A Potential Strategy to Accelerate Coral Growth. The 3rd International Conference on Natural Resources and Life Sciences (NRLS) 2020. Surabaya, 27 March 2020. DOI: 10.1051/e3sconf/202337400020.
Nelson HR, Altieri AH. 2019. Oxygen: The universal currency on coral reefs. Coral Reefs 38 (2): 177-198. DOI: 10.1007/s00338-019-01765-0.
Oetama D, Hakim L, Lelono TD, Musa M. 2024. Health status of coral reef at Moramo Bay Marine Conservation Area, Southeast Sulawesi, Indonesia. Biodiversitas 25 (4): 1454-1464. DOI: 10.13057/biodiv/d250413.
Patthanasiri K, Lirdwitayaprasit T, Yeemin T, Thongcamdee I, Potisan N. 2022. Effects of temperature and salinity on coral bleaching in laboratory. Intl J Environ Sci Dev 13 (1): 21-25. DOI: 10.18178/ijesd.2022.13.1.1367.
Patty SI, Souhoka J, Makatipu PC, Rizqi MP, Oseanografi PR, Riset B, Inovasi D. 2024. Mapping benthic habitat distribution and coral reef health index in Ternate Island and Tidore Island, North Maluku. Jurnal Ilmiah Platax 12 (1): 201-214. DOI: 10.35800/jip.v12i1.54054.
Reskiwati R, Ompi M, Rembet UNWJ, Kusen JD, Mantiri ROSE, Sumilat DA. 2022. Vertical distribution and effect of the depth on growth form and genus of hard coral on coral reef in Bunaken Island, North Sulawesi, Indonesia. Aquat Sci Manag 10 (1): 1. DOI: 10.35800/jasm.v10i1.35238.
Riegl B, Piller WE. 1999. Coral frameworks revisited-reefs and coral carpets in the northern Red Sea. Coral Reefs 18 (3): 241-253. DOI: 10.1007/s003380050188.
Rogers CS, Ramos-Scharrón CE. 2022. Assessing effects of sediment delivery to coral reefs: A caribbean watershed perspective. Front Mar Sci 8: 1-23. DOI: 10.3389/fmars.2021.773968.
Sabbagh SM, Hickey GM. 2020. Social factors affecting sustainable shark conservation and management in Belize. Sustainability 12 (40): 1-19. DOI: 10.3390/su12010040.
Samuel PD, Fakhri M, Dewi CSU, Ellona J, Anam MC. 2023. Percentage of hard coral cover and coral recruitment on in Bangsring Beach, Banyuwangi Regency. Res J Life Sci 10 (1): 21-28. DOI: 10.21776/ub.rjls.2023.010.01.3.
Sari SRK, Setiahadi R, Wardhani RM, Sanyoto R, Anom P. 2021. Strategy mitigation action of climate change of land-based in geopark karst area of Gunungsewu, Yogyakarta, Indonesia. IOP Conf Ser Earth Environ Sci 824 (1): 012071. DOI: 10.1088/1755-1315/824/1/012071.
Sartori G. 2024. Morphologically driven sedimentation patterns on a coral reef. Res Sq 1: 1-26. DOI: 10.21203/rs.3.rs-4249844/v1.
Serrano-Moreno JE. 2024. Latin America and the Caribbean: How the Belt and Road Initiative Diminished the United States Influence. The United States and China in the Era of Global Transformations: Geographies of Rivalry Cambridge University Press, United Kingdom. DOI: 10.1332/policypress/9781529228441.003.0007.
Setiahadi R, Lukitasari M, Pratiwi D, Kartikasari SR. 2019. Diagnostic and design approach: Preparation masterplan policies of agroforestry development in Madiun, Java, Indonesia. IOP Conf Ser Earth Environ Sci 347 (1): 012120. DOI: 10.1088/1755-1315/347/1/012120.
Setiahadi R, Pratiwi D, Ratnaningtyas D. 2017. Deliberation process analysis of community based forest management policies implementation in Indonesia. Intl J Adv Sci Eng Inf Technol 7 (3): 1076-1082. DOI: 10.18517/ijaseit.7.3.2127.
Setiahadi R, Sari SRK, Maryudi A, Kalmirah J, Baskorowati L. 2020. Monitoring implementation impact of the EU-Indonesia's VPA on SME livelihood. Intl J For Res 2020: 4327802. DOI: 10.1155/2020/4327802.
Sukri A, Utami SD, Zurlina, Lukitasari M. 2023. The effect of local wisdom-based comic media on students' coral reef conceptual understanding viewed from gender. AIP Conf Proc 2619: 070013. DOI: 10.1063/5.0130474.
Tiu D, Abelson A. 2023. When and where to restore coral reefs: The key role of pre-launch assessment to reef restoration. Peprints 101-107. DOI: 10.20944/preprints202310.1107.
Tuttle LJ, Donahue MJ. 2022. Effects of sediment exposure on corals: A systematic review of experimental studies. Environ Evid 11 (1): 1-33. DOI: 10.1186/s13750-022-00256-0.
Tuttle LJ, Johnson C, Kolinski S, Minton D, Donahue MJ. 2020. How does sediment exposure affect corals? A systematic review protocol. Environ Evid 9 (1): 1-7. DOI: 10.1186/s13750-020-00200-0.
Tuwo A, Tresnati J. 2021. Advances in Biological Sciences and Biotechnology. Integrated Publications, India.
Vidayanti V, Retnaningdyah C. 2024. Microplastic pollution in the surface waters, sediments, and wild crabs of mangrove ecosystems of East Java, Indonesia. Emerg Contam 10 (4): 100343. DOI: 10.1016/j.emcon.2024.100343.
Wang M, Lian S, Xiong X, Yang J, Chen C, Shi X. 2024. Assessing the consistency and reliability of the line intercept transect method in coral cover estimation using structure from motion photogrammetry techniques. Geocarto Intl 39 (1): 1-17. DOI: 10.1080/10106049.2024.2322065.
Watt-Pringle R, Razak TB, Jompa J, Rappe RA, Nadhira A, Smith DJ. 2023. Coral reef restoration in Indonesia: Lessons learnt from the world's largest coral restoration nation. Res Sq 1: 1-32. DOI: 10.21203/rs.3.rs-3753787/v1.
Wirabuana PYAP, Setiahadi R, Sadono R, Lukito M, Martono DS, Matatula J. 2020. Allometric equations for estimating biomass of community forest tree species in Madiun, Indonesia. Biodiversitas 21 (9): 4291-4300. DOI: 10.13057/biodiv/d210947.
Woodroffe SA, Wake LM, Kjeldsen KK, Barlow NLM, Long AJ, Kjær KH. 2023. Missing sea level rise in southeastern Greenland during and since the Little Ice Age. Clim Past 19 (8): 1585-1606. DOI: 10.5194/cp-19-1585-2023.