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Coral Reef Diversity and Habitat Characteristics in the Waters of Nasi Island, Aceh Province, Indonesia

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ABSTRACT

As benthic marine organisms within the class Anthozoa (Phylum Cnidaria), corals form the foundational structure of coral reef ecosystems. These ecosystems are vital marine habitats, supporting diverse aquatic species. This study aims to analyze the coral diversity index and habitat characteristics in the waters of Nasi Island, Aceh Province. The research was conducted in July and August 2024. The survey was conducted across three distinct research sites. Using a purposive sampling method, thirty coral samples were collected from a 2 × 2-meter plot at each location. The Shannon-Wiener diversity index was used to analyze the diversity of coral species. The research identified 32 coral species belonging to 6 families. The diversity index analysis indicated that the coral diversity index ranged from 2.26 to 2.97, falling into the moderate category. Among the study locations, Pasie Janeung had the highest coral diversity, while the lowest diversity was observed at Dedap. In the Dedap and Alue Rieung areas, the decline of coral reef ecosystems is linked to community activities, particularly the use of boats and fishing vessels for fishing and docking. This highlights the urgent need for intensified conservation efforts, such as establishing no-anchoring zones, to ensure the long-term sustainability of the coral reefs.

1. INTRODUCTION

Nasi Island is one of the outermost small islands in Aceh Province, directly connected to the Indian Ocean and the Andaman Sea [1]. Administratively, this area is recognized as the zero point of Indonesia in the western region [2]. Nasi Island is situated far from the provincial and district capitals, separated by the sea. Transportation for the local community generally relies on water transport, such as boats and ships. The Indo-Pacific region, including this area, is renowned for its high coral reef diversity and remarkable ecological complexity [3]. Coral reef ecosystems play a vital role in maintaining the physical, ecological, and economic stability of the surrounding area [4].

Corals are benthic marine organisms belonging to the class Anthozoa, classified under the Phylum Coelenterata or Phylum Cnidaria. These corals exhibit a wide variety of forms and unique, vibrant colors. Morphologically, corals are often found with branching structures, mushroom-like shapes, or forms resembling musical instruments [5]. Various coral species predominantly inhabit the seabed of oceans, straits, and even the ocean floor. These organisms are classified as benthos, thriving on the seabed, and are widely found in the Indian Ocean, Atlantic Ocean, and Pacific Ocean [6]. Generally, corals exhibit a colonial life characteristic in marine habitats, although certain species are also found living solitarily [7].

Corals are known as a group of benthic organisms with highly specific habitat characteristics in marine waters. These marine organisms thrive and grow optimally under conditions of water salinity ranging from 33‰ to 36‰, with high dissolved oxygen levels reaching 13.73 ppm [8]. They live by attaching themselves to the seabed, such as rocks or hard substrates, as an adaptation to withstand wave action [9]. Coral reef ecosystems serve as the fundamental foundation for marine life, playing a crucial role in marine areas as habitats for various aquatic species, including Pisces, Crustaceans, Mollusks, and Plankton [10, 11]. These ecosystems are recognized as areas with the highest biodiversity in the world due to their roles as protective zones, spawning grounds, rich food sources, and their complex food chains [12]. More than 25% of various flora and fauna species in coastal areas, directly or indirectly, depend on coral reef ecosystems. Additionally, these ecosystems support the growth and development of seagrass beds and mangrove vegetation in adjacent areas [13].

Coral reef ecosystems play a vital role in the food chain system within marine waters. A higher level of coral diversity indicates the complexity of the marine environment, as coral reef ecosystems serve as habitats for various species of Pisces, Crustacea, Gastropoda, Bivalvia, and other aquatic species [14, 15]. Coral reef ecosystems also function as spawning grounds, nursery areas, and protective zones for various aquatic organisms against marine predators [16]. If coral reef ecosystems are not well-preserved in a marine area, it will lead to a decline in the populations of various aquatic organisms within that area [17].

Research conducted in the waters of Aceh Province indicates that coral reef ecosystems have suffered damage ranging from moderate to severe. The primary cause of this damage is human activity, particularly the use of water transportation and the operations of boats and fishing vessels, including their docking along the coastline [18]. Conservation efforts are among the most effective solutions for preserving coral reef ecosystems in their natural marine habitats. However, there is a significant lack of information regarding the population and diversity of corals in the waters of Aceh Province.

This study aims to assess coral species diversity and identify environmental drivers influencing coral distribution in Nasi Island's neritic waters. Research to examine coral diversity in the neritic zone waters around Nasi Island is crucial, given the vital role coral reef ecosystems play in marine environments as habitats for various aquatic biota, which local communities rely on for their daily livelihoods. Coral diversity in a marine area can serve as an initial indicator of the condition of the marine environment, whether it remains in good condition or is subject to mild to severe pollution. Data on coral diversity can also serve as a reference for communities and governments in managing coastal and marine areas to ensure sustainability and support the livelihoods of coastal communities.

2. MATERIALS AND METHODS

2.1 Study area

The study was conducted in the neritic zone of Nasi Island waters, Aceh Province, from July to August 2024. Sampling was conducted once a week, specifically on Saturdays at midday during high tide. This research area represents one of the outermost small islands of Aceh Province, directly connected to the Indian Ocean and the Andaman Sea (Figure 1). Nasi Island is located far from the provincial and district capitals, separated by the sea.

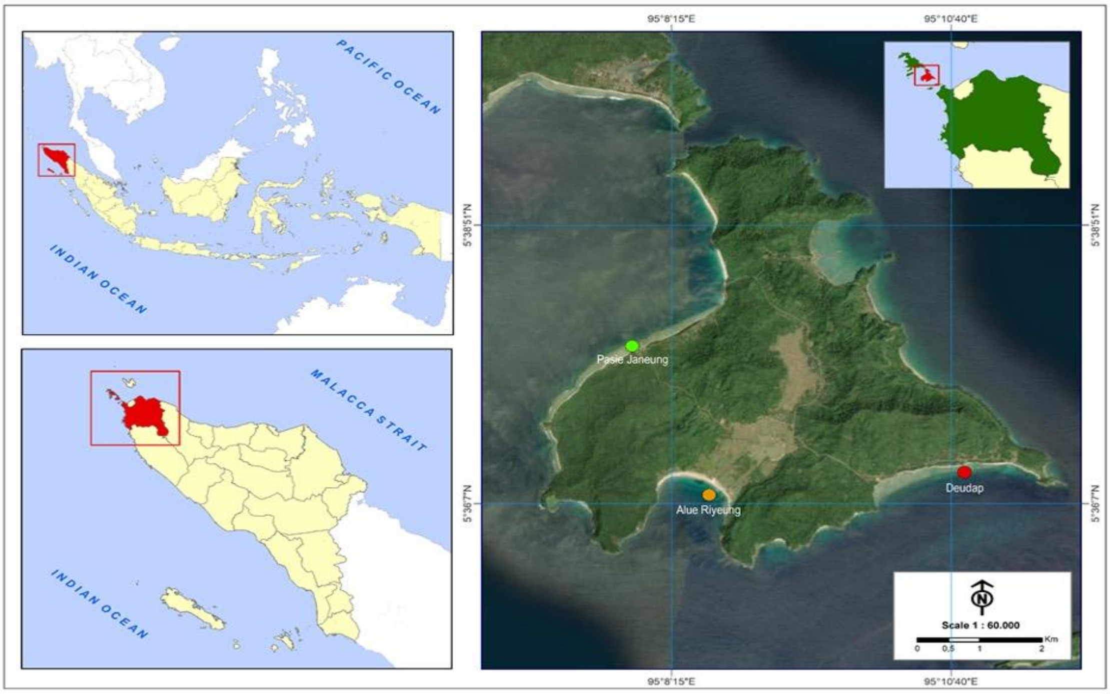

Figure 1. Map of the study location in the Nasi Island area, Aceh Province

Coral sampling in the neritic zone was carried out in three locations with highly varied environmental characteristics, including topography, community activities, and sea depth. Location Dedap (coordinates 5°36'25.8"N, 95°10'45.8"E) is a marine area actively utilized by local communities as a landing site for fishing boats. Location Alue Riyeung (coordinates 5°36'13.7"N, 95°08'36.3"E) is characterized by an environment that extends inland, and Location Pasie Janeung (coordinates 5°37'42.7"N, 95°07'56.6"E) has features that include protection on the northwestern front by Pulau Beras (Table 1).

2.2 Data collection

Coral sampling at the three research locations was carried out based on topography and varying community activities. Coral data were collected using transects from the land to the sea within the neritic zone, each transect being 100 meters long. Three transects were set up at each research location, and each transect was divided into 10 plots measuring 2 meters by 2 meters. Coral sampling was carried out at high tide to facilitate the calculation and documentation of each species found. Each coral sample found in the designated plots was documented using a waterproof digital camera and then identified based on morphological similarities, including size, color, and other morphological features [19]. Several environmental parameters were also measured during the in-situ coral sampling, including water salinity using a hand refractometer, dissolved oxygen with a dissolved oxygen meter, water pH using a pH meter, and water temperature using a mercury thermometer. For every environmental parameter measurement using a hand refractometer, a dissolved oxygen and pH meter, all of these tools must be calibrated first.

Table 1. The environmental condition characteristics in the research area on the coast of Aceh

Location	Coordinate	Environmental Characteristics
Dedap	5°36'25.8"N 95°10'45.8"E	Sampling was conducted in the neritic zone waters, with water depths ranging from 2 to 3 meters during high tide. This area is home to healthy corals, with damage to individual species ranging from 10-15%. The area is used as a docking site for local fishing boats and ships, resulting in significant coral damage. The sediment in this area is predominantly sand, along with dead coral reefs.
Alue Riyeung	5°36'13.7"N 95°08'36.3"E	This marine area features an environment that extends toward the land. Sampling was conducted in the neritic zone waters, with water depths ranging from 2 to 3 meters during high tide. The area is home to healthy corals, with species damage ranging from 10-14%. The seabed sediment is predominantly sand, along with dead coral reefs
Pasie Janeung	5°37'42.7"N 95°07'56.6"E	Sampling was conducted in the neritic zone waters, with water depths ranging from 2 to 4 meters during high tide. This area is home to healthy corals, with species damage ranging from 11-15%. The water condition in the northwestern part is protected by the Pulau Beras area. This marine area serves as a landing site for local fishermen. The sediment in this area is predominantly sand, along with dead coral reefs.

2.3 Data analysis

Coral samples at the three research locations that have been identified by species name based on similarities in morphological characteristics, to obtain the diversity index value, were analyzed using the Shannon-Wiener diversity index equation (H') with the following formula equation [20].

$$H' = -\sum_{i=1}^{s} Pi \ln Pi$$

where,
H': Species diversity index
Pi: Number of individuals of each species (i=1,2,3,..)
s: Number of species

If H' < 1, it is classified as low diversity; if 1 < H' < 3, it is classified as medium diversity; and if H' > 3, it is classified as high diversity. This study also analyzed the dominance index (D) to determine the dominance value using the following formula.

$$D = \sum_{i=1}^{s} Pi^2$$

where,
Pi = ni/N
D: Dominance index
ni: Number of individuals of species i
N: Total number of individuals
Criteria:
$0.0 < D \leq 0.30$: low dominance level
$0.30 < D \leq 0.60$: medium dominance level
$0.60 < D \leq 1.00$: high dominance level

The species richness of coral reefs at the research site was analyzed using the following formula.

$$R = \frac{(S-1)}{\ln N}$$

where,
R: Species richness index
S: Number of species
N: Total number of individuals across all species
Criteria:
R < 3.5: low species richness
R = 3.5 – 5.0: moderate species richness
R>5.0: High species richness

Furthermore, coral reef evenness was analyzed using the following formula.

$$E = \frac{H'}{\ln S}$$

where,
E: Species evenness index
H': Species diversity index
S = Number of species
ln = Natural logarithm

The evenness index ranges between 0 and 1, with the following categories.
$0 < E \leq 0.4$: Low evenness, stressed community
$0.4 < E \leq 0.6$: Moderate evenness, unstable community
$0.6 < E \leq 1.0$: High evenness, stable community

Analysis of the relationship between various physical and chemical environmental parameters and coral diversity using Principal Component Analysis (PCA).

3. RESULTS

Table 2. Number of coral families and species by research location

Family	Species	Location		
		Dedap	Alue Riyeung	Pasie Janeung
Acroporidae	*Acropora clathrata* (Brook, 1891)	+	-	+
	Acropora intermedia (Brook, 1891)	+	-	+
	Acropora millepora (Ehrenberg, 1834)	+	+	+

	Acropora robusta (Dana,1846)	+	+	+
	Acropora rudis (Rehberg, 1892)	+	+	+
	Acropora tenuis (Dana,1846)	+	-	-
	Montipora danae (Milne Edwards & Haime, 1851)	-	-	+
	Montipora informis (Bernard, 1897)	-	-	+
	Montipora foliosa (Pallas, 1766)	-	-	+
	Dipsastraea lizardensis (Veron, Pichon & Wijsman-Best, 1977)	+	+	+
	Dipsastraea favus (Forskål, 1775)	-	-	+
	Favites halicora (Ehrenberg, 1834)	-	-	+
Merulinidae	*Hydnophora microconos* (Lamarck, 1816)	+	-	-
	Astrea annuligera (Milne Edwards & Haime, 1849)	-	+	-
	Platygyra daedalea (Ellis & Solander, 1786)	-	-	+
	Platygyra pini (Chevalier, 1975)	-	+	+
	Platygyra sinensis (Milne Edwards & Haime, 1849)	-	+	-
	Heliofungia actiniformis (Quoy & Gaimard, 1833)	+	-	-
Fungiidae	*Pleuractis paumotensis* (Stutchbury, 1833)	-	-	+
	Lobactis scutaria (Lamarck, 1801)	-	-	+
Euphylliidae	*Galaxea astreata* (Lamarck, 1816)	-	+	–
	Galaxea fascicularis (Linnaeus, 1767)	-	+	–
	Goniopora lobata (Reuss, 1864)	-	-	+
	Porites cylindrica (Dana, 1846)	-	-	+
Poritidae	*Porites lobata* (Dana, 1846)	+	+	+
	Porites lutea (Milne Edwards & Haime, 1851)	+	+	+
	Porites mayeri (Vaughan, 1918)	-	-	+
	Pocillopora damicornis (Linnaeus, 1758)	-	+	+
	Pocillopora verrucosa (Ellis & Solander, 1786)	+	+	-
Pocilloporidae	*Seriatopora caliendrum* (Ehrenberg, 1834)	-	-	+
	Seriatopora hystrix (Dana, 1846)	-	-	+
	Stylophora pistillata (Esper, 1792)	-	-	+

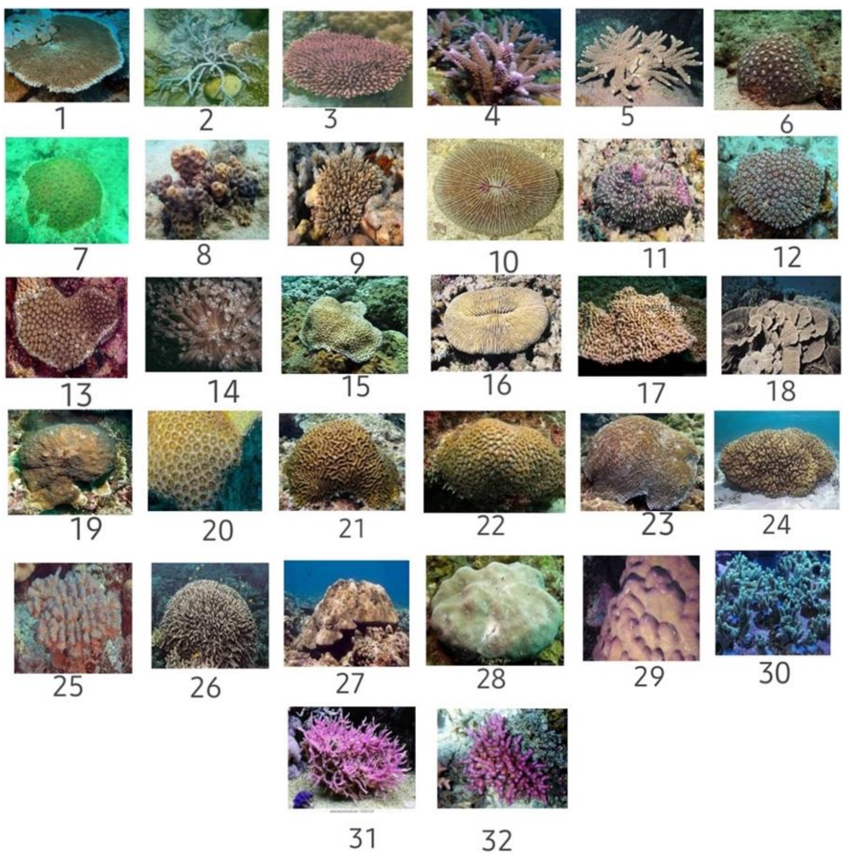

Figure 2. Coral species collected at the research location

1. *Acropora clathrata* (Brook, 1891), 2. *Acropora intermedia* (Brook, 1891), 3. *Acropora millepora* (Ehrenberg, 1834), 4. *Acropora Robusta* (Dana, 1846), 5. *Acropora rudis* (Rehberg, 1892), 6. *Dipsastraea lizardensis* (Veron, Pichon & Wijsman-Best, 1977), 7. *Dipsastraea favus* (Forskål, 1775) , 8. *Favites halicora* (Ehrenberg, 1834), 9. *Acropora tenuis* (Dana, 1846), 10. *Heliofungia actiniformis* (Quoy & Gaimard, 1833), 11. *Lobactis scutaria* (Lamarck, 1801), 12. *Galaxea astreata* (Lamarck, 1816), 13. *Galaxea fascicularis* (Linnaeus, 1767), 14. *Goniopora lobata* (Reuss, 1864), 15. *Hydnophora microconos* (Lamarck, 1816), 16. *Pleuractis paumotensis* (Stutchbury, 1833), 17. *Montipora danae* (Milne Edwards & Haime, 1851), 18. *Montipora foliosa* (Pallas, 1766), 19. *Montipora informis* (Bernard, 1897), 20. *Astrea annuligera* (Milne Edwards & Haime, 1849), 21. *Platygyra daedalea* (Ellis & Solander, 1786), 22. *Platygyra pini* (Chevalier, 1975), 23. *Platygyra sinensis* (Milne Edwards & Haime, 1849), 24. *Pocillopora damicornis* (Linnaeus, 1758), 25. *Pocillopora verrucosa* (Ellis & Solander, 1786), 26. *Porites cylindrica* (Dana, 1846), 27. *Porites lobata* (Dana, 1846), 28. *Porites lutea* (Milne Edwards & Haime, 1851), 29. *Porites mayeri* (Vaughan, 1918), 30. *Seriatopora caliendrum* (Ehrenberg, 1834), 31. *Seriatopora hystrix* (Dana, 1846), 32. *Seriatopora pistillata* (Esper, 1792)

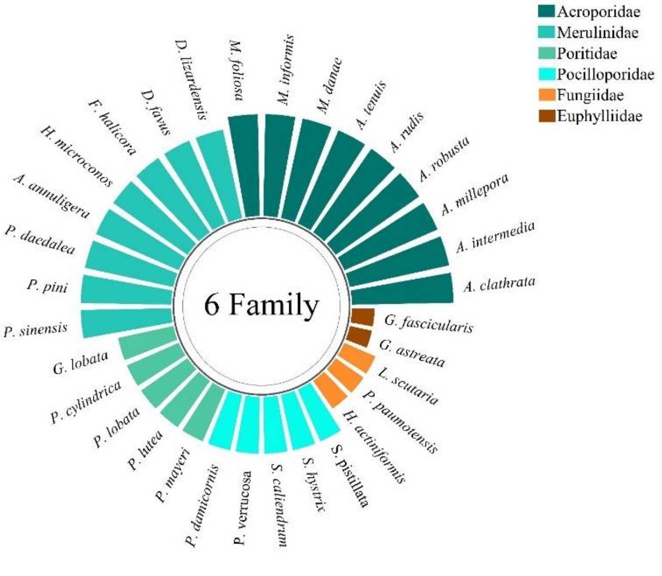

Figure 3. Distribution of coral families and species at the research location

The research results in the waters of Nasi Island in the neritic zone successfully collected 32 coral species (Figure 2) from 6 families (Figure 3). Acroporidae was the family with the highest number of species in the study area, while Euphylliidae had the lowest number of species collected at the research location (Table 2).

In general, the distribution of corals in the study area shows that the Acroporidae family is the most prevalent, accounting for 28.1% of the samples, while the Euphylliidae family is the least found at 6.2% (Figure 4). The habitat characteristics and the ability to adapt to the conditions of the neritic zone, which are disturbed by the activities of local fishing boats and vessels using water transportation, influence the life of various aquatic organisms, including the coral reef ecosystem.

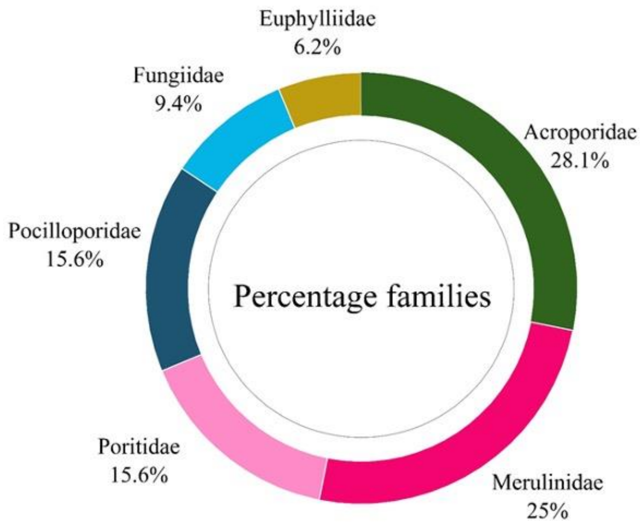

Figure 4. Percentage of coral families in the study area

The characteristics of habitat and the abundance of food sources in a marine area have a significant impact on the abundance of coral species and families living in a particular area. Species from the Acroporidae family were the most dominant across all three research locations, with this family accounting for up to 50% of the corals collected in the Dedap area. The Fungiidae family had the lowest number of species found in the research locations, and no species from the Fungiidae family were found in the Alue Riyeung area (Figure 5).

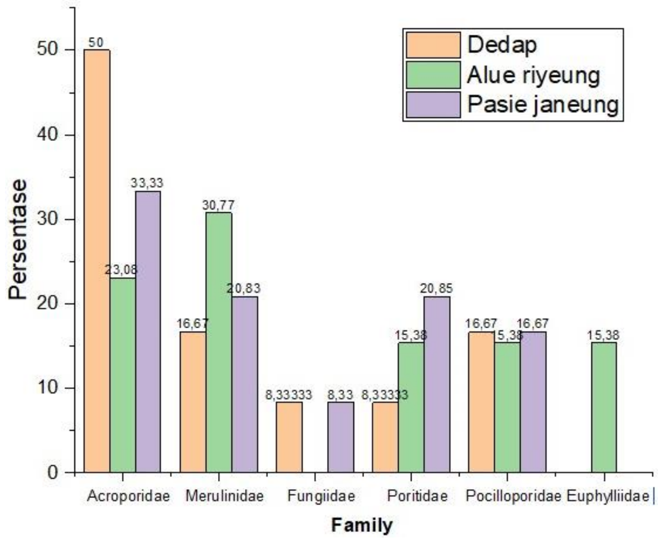

Figure 5. Percentage composition of corals based on species and family

Based on the research results from the three study locations, the highest number of species was collected in the waters of Pasie Janeung, with 24 coral species out of a total of 32 species overall. In contrast, the lowest number of species was collected in the waters of Dedap, with only 12 coral species. Across all three research locations, the same number of coral families was found, with each location having 5 coral families (Figure 6).

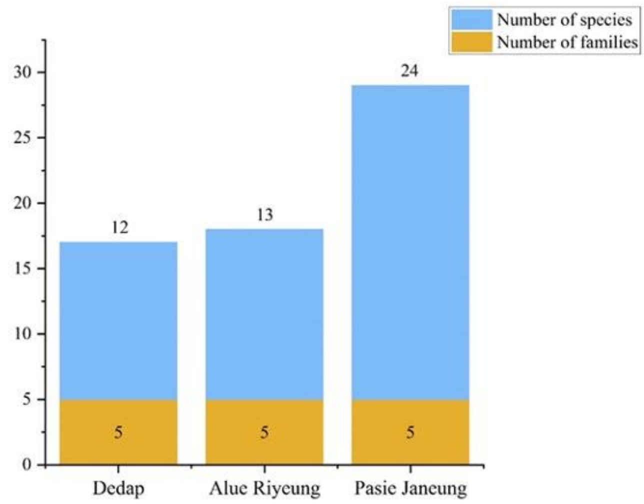

Figure 6. Number of coral families and species by research location

Based on the analysis of the diversity index in the waters of Nasi Island, the coral diversity varies significantly between locations. However, all three locations still fall within the moderate diversity index category. The waters of Pasie Janeung exhibited the highest diversity index with a value of H' = 2.97, nearly reaching 3. The lowest diversity index was found in the waters of Dedap, with a value of H' = 2.26. The coral dominance index in the three research locations ranged from 0.06 to 0.12, which is considered low. The highest dominance index was found at the Dedap and Alue Riyeung locations, while the lowest was at Pasie Janeung (Table 3).

Table 3. Coral diversity index (H') and coral dominance index (D) at the research locations

Location	H'	Category	D	Category
Dedap	2.26	Moderate	0.12	Low
Alue Riyeung	2.30	Moderate	0.12	Low
Pasie Janeung	2.97	Moderate	0.06	Low

The analysis of species richness and evenness of coral reefs at the research sites revealed differences in species richness among the three locations. However, all remained within the same category, namely, low. Similarly, the evenness index of coral reefs varied across locations, but consistently fell into the high category, indicating that the coral reef communities at the study sites are still stable. The detailed data on coral reef species richness and evenness at the research sites are presented in Table 4.

Table 4. Species richness and evenness of coral reefs

Location	Species Richness	Category	Evenness	Category
Dedap	1.18	Low	0.91	High
Alue Riyeung	1.11	Low	0.90	High
Pasie Janeng	1.67	Low	0.93	High

3.1 The relationship between physical and chemical environmental parameters and coral diversity

The measurement of environmental parameters at the study sites revealed variations across the three locations. The highest water salinity was recorded at Pasie Janeng, ranging from 34.5‰ to 35.5‰, while the lowest was observed at Dedap, ranging from 31‰ to 33‰. Similarly, dissolved oxygen levels were highest at Pasie Janeng and lowest at Dedap. The detailed environmental parameters are presented in Table 5.

Table 5. Environmental parameters at the study sites

Location	Water Salinity (‰)	Water pH	Water Temperature (℃)	Dissolved Oxygen (mg/L)
Dedap	31 - 33	6.6 - 6.8	29	7.1 - 7.3
Alue Riyeung	32 - 34	6.5 - 6.7	29	7.4 - 7.6
Pasie Janeng	34.5 - 35.5	6.7 - 6.9	30	8.0 - 8.2

Principal Component Analysis (PCA) analysis shows a strong relationship between coral diversity in the study locations and several physical and chemical environmental parameters. The neritic zone of Pasie Janeung exhibits the highest coral diversity, which is strongly correlated with water temperature, dissolved oxygen, salinity, and pH levels. This is evidenced by the proximity of these environmental parameters' axes to the Pasie Janeung location in the PCA plot (Figure 7).

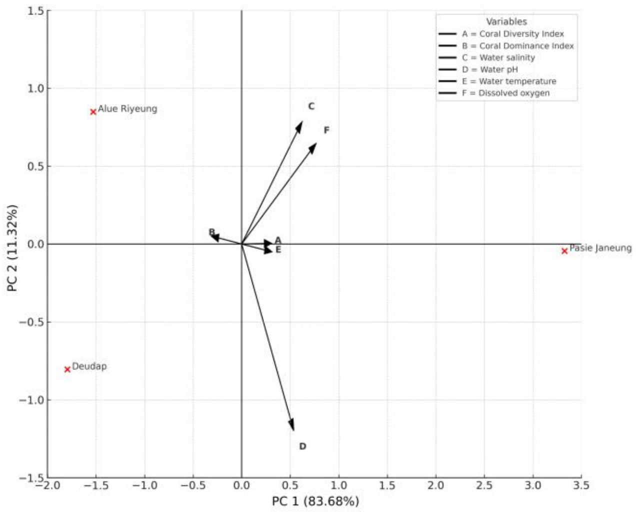

Figure 7. Relationship between physical and chemical environmental parameters and coral diversity

4. DISCUSSION

The research successfully collected 32 coral species in the neritic zone waters around Nasi Island, Aceh Province. The diversity was found to vary between locations. A variation in coral diversity was found between the research locations, ranging from H' = 2.26 to H' = 2.97. The coral diversity in all three research locations falls within the moderate category. The waters of Pasie Janeung exhibited the highest diversity, with a value of H' = 2.97, nearly approaching the high diversity criteria. The protected environment, shielded by the nearby small island of Pulau Beras, is one of the reasons why the coral ecosystem in this area is in better condition compared to the other two locations [21]. The deeper waters and the lack of fishing boat docking activity also benefit the Pasie Janeung area, making its marine ecosystem more protected [22]. The high frequency of water transportation activities, such as fishing boats and vessels regularly passing through or docking in the neritic zones of Dedap and Alue Riyeung, has caused damage to various coral species and hindered their optimal growth. This has resulted in lower coral diversity compared to the waters of Pasie Janeung. Increased water transportation activities in an area lead to a decline in the populations of various aquatic organisms, including coral populations [23].

The coral diversity in the study locations reflects the quality of marine waters, indicating conditions of heavy pollution, light pollution, or healthy waters. Higher coral diversity signifies the complexity of other marine organisms' diversity, as coral reef ecosystems serve as habitats and are utilized by aquatic organisms for spawning and protection [24]. Conversely, low coral diversity in a neritic marine area indicates that the waters are experiencing light to heavy pollution [25]. Intensive human activities in coastal and marine areas, coupled with unmanaged domestic and industrial waste, often result in marine pollution. Continuous contamination of the marine environment significantly impacts the decline of aquatic organism populations, including corals [17]. Cahyani and Nugroho [14] reported that coral diversity in a marine area has a significant effect on the abundance and diversity of fish species and other aquatic organisms. Suitable habitats and the abundance of available food resources in a marine area are key factors that significantly influence the population abundance and diversity of coral reef ecosystems in specific regions [26]. The results of the study indicate that the diversity index with an H' value of 2.97 is classified as moderate and lower than the typical value for the Coral Triangle region in general, H' > 3.5. This difference indicates that the diversity of coral species at the study site is not as high as the ideal conditions of coral in potential habitats. This occurs due to anthropogenic pressures, environmental disturbances, and the physical damage to the habitat that reduces community complexity and increases the dominance of certain species. This condition indicates the need for sustainable management efforts for this aquatic biota to approach or even equal the ideal conditions of the Coral Triangle.

A stable environment supported by more suitable habitat characteristics plays a vital and significant role in the abundance and diversity of various coral species in the study area. The results of the Principal Component Analysis (PCA) indicate that water temperatures reaching 30℃ and high dissolved oxygen levels ranging from 8.0 mg/L to 8.2 mg/L are strongly and significantly correlated with coral diversity in the neritic waters of Pasie Janeung [27]. The mutualistic symbiotic relationship between some coral species, plankton, and various seagrass species in the food chain requires higher sunlight intensity to support photosynthesis, providing the necessary nutrients for these organisms [28]. Additionally, seawater salinity reaching 35‰ and a near-neutral pH also exhibit a strong correlation with coral diversity in the study locations. These conditions contribute to Pasie Janeung having the highest coral diversity among the three locations, as the water temperature and various other physical and chemical parameters create an ideal habitat for corals that thrive in symbiosis with seagrass and plankton [1].

This study indicates that routine water transportation activities conducted by coastal communities, along with the use of coastal areas as docking sites for fishing boats and vessels, have negative impacts on the sustainability of marine environments. These activities contribute to the decline of various aquatic organisms, including corals, which serve as habitats for numerous marine species. Serious conservation efforts are crucial for coral reef ecosystems in the waters of Dedap and Alue Riyeung to preserve them as habitats for various species, including Pisces, Crustacea, and Bivalvia, which provide a high-quality source of animal protein for local communities [29]. It is essential for us all to show greater attention and care in preserving coastal and marine areas, which serve as the ultimate destination for various pollutants from human activities. These pollutants have a significant impact on the life of marine organisms, which are highly dependent on coral reef ecosystems [30]. It's crucial to establish a no-go zone for ships 50 meters from coral habitats to ensure their continued sustainability. Regular quarterly surveys of coral cover are also necessary to ensure the optimal growth of this aquatic biota in the waters off Nasi Island, Aceh Province.

5. CONCLUSION

The research successfully collected 32 coral species belonging to 6 families. The coral diversity index at the research locations ranged from 2.26 to 2.97, which falls under the moderate category. The Pasie Janeung location exhibited the highest coral diversity compared to the other two locations, while the lowest diversity was found at the Dedap location. Suitable habitat characteristics, such as water temperature, dissolved oxygen, salinity, and pH levels, have a strong correlation with coral diversity at the study locations. The use of water transportation, such as boats and fishing vessels, for fishing and docking is one of the factors contributing to the decline of the coral reef ecosystem in the Dedap and Alue Riyeung areas. The importance of local wisdom-based conservation efforts to maintain the sustainability of coral reefs in a sustainable manner, considering that coral reef ecosystems are the habitat of various marine fishery animals, as a livelihood for fishermen.

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