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PRIORITY MANAGEMENT OF CORAL REEF ECOSYSTEMS IN POMBO ISLAND NATURE TOURISM PARK, CENTRAL MALUKU REGENCY

PRIORITAS PENGELOLAAN EKOSISTEM TERUMBU KARANG DI TAMAN WISATA ALAM PULAU POMBO, KABUPATEN MALUKU TENGAH

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ABSTRACT

The coral reef ecosystem in the Pombo Island Nature Tourism Park area has experienced a decline in quality due to environmentally damaging fishing practices, thereby affecting coral reef productivity. This study aims to identify the actual condition of the coral reef ecosystem by analyzing water quality, the level of live coral cover, and the reef fish species abundance to formulate a main-priority management strategy. Water quality parameters were measured directly, while coral reefs were measured through diving using scuba gear. Coral condition evaluation was carried out using the point intercept transect method, while reef fish abundance was calculated using the underwater visual census technique. Determination of priority strategies for coral reef ecosystem management used the analytic network process approach. The results showed that water quality was considered good to support coral reef ecology. The average coral cover was 47.75% (fair category), with variations between blocks: utilization (24%, poor), rehabilitation (35%, fair), marine protection (57%, good), and traditional (42%, fair). Forty-nine reef fish species from 16 families were found with an abundance of 2,545 individuals per 1,500 m² of observation area, including major, target, and indicator fish, and the species abundance was categorized as high. Coral reef ecosystem restoration can be prioritized through community-based coral transplantation to enhance the effectiveness of both restoration efforts and environmental education.

Keywords: management priorities, percentage of live coral cover, reef fishes abundance, water quality

ABSTRAK

Ekosistem terumbu karang di kawasan Taman Wisata Alam Pulau Pombo mengalami penurunan kualitas akibat praktik penangkapan ikan yang merusak lingkungan, sehingga memengaruhi produktivitas terumbu karang. Penelitian ini bertujuan untuk mengidentifikasi kondisi aktual ekosistem terumbu karang dengan cara menganalisis kualitas perairan, tingkat tutupan karang hidup, serta kelimpahan spesies ikan karang guna merumuskan strategi pengelolaan yang menjadi prioritas utama. Pengukuran parameter kualitas perairan dilakukan secara langsung, sedangkan terumbu karang diamati melalui penyelaman menggunakan perlengkapan selam. Evaluasi kondisi karang dilakukan dengan metode *point intercept transect*, sementara kelimpahan ikan karang dihitung melalui teknik *underwater visual census*. Penentuan strategi prioritas pengelolaan ekosistem terumbu karang menggunakan pendekatan *analytic network process*. Hasil menunjukkan kualitas perairan tergolong baik untuk mendukung ekologi terumbu karang. Tutupan karang rata-rata 47,75% (kategori cukup baik), dengan variasi antar blok: pemanfaatan (24%, buruk), rehabilitasi (35%, cukup baik), perlindungan bahari (57%, baik), dan tradisional (42%, cukup baik). Ditemukan 49 spesies ikan karang dari 16 famili dengan kelimpahan 2.545 individu/1.500 m² luas pengamatan, mencakup ikan mayor, target, dan indikator, serta kelimpahan spesies termasuk dalam kategori banyak. Prioritas pemulihan ekosistem terumbu karang dapat dilakukan menggunakan transplantasi karang berbasis kolaboratif dengan melibatkan masyarakat untuk meningkatkan efektivitas pemulihan dan edukasi.

Kata kunci: kelimpahan spesies ikan karang, kualitas perairan, persentase tutupan karang hidup, prioritas pengelolaan

INTRODUCTION

The coral reef ecosystem spread across Maluku waters covers an area of 366,545.04 hectares, making Maluku part of the Coral Triangle (Maluku Province Marine Affairs and Fisheries Office 2022). This inclusion provides both direct and indirect benefits. Direct benefits include the utilization of fishery resources, tourism development, and research activities. Indirect benefits include protecting the coast from abrasion, maintaining biodiversity, serving as a site for biological and chemical processes, and supporting marine productivity (Isdianto and Luthfi 2020).

The coral reefs in Maluku waters are currently vulnerable to damage. According to findings from the Maluku Province Marine Affairs and Fisheries Office (2022), damage had affected 4,854.06 hectares (1.32%) of the total 366,545.04 hectares of the coral reef ecosystem. This indicates that coral reef ecosystems are highly vulnerable to various forms of damage caused by human activities. Pressures stem from destructive fishing practices and increased environmentally unfriendly tourism activities (Ritonga *et al.* 2022). Uncontrolled resource exploitation has also been occurring in the Pombo Island Nature Tourism Park, a conservation area in the Maluku waters. These activities have negatively impacted the conservation area officially designated by the government for the protection of marine biota (Lestaluhu 2023).

Pombo Island, a conservation area within the Nature Tourism Park, holds management rights over 218.746 hectares, including a coral reef ecosystem that spans 211.82 hectares (Maluku Province Marine and Fisheries Office 2022). The management system in the Pombo Island Nature Tourism Park is block-based, as regulated in Decree of the Minister of Environment and Forestry Number 998/MENLHK/SETJEN/PLA.2/9/2022. Pombo Island has five management blocks: a protection block (2,280 ha), a marine protection block (23,338 ha), a rehabilitation block (10,471 ha), a utilization block (105,196 ha), and a traditional block (77,461 ha) (BKSDA 2023).

This study aims to identify the condition of the coral reef ecosystem in Pombo Island Nature Tourism Park through analysis of water quality, live coral cover, and reef fish abundance. The study is also intended to provide a comprehensive understanding of the ecosystem's health and its relationship to the associated biota. The research findings are expected to provide a scientific basis for formulating adaptive and sustainable conservation area management strategies.

METHODS

Time and location

The research was conducted at the Pombo Island Nature Tourism Park, Central Maluku Regency, Maluku Province, a conservation area managed by the Maluku Provincial Resource Conservation Agency (Figure 1). A purposive sampling method was used to determine six observation points representing the entire coral reef ecosystem in each management block, and was supported by secondary data from observations by the Wildlife Conservation Society *et al.* (2023).

Materials and tools

The equipment used in this research activity included diving equipment, a roll meter, an underwater camera, a GPS, and water parameter data collection devices (Secchi disc, deep gauge, thermometer, refractometer, pH meter, and current meter). In addition, underwater paper, stationery, and a coral species identification book referring to Coral Finder 3.0 published by Kelley Russel in 2016 were also used, and coral fish identification referred to the book Reef Fish Identification: Tropical Pacific by Allen *et al.* (2003).

Data collection techniques

Water quality data collection

Water quality data were measured directly to determine current conditions. Observed variables included temperature using a thermometer, salinity using a refractometer, depth using a deep gauge, current velocity using a current meter, and transparency using a Secchi disc. These measurements were conducted directly at the research site to serve as physical and chemical baseline data for the coral reef ecosystem (Handayani and Dewi 2023).

Coral reef ecosystem data collection

Coral reef data collection was conducted using the point intercept transect (PIT) method, installing a 50-m transect parallel to the shoreline (Najmi *et al.* 2021). Along the 50-m transect, installed parallel to the shoreline,

100 observation points were obtained at 0.5-m intervals. Coral reefs were identified based on their growth form, with an observation area of 1,500 m^2. Observations were conducted at six stations: Station I in the utilization block, Station II in the rehabilitation block, Stations III and IV in the marine protection block, and Stations V and VI in the traditional block. All observation stations are shown in Figure 1. The identification process used the Coral Finder 3.0 book published by Kelley Russell in 2016.

Reef fish data collection

Reef fish observations were conducted using the underwater fish visual census (UVC) method at the same transect location as the coral reef ecosystem observations (Tentri *et al.* 2020). Observations were conducted carefully at a depth of 8 to 10 m using SCUBA equipment, an underwater camera, and an underwater slate. The observation area covered 2.5 m to the left and right of the transect line, and the number of individual fish observed was recorded (Sudarmaji and Efendy 2021).

Data analysis

Water quality analysis

The collected water quality data were analyzed descriptively and qualitatively to describe the water conditions in the Pombo Island Nature Tourism Park area. This approach identified factors influencing the water conditions in Pombo Island Nature Tourism Park (Sari *et al.* 2022). The water quality parameters used in this study are presented with their optimal values (Table 1).

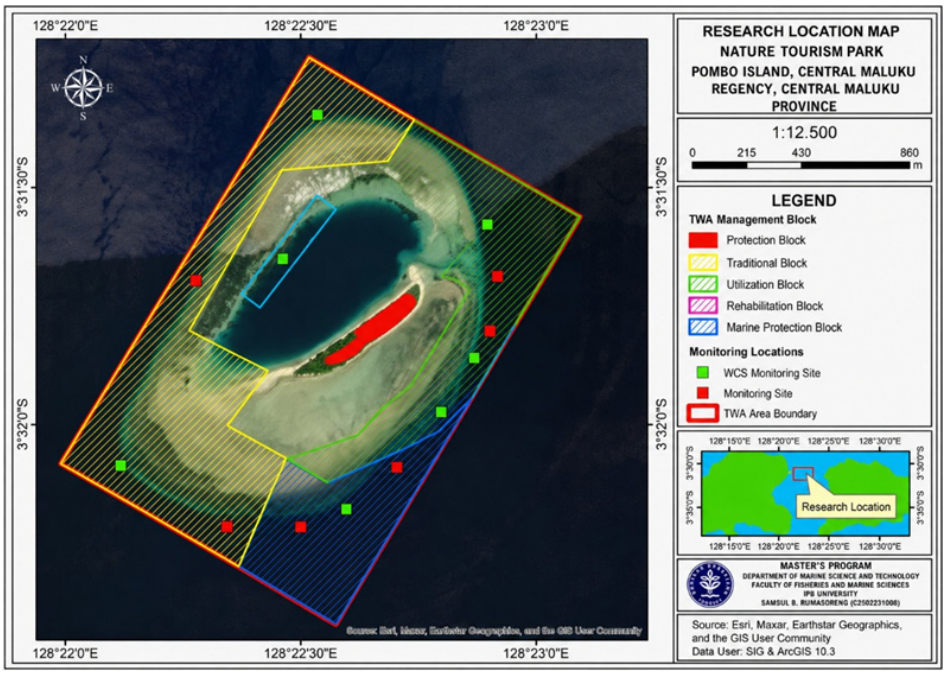


Figure 1. Location and observation points of the research in Pombo Island Nature Tourism Park, Central Maluku Regency, Maluku Province.

Table 1. Water quality parameters and optimal values at Pombo Island Nature Tourism Park.

Parameters	Units	Optimal Values	References
Transparency	%	100% of the depth of the coral reef is located	Zurba (2019)
Depth	M	< 20 m	Zurba (2019)
pH	-	6–9	Edwards dan Gomez (2007)
Salinity	‰	30–36‰	Giyanto *et al.* (2017)
Temperature	°C	26–34 °C	Suharsono (2010)
Current speed	m/det	0–17 m/det	Zurba (2019)

Coral reef data analysis

Coral reef analysis was conducted by calculating the percentage of live coral cover using the formula from English *et al.* (1994), calculated from the total area observed. This analysis aims to evaluate coral reef health, changes, and factors influencing coral reef degradation or recovery (Cahyani *et al.* 2018).

$$Ni = \frac{Li}{L} \times 100$$

Description:
Ni = Percentage of life form ke-i (%)
Li = Point number of life form ke-i
L = Point number of life form per transect (50 m)

Coral reef damage was assessed using the criteria developed by Yap and Gomez (1984), which classified the areas as: "excellent" (score 3, 75–100%), "good" (score 2, 50–74.9%), "fair" (score 1, 25–49.9%), and "poor" (score 0, 0–24.9%) (Table 2).

Reef fish data analysis

Reef fish abundance was analyzed using the Odum (1993) formula, which included the abundance index, number of individuals, and the area of observation. This analysis identified ecosystem conditions and the impact of environmental disturbances or human activities.

$$Di = \frac{ni}{A}$$

Description:
Di = Abundance of coral fish (ind/ha)
ni = Number of coral fish individuals at each station (ind)
A = Area of observation (ha)

The number of reef fish species was calculated based on their presence in the observation area, then categorized based on Yulianda's (2019) criteria into several levels with different scores reflecting population abundance or density (Table 3).

Management strategy analysis

The management strategy in this study was formulated using the analytic network process (ANP) approach supported by Super Decision software version 2.10 (Juliyanto *et al.* 2019). The ANP was used to determine priorities for coral reef ecosystem management in the Pombo Island Nature Tourism Park. This analysis involved three clusters: management priorities, ecological problems, and alternative ecological solutions, based on assessments by stakeholders and experts (Saaty 2006).

The selection criteria for stakeholders and experts included competence and experience in research, position and relevance to the field of study, and high credibility within the research location (Ramdhan *et al.* 2018). Respondents included the Maluku Province Natural Resources Conservation Agency, the Maluku Province Marine Affairs and Fisheries Agency, academics from Pattimura University Ambon, the Maluku Province Tourism Office, the Maluku Province Regional Development Planning Agency (BAPPEDA), the Wildlife Conservation Society, the National Research and Innovation Agency, the Central Maluku Regency Fisheries Office, the Central Maluku Regency Tourism and Youth Office, and the Central Maluku Regency Development Planning Agency (BAPPLITBANGDA).

The weighted scores from stakeholders and experts were processed using Super Decision software version 2.10, and then a geometric mean was calculated to obtain consensus.

$$\left(\prod_{\iota}^{n} = 1\iota\right)^{\frac{1}{n}} = \sqrt[n]{a1, a2, a3, \ldots an}$$

The total ranking value for each cluster was calculated using the following formula:

$$Xa = (R_1 + R_2 + R_3 + \cdots + R_n)$$

Table 2. Criteria for assessing coral reef conditions based on the percentage of live coral cover according to Yap and Gomez (1984).

Scores	Conditions	Covering Percentage (%)
3	Very good	75–100
2	Good	50–74.9
1	Fair	25–49.9
0	Poor	0–24.9

Table 3. Categories of coral fish abundance based on the number of individuals, according to Yulianda (2019).

Reef Fish Numbers (ind.)	Conditions	Scores
0–15	A few	0
> 15–30	Medium	1
> 30–50	Many	2
> 50	Very many	3

The calculation of the average value (U) of the total ranking of each cluster was done using the following formula:

$$U = \frac{x_a + x_b + x_c + \cdots + x_z}{z}$$

The calculation of the squared deviation value (S) was done using the following formula:

$$S = (R_1 - u)^2 + (R_2 - u)^2 + (R_3 - u)^2 + \cdots + (R_n - u)^2$$

The calculation of the peak value of the square of the deviation (Max S) was done using the following formula:

$$Max\ S = (n - u)^2 + (2n - u)^2 + (3n - u)^2 + \cdots + (Zn - u)^2$$

Description:
X = Number of each cluster
R = Ranking weight of each respondent
n = Number of respondents
z = Number of clusters
U = Average total score in each cluster
S = Sum of squared deviations
The rater agreement (W) value indicates the level of agreement between respondents in each cluster. This approach used Kendall's Coefficient of Concordance (W; 0 < W ≤ 1).

RESULTS AND DISCUSSION

Water conditions

Water quality is crucial for supporting the sustainability of coral reef ecosystems because it directly impacts the health and function of the organisms living within them. The waters of the Pombo Island Nature Tourism Park exhibit characteristics that support coral reef ecosystems, such as water transparency that can penetrate to depths of 8 to 10 m in each management block. This level of light penetration plays a significant role in the growth dynamics and vertical distribution of coral reef ecosystems (Morgan *et al.* 2020).

The pH of Pombo Island waters was slightly alkaline (8.01–8.12), within a range that is not harmful to marine life (Table 4). This pH stability supports the survival of marine organisms, particularly those dependent on calcium carbonate, such as corals and mollusks (Barkley *et al.* 2015).

Coral reefs generally grow and develop optimally in marine environments with a salinity range of 30 psu to 35 psu (Zurba 2019). The salinity of Pombo Island waters exhibited stable seawater characteristics, namely 30 psu to 31.01 psu. This range is still within normal limits (30–36‰), making it suitable for various marine species such as reef fish and invertebrates. The surface temperature of Pombo Island waters remained consistent at 31 °C, which was within the standard quality range (26–34 °C) and indicated suitable conditions for marine life (Siregar *et al.* 2023).

Several management blocks within Pombo Island Nature Tourism Park, such as the utilization and rehabilitation blocks, experience current velocities exceeding normal limits. This current velocity can disrupt sediment stability and the habitat of benthic organisms. However, in the marine protection blocks and traditional blocks, current velocities remain normal enough to distribute nutrients and oxygen and prevent excessive sedimentation that could disrupt the coral reef ecosystem (Zurba 2019). The combination of parameters such as current velocity, depth, temperature, salinity, transparency, phosphate, silicate, nitrate, nitrite, oxygen, and pH in the waters of Pombo Island Nature Tourism Park supports the coral reef ecosystem (Widhiatmoko *et al.* 2020).

The waters of Pombo Island Nature Tourism Park support marine biodiversity, but the problem of waste discharged by local communities remains a challenge in managing the conservation area. Observations have found plastic food and drink packaging, pieces of wood, and plastic waste from household items discarded into the sea in the waters and beaches of Pombo Island Nature Tourism Park. According to BRIN *et al.* (2021), the debris carried by these currents is generally found on only one side of the beach during the west wind season, and the beach is located in the northern part. If left untreated, it could

eventually negatively impact the sustainability of the Pombo Island Nature Tourism Park.

Coral reef condition

The coral reefs in Pombo Island Nature Tourism Park cover 211.82 hectares and form a coral atoll (Maluku Province Marine and Fisheries Office 2022). Pombo Island Nature Tourism Park is managed using a block system based on Regulation of the Minister of Environment and Forestry Number 76 of 2016 concerning Criteria for National Park Management Zones and Management Blocks for Nature Reserves, Wildlife Sanctuaries, Grand Forest Parks, and Nature Tourism Parks. These blocks consist of a protection block (2,280 hectares), a marine protection block (23,338 hectares), a rehabilitation block (10,471 hectares), a utilization block (105,196 hectares), and a traditional block (77,461 hectares) (BKSDA 2023). The coral reefs in Pombo Island Nature Tourism Park significantly support marine biodiversity and serve as life support for marine life, including reef fish and benthic organisms. Healthy coral reefs play a crucial role in maintaining the overall balance of the marine ecosystem (Permatasari *et al.* 2023).

The highest percentage of live coral cover in each management block was found in the marine protection block, with 57% in good condition. This aligns with the function of the block system, which protects coral reefs within the marine protection block (Wildlife Conservation Society *et al.* 2023). The traditional block had 42% live coral cover, in fair condition, while the rehabilitation block showed fair condition (35% live coral), and the utilization block showed poor condition (24% live coral). Overall, coral reef cover in Pombo Island Nature Tourism Park was 47.75% in fair condition (Figure 2). Indicators for determining coral reef condition in each management block of Pombo Island Nature Tourism Park refer to Yap and Gomez (1984).

Table 4. Results of water quality parameter measurements in Pombo Island Nature Tourism Park.

Water Parameters	Units	P1	P2	P3	P4	Optimal Values	Data Sources
Surface temperature	°C	31	31	31	31	26–34 °C	Primary
Water salinity	‰	30	31	30–31.01	30	30–36‰	Primary
Water transparency	%	100%	100%	100%	100%	100%	Primary
Current speed	(m/det)	18.21	17.32	12.36–16.54	14.08	0–17 m/det	Primary
Depth	m	8 >10	8 >10	8 >10	8 >10	< 20 m	Primary
pH	-	8,01	8,05	8.03–8,07	8,07	6–9	Primary

Notes: (P1) Utilization block; (P2) Rehabilitation block; (P3) Marine protection block; (P4) Traditional block.

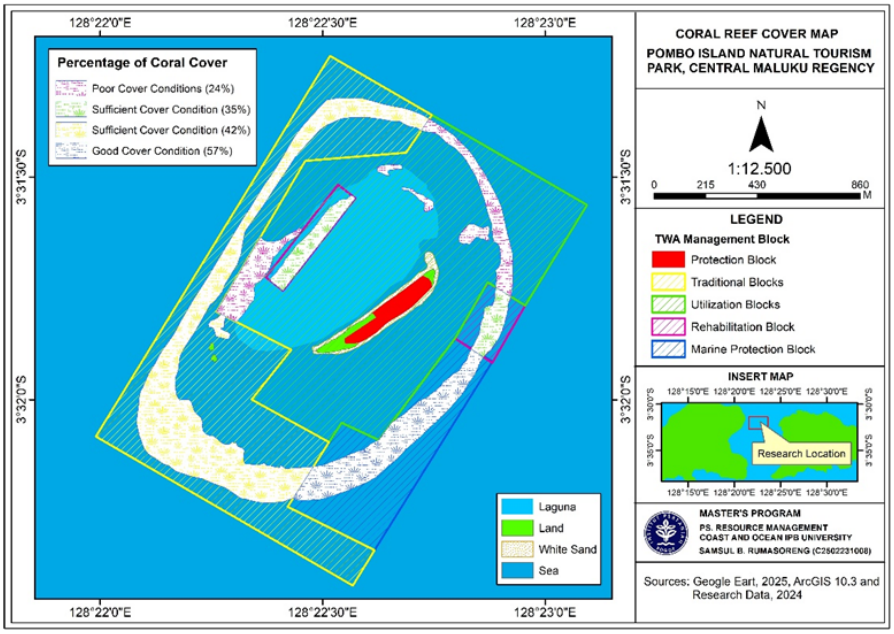


Figure 2. Percentage of live coral cover in each management block in Pombo Island Nature Tourism Park.

Coral reef cover in each management block has generally been damaged, ranging from good to poor. The decline in coral reef cover is strongly correlated with high utilization intensity and has continued over a long period (Noviana *et al.* 2019). This condition is reflected in the percentage of abiotic damage (coral fragments and sand sediment) found in each management block: 60% of the utilization block, 42% of the rehabilitation block, 26% of the marine protection block, and 50% of the traditional block (Figure 3).

The substrate conditions found at the research site were also confirmed by research conducted by the Wildlife Conservation Society *et al.* (2023), which found an average substrate composition of 11% sand, 26% hard coral, 5% soft coral, 25% algae, 5% other corals, and coral fragments comprising 28% of the total area of the Pombo Island coral reef ecosystem. The high percentage of coral fragments indicates physical factors affecting the coral reef, leading to its fracture.

Fishermen in the Pombo Island Nature Tourism Park area are known to use eight types of fishing gear, grouped into four categories based on their impact on the ecosystem: (1) very environmentally friendly, such as lines; (2) environmentally friendly, such as traps and surface gillnets; (3) destructive, such as nets and bottom gillnets; and (4) very destructive, such as the use of bombs, tranquilizers, and the "bameti" technique (collecting marine biota directly by hand when the sea water is low tide) (Latuconsina 2010). Recent research conducted by Lestaluhu (2023) found that on Pombo Island, bottom fishing gear and bottom nets are frequently used by locals to catch fish in coral reef areas. Fishing gear such as bottom nets used by fishermen can be classified as environmentally unfriendly because their use on reef fish targets located at the bottom of the coral reef substrate can cause damage, caused by the nets getting caught in branching corals, especially *Acropora* (Lestaluhu 2023). This damage hurts the Pombo Island Nature Tourism Park conservation area, which has been established by the government to protect marine biodiversity. It is crucial to implement regulations and policies aimed at reducing ongoing coral reef damage. Restoration measures must also be taken to restore the condition of damaged coral reef ecosystems (Ulfah *et al.* 2020).

Reef fish abundance

Reef fish are among the most dominant groups of marine organisms inhabiting coral reef ecosystems (Assyifa *et al.* 2023). The number of reef fish in the waters of Pombo Island Nature Tourism Park shows significant differences. A total of 49 reef fish species from 16 families were identified, with a total abundance of 2,545 individuals within the 1,500 m^2 observation area. Based on the results of observations at six stations spread across each management block, there were 18 species from 14 families with a total number of 376 individuals/250 m^2 in the utilization block (moderate species category), the rehabilitation block 21 species from 10 families with a total number of 529 individuals/250 m^2 (moderate species condition), the marine protection block 28 species from 15 families with a total number of 963 individuals/500 m^2 (moderate species condition), and the traditional block 22 species from 16 families with a total number of 610 individuals/500 m^2 (moderate species condition) (Figure 4). The overall abundance of species in the Pombo Island Nature Tourism Park is classified as very abundant based on the assessment indicators from Yulianda (2019).

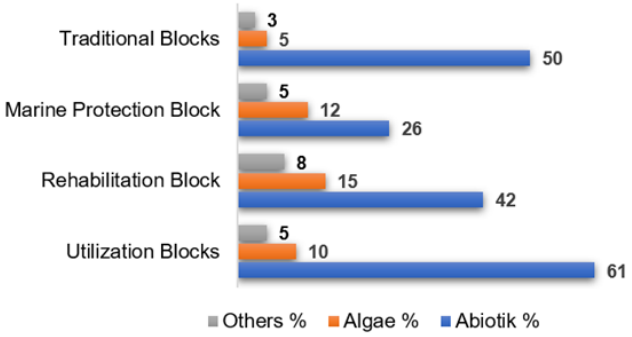


Figure 3. Percentage of substrate composition in Pombo Island Nature Tourism Park.

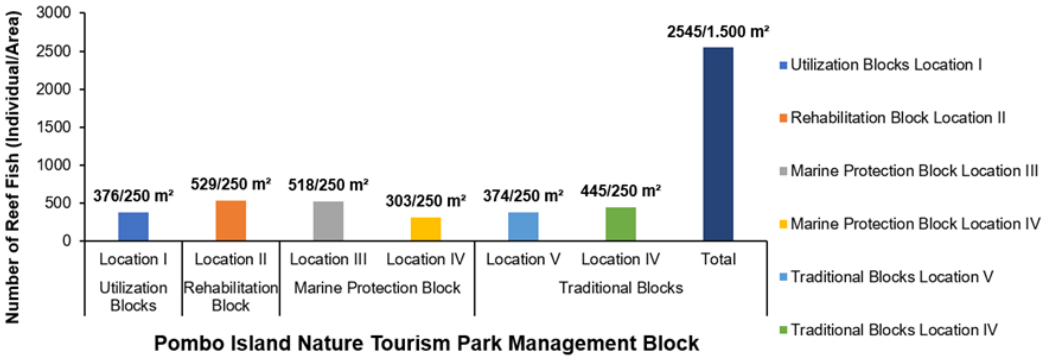


Figure 4. An abundance of coral fish in each management block in Pombo Island Nature Tourism Park.

A comparison of species abundance was conducted by the Indonesian Institute of Sciences (2014), which found 197 species from 30 families with a total of 2,170 individuals. Variations in reef fish species abundance reflect both the close relationship between habitat conditions and fishing intensity, as well as broader population declines driven by habitat destruction, limited ecosystem resilience, and overfishing pressure (Adiyoga *et al.* 2020; Ulfah *et al.* 2020).

Pressure on the coral reef ecosystem comes from irresponsible activities carried out by the local community around the Pombo Island Nature Tourism Park, particularly through the use of fishing gear that damages the coral reef ecosystem (Latuconsina 2010). In general, healthy coral reef conditions play a significant role in determining the level of reef fish abundance (Adiyoga *et al.* 2020). These results indicate that coral reefs are a marine ecosystem that plays a vital role in the life of marine life (Sudarmaji and Efendy 2021), as reef fish use coral reefs as feeding grounds, sheltering, spawning grounds, and nursery grounds (Armanto *et al.* 2022).

Functionally, the coral fish community still reflects a complete composition, encompassing major, indicator, and target fish groups, even though the coral reef ecosystem in the Pombo Island Nature Tourism Park has experienced significant levels of damage (Ampou *et al.* 2020). Target fish are high-value fish primarily caught for consumption, utilizing coral reefs as spawning and nursery grounds. This group includes the families Serranidae, Lutjanidae, Lethrinidae, Nemipteridae, Caesionidae, Siganidae, Haemulidae, Scaridae, and Acanthuridae. Meanwhile, indicator fish are typical coral reef-dwelling species that serve as markers of ecosystem fertility, such as the Chaetodontidae family. Major fish are small ornamental fish (5 to 25 cm) characterized by a variety of striking colors (English *et al.* 1997). Major fish groups generally have high abundance, both in terms of the number of individuals and the dominance of territorial species. Species in this group tend to settle permanently in coral reef ecosystems, such as the families Pomacentridae, Apogonidae, Labridae, and Blenniidae (Paulangan *et al.* 2019). Several target fish, major fish, and indicator fish found in the coral reef ecosystem in the waters of Pombo Island Nature Tourism Park are presented in Figure 5.

English *et al.* (1997) categorized reef fish into major fish, target fish, and indicator fish. Major fish found in the waters of Pombo Island Nature Park included 281 individuals from the family Pomacentridae, 12 individuals from Apogonidae, and 109 individuals from Labridae. The family Blenniidae was not found at all. Meanwhile, the target fish family consisted of 191 individuals from Serranidae, 153 individuals from Lutjanidae, 66 individuals from Lethrinidae, 96 individuals from Nemipteridae, 310 individuals from Caesionidae, 28 individuals from Siganidae, 94 individuals from Scaridae, and 359 individuals from Acanthuridae. The indicator fish family consisted of 135 individuals from the Chaetodontidae.

The family Chaetodontidae, as indicator fish, plays a crucial role in coral reef growth. Based on research by Titaheluw *et al.* (2015), increased coral reef cover shows a positive correlation with the presence of fish from the Chaetodontidae, which act as indicators of ecosystem condition. An increased number of live corals will result in abundant food availability for fish from the Chaetodontidae. This occurs because the optimal percentage of coral cover allows more coral polyps to survive, thus increasing the food source for these fish (Adiyoga *et al.* 2020). The decline in the quality of coral reef ecosystems, caused by natural factors and anthropogenic activities, can have a direct impact on shifting distribution patterns

and the distribution of reef fish. This decline in habitat quality impacts coral reef ecosystems, affecting the presence and diversity of reef fish that live within them.

Priority management strategy

The management of the Pombo Island Nature Tourism Park conservation area faces various complex problems, particularly those related to human activities and environmental pressures. Destructive practices such as the use of bombs, potassium, and "bameti" have been found within the Pombo Island Nature Tourism Park. This has undoubtedly damaged the coral reef ecosystem, a crucial habitat within the conservation area. Furthermore, a lack of effective monitoring and low public awareness of the importance of conservation often hampers preservation efforts. According to Latuconsina (2010), destructive activities can occur due to a lack of oversight by area managers, allowing the community to freely damage the coral reef ecosystem.

The identified problems were then clustered into several ecological problems. The ecological problem clusters in the management of Pombo Island Nature Tourism Park include coral reef ecosystem degradation (0.3652), a decline in the number of reef fish species (0.2355), declining water quality due to plastic waste pollution (0.1663), and the failure to implement the area's carrying capacity in management (0.2251). The rater agreement results showed a W value of 0.852, indicating that 85.2% of respondents agreed that the priority for managing ecological issues in the Pombo Island Nature Tourism Park area is addressing coral reef ecosystem degradation (Figure 6a). Healthy coral reefs can support marine biodiversity and provide a major attraction for underwater tourism (Permatasari *et al.* 2023).

In line with the problem clusters, alternative ecological solutions within the Pombo Island Nature Tourism Park conservation area management priorities include coral reef ecosystem restoration (0.4332), followed by an assessment of the area's carrying capacity (0.2640), education and collaboration with the surrounding community to prevent plastic waste (0.1527), and monitoring and enforcement (0.1425) (Figure 6b). All priority ecological solutions in this study were selected based on the consideration that each analyzed priority has a direct and indirect relationship and impact on the coral reef ecology in the waters of Pombo Island Nature Tourism Park. One of the main weaknesses in designing a marine conservation area management plan is the managers' limited capacity to conduct effective planning, especially in identifying problems, seeking alternative solutions, and setting priorities in management (Juliyanto *et al.* 2019).

Coral reef ecosystem restoration is a priority ecological strategy in the management of Pombo Island Nature Tourism Park. A collaborative coral reef transplantation approach with the local community could be an effective and long-term solution. Implementing this strategy not only supports the conservation area but also strengthens the well-being of local communities that depend on marine resources for their daily lives. This demonstrates that coral reef restoration is not only an ecological solution but also a crucial contribution to sustainability (Cabral and Geronimo 2018). Furthermore, an integrated approach involving stakeholders, such as relevant government agencies, local communities, and conservation organizations, is needed to support the success of the coral reef rehabilitation program and encourage the strengthening of socio-economic functions in the Pombo Island Nature Tourism Park conservation area.

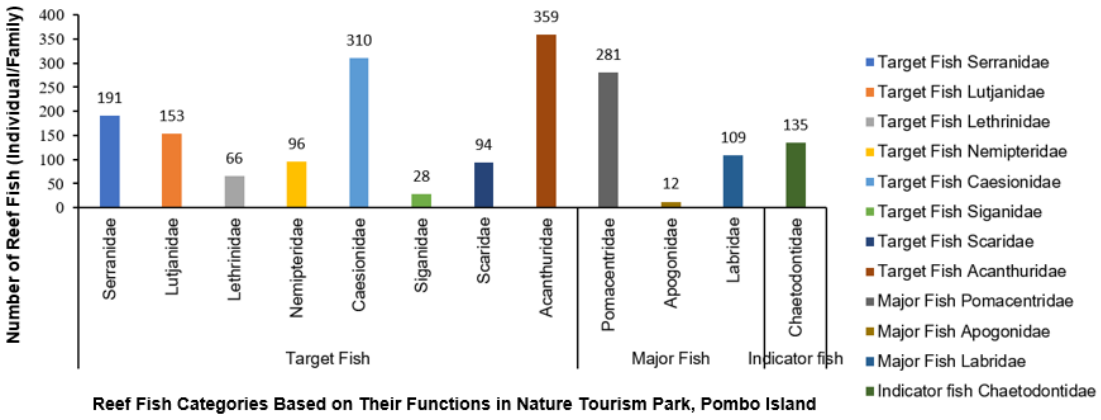
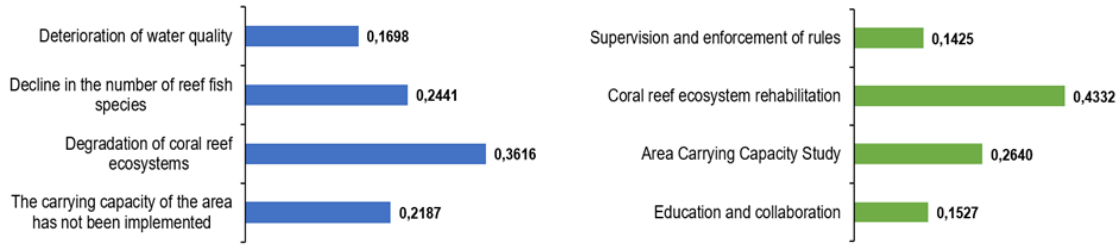


Figure 5. Number of individual coral fish based on their role in Pombo Island Nature Tourism Park.



(a) (b)

Figure 6. Ecological problem cluster (a), and ecological solution cluster (b) in Pombo Island Nature Tourism Park.

CONCLUSION

The current condition of the coral reef ecosystem in Pombo Island Nature Tourism Park indicated that water quality remains good enough to support ecological functions, with an average live coral cover of 47.75% (fair). The highest coral cover was found in the marine protection block at 57% (good), while the lowest was in the utilization block at 24% (poor). The abundance of reef fish was recorded at 2,545 individuals/1,500 m², consisting of 49 species from 16 families, with the highest abundance in the marine protection block and the lowest in the utilization block. Based on these conditions, the priority management strategy is directed at ecosystem restoration through collaborative coral transplantation involving the community, especially in the utilization and rehabilitation blocks, to support the sustainability of the coral reef ecosystem.

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