

Baseline assessment of target macrozoobenthos assemblages in the Tanjung Palas Timur Marine Protected Area, Indonesia

^{1,2}Encik Weliyadi, ¹Sutrisno Anggoro, ¹Haeruddin, ¹Suradi, ³Muhammad Najib, ⁴Fahyuni Amaliah, ²Ardy A. B. Kase, ²Muhammad Y. Yusuf, ⁵Burhanuddin Ihsan, ⁶Mohammad F. Akhmadi

¹ Aquatic Resources Management Doctoral Study Program, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Semarang, Indonesia; ² Department of Aquatic Resource Management, Faculty of Fisheries and Marine Sciences, University of Borneo Tarakan, Indonesia;

³ Head of Marine Spatial Management, Ministry of Maritime Affairs and Fisheries, North Kalimantan, Indonesia; ⁴ Marine and Coastal Ecosystem Management, Ministry of Maritime Affairs and Fisheries, North Kalimantan, Indonesia; ⁵ Department Aquaculture, Faculty of Fisheries and Marine Science, Borneo University, Indonesia;

⁶ Department Fisheries Product Technology, Faculty of Fisheries and Marine Science, Borneo University, Indonesia. Corresponding author: M. F. Akhmadi, adnan_ub@borneo.ac.id

Abstract. Macrozoobenthos are useful indicators of local habitat and environmental conditions because of their close association with benthic substrates and limited mobility. This study assessed target macrozoobenthos assemblages in the core zone of the Tanjung Palas Timur Marine Protected Area, North Kalimantan, Indonesia, using coral assemblage composition and water-quality conditions as supporting ecological context. Surveys were conducted at six observation stations from 30 July to 3 August 2025. Target macrozoobenthos were recorded using underwater visual census along one 50-m belt transect per station, covering 250 m² at each station. Coral assemblages were documented using the underwater photo transect method, while water-quality parameters were measured at station level. A total of 62 individuals from five target macrozoobenthos groups were recorded. Giant clams were the most abundant group and occurred at all stations, while sea cucumbers, sea urchins, crown-of-thorns starfish, and triton shells showed more restricted distributions. Target macrozoobenthos diversity was generally low, although Stations III and V showed comparatively higher abundance, diversity, or more balanced assemblage structure than the other stations. The related coral dataset documented 40 coral species and was used as supporting habitat context rather than as the primary focus of the study. Reef-slope stations generally showed higher live coral cover and tended to support higher target macrozoobenthos abundance or lower dominance than rubble- and sand-dominated stations. Exploratory PCA separated stations mainly along gradients of target macrozoobenthos abundance, diversity, dominance, and coral species richness. Exploratory Spearman analysis did not show statistically significant relationships and was interpreted only as station-level tendencies. Overall, this study provides an initial baseline for target macrozoobenthos monitoring in KKPTPT and highlights the need for replicate transects, seasonal surveys, direct habitat-complexity measurements, sediment assessment, and size-structure monitoring of key taxa such as giant clams.

Keywords: baseline monitoring, coral habitat context, giant clams, marine protected area, North Kalimantan, target macrozoobenthos.

Introduction. Macrozoobenthos are important components of benthic ecosystems because they contribute to organic-matter processing, nutrient cycling, and sediment remineralization. Their limited mobility and close association with benthic substrates make them useful indicators of local habitat and environmental conditions (Crespo & Pardal, 2020; Aulia et al., 2024). In reef-associated habitats, field-based macrozoobenthos surveys remain important because they provide direct information on abundance, assemblage structure, and ecological indices that can be linked to station-

level habitat conditions. Such information is particularly valuable in newly surveyed marine protected areas, where baseline data are often limited and management decisions require practical indicators that can be repeatedly monitored.

Coral reef habitats can influence macrozoobenthos assemblages by providing substrate heterogeneity, shelter, feeding areas, and settlement surfaces for reef-associated invertebrates. Live coral cover, coral assemblage composition, rubble, sand, and other benthic substrates may create different habitat conditions across reef stations. However, coral richness alone may not fully explain macrozoobenthos patterns because benthic assemblages are also shaped by substrate stability, hydrodynamic exposure, sedimentation, and water-quality conditions (Burns et al., 2019; Otaño-Cruz et al., 2019; Wakwella et al., 2020). Therefore, coral data are most useful when interpreted as habitat context rather than as a single direct predictor of macrozoobenthos distribution.

Water-quality conditions provide an additional layer of interpretation for reef-associated benthic communities. Parameters such as dissolved oxygen, pH, suspended solids, salinity, and current exposure can influence habitat suitability, sediment dynamics, and the distribution of benthic organisms. In coral reef and reef-margin ecosystems, short-term water-quality measurements cannot fully represent long-term environmental pressure, but they can provide important supporting information for interpreting biological patterns. For this reason, macrozoobenthos data should be evaluated together with coral habitat context and station-level environmental conditions rather than treated as isolated biological observations (Isdianto et al., 2023; Khasanah et al., 2024; RabiYanti et al., 2025).

Tanjung Palas Timur Marine Protected Area, locally known as KKPTPT, is a newly designated conservation area in North Kalimantan Province, Indonesia. The area is located approximately 10 nautical miles from the coastline and was officially established under the Ministerial Decree of Marine Affairs and Fisheries No. 28 of 2022. Although macrozoobenthos and coral reef conditions have been studied in several Indonesian coastal and reef systems, station-level information on target macrozoobenthos assemblages within the newly established KKPTPT core zone remains limited. This gap is important because early monitoring in a new marine protected area requires site-specific information on spatial variation among stations, rather than only broad descriptions of reef condition.

The novelty of this study lies in providing an initial station-based assessment of target macrozoobenthos assemblages in the KKPTPT core zone and interpreting these data together with coral assemblage composition and water-quality conditions from the same survey framework. Compared with more general reef assessments, this study focuses on target macrozoobenthos groups that can be monitored consistently using underwater visual census and linked with supporting coral and environmental information. This approach provides a practical baseline for identifying stations with different ecological characteristics and for guiding future monitoring design in a newly established marine protected area.

We expected that stations with higher coral habitat quality and more favourable environmental conditions would support higher target macrozoobenthos abundance, richness, or more balanced assemblage structure. Therefore, this study aimed to: (1) characterize the composition and spatial distribution of target macrozoobenthos assemblages across six observation stations; (2) describe coral assemblage composition as supporting habitat context; (3) evaluate station-level water-quality conditions; and (4) explore relationships among target macrozoobenthos, coral habitat context, and environmental variables. The study provides practical baseline information for future monitoring of KKPTPT and contributes site-specific ecological data from a newly established marine protected area in North Kalimantan.

Material and Method

Study area and sampling period. This study was conducted from 30 July to 3 August 2025 in the core zone of the Tanjung Palas Timur Marine Protected Area (KKPTPT), Bulungan Regency, North Kalimantan Province, Indonesia (Figure 1). The same station framework as the related KKPTPT baseline survey was used, while the present manuscript focused on target macrozoobenthos assemblages and their relationship with coral reef composition and environmental conditions (Mellin et al., 2016).

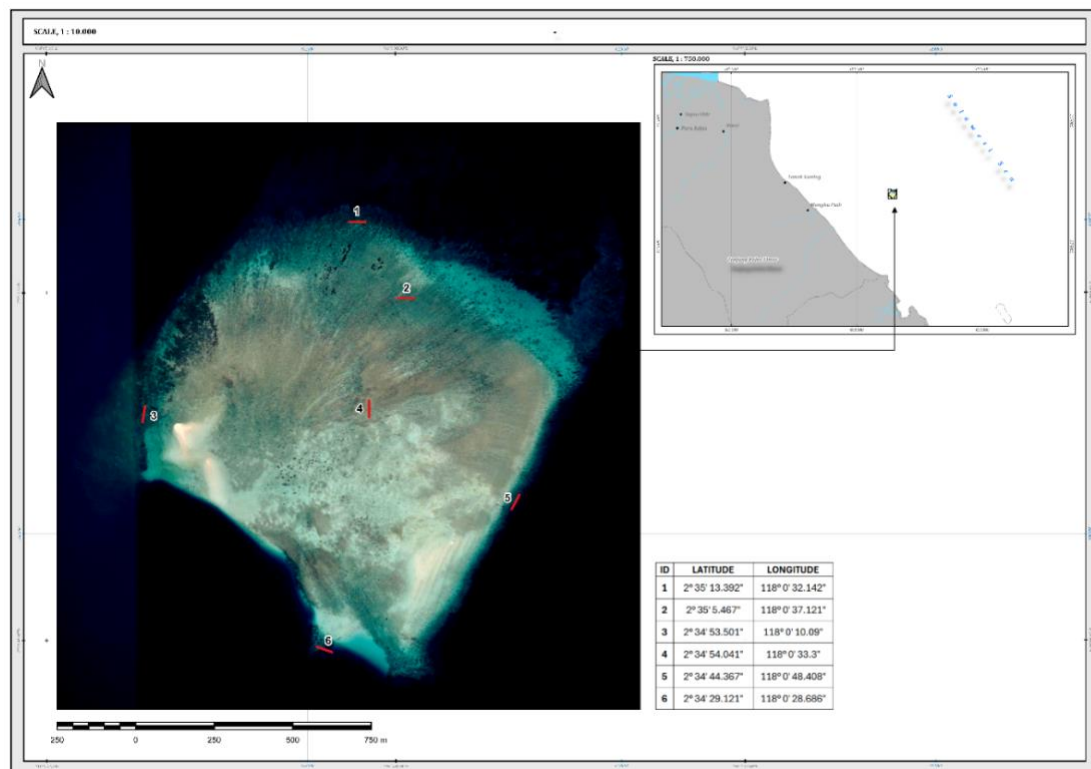


Figure 1. Map of the study area and sampling stations in the core zone of the Tanjung Palas Timur Marine Protected Area, North Kalimantan, Indonesia.

Six observation stations were selected within the core zone of KKPTPT to represent the main reef-associated habitat characteristics observed in the study area. Station I was located at 2°35'13.2"N, 118°0'32.4"E and represented a reef-slope habitat dominated by hard and soft corals at approximately 8 m depth. Station II was located at 2°35'06.0"N, 118°0'36.0"E and was dominated by coral rubble at approximately 4 m depth. Station III was located at 2°34'55.2"N, 118°0'10.8"E and represented a reef-slope habitat dominated by hard corals at approximately 6-7 m depth. Station IV was located at 2°34'55.2"N, 118°0'32.4"E and was dominated by coral rubble at approximately 3-4 m depth. Station V was located at 2°34'44.4"N, 118°0'46.8"E and represented a reef-slope habitat dominated by hard corals at approximately 7-8 m depth. Station VI was located at 2°34'30.0"N, 118°0'28.8"E and was dominated by sandy substrate at approximately 3 m depth. At each station, target macrozoobenthos assemblages were recorded, while coral reef composition and water-quality parameters were used as supporting ecological context (Isdianto et al., 2023; Khasanah et al., 2024; RabiYanti et al., 2025).

Research equipment. The equipment used in this study included SCUBA diving equipment, compressed-air cylinders, an underwater digital camera, a 50-m roll meter, an underwater slate, waterproof writing tools, and a 58 × 44 cm underwater photo frame. Temperature, salinity, pH, and dissolved oxygen were measured in situ using a calibrated YSI multiparameter probe. Total suspended solids were determined gravimetrically from 1-L water samples filtered through pre-weighed GF/C filters and

oven-dried at 105°C. Current velocity was measured using a flow meter at three points per station. Depth values refer to the approximate diving depth at each observation station and were used as supporting habitat information.

Sampling design and macrozoobenthos data collection. Macrozoobenthos were surveyed using the Underwater Visual Census method at the same stations used for coral reef observations. At each station, one 50-m transect was laid parallel to the shoreline or reef contour. Target macrozoobenthos were recorded within a belt transect extending 2.5 m to the left and 2.5 m to the right of the transect line, resulting in a total observation width of 5 m and an estimated surveyed area of 250 m² per station. Macrozoobenthos abundance was therefore expressed as the total number of individuals recorded per 250 m² belt transect at each station. All observed target macrozoobenthos were counted by taxon and station (Crespo & Pardal, 2020; Gopal et al., 2020; Khasanah et al., 2024).

Target taxa were classified following the Reef Check protocol. The present analysis focused on benthic target macrozoobenthos groups recorded in the manuscript, including *Diadema* spp. and *Echinothrix* spp. as sea urchins, holothurians as sea cucumbers, *Acanthaster planci* as crown-of-thorns starfish, *Charonia tritonis* as triton shells, and *Tridacna* spp. as giant clams with shell length > 10 cm. Taxonomic identification was carried out in the field based on external morphological characteristics and was supported by underwater photographs when confirmation was required. Because the survey was designed as an initial baseline assessment and logistical constraints limited within-site replication, one transect was surveyed per station; this limitation was considered in the interpretation of the exploratory statistical analyses.

Coral reef data collection. Coral reef composition and benthic cover were assessed using the Underwater Photo Transect method. At each station, a 50-m transect was laid parallel to the coastline or reef contour to capture representative benthic conditions. Benthic photographs were taken alternately on the left side at odd-numbered metre points and on the right side at even-numbered metre points using a 58 × 44 cm photo frame. This procedure generated 50 photographic quadrats per station. This systematic photographic record was used to describe coral reef composition and to provide supporting habitat context for interpreting macrozoobenthos assemblage patterns (Burns et al., 2019).

Coral taxa and benthic categories were identified from the photographs using Coral Point Count with Excel extensions (CPCe) version 4.1 (Kohler & Gill, 2006). A 50-point random grid was applied to each photograph. The analysed benthic categories followed Reef Check guidelines and included hard coral, soft coral, sponge, recent dead coral, dead coral with algae, fleshy seaweed, rubble, sand, silt, rock, and other biota. Live coral cover values from the same station framework were used only as supporting habitat context and were cited from the related baseline study conducted in the KKPTPT core zone. The present manuscript retained macrozoobenthos assemblages as its primary focus (Burns et al., 2019; Weliyadi et al., 2025).

Water-quality measurement. Water-quality parameters were measured at each observation station to describe the environmental conditions associated with macrozoobenthos assemblages. The measured water-quality parameters included temperature, salinity, dissolved oxygen, pH, total suspended solids, and current velocity. Depth was recorded as supporting station-level habitat information. Station-level water-quality data from the same survey framework were incorporated as supporting environmental context, while the present study focused specifically on target macrozoobenthos assemblages. Temperature, salinity, pH, and dissolved oxygen were measured using a calibrated YSI multiparameter probe; TSS was determined gravimetrically; and current velocity was measured using a flow meter at three points per station (Otaño-Cruz et al., 2019; Wakwella et al., 2020; Isdianto et al., 2023; Rabiyaniti et al., 2025).

Temperature, salinity, dissolved oxygen, and pH were used to describe the general physicochemical condition of the water column. Total suspended solids were used as an

indicator of suspended particulate matter and potential sediment-related stress. Current velocity and depth were recorded to support the interpretation of hydrodynamic exposure and habitat characteristics. Depth was reported in metres, and station-level environmental values were used to avoid relying only on broad parameter ranges.

Data analysis. Macrozoobenthos assemblages were assessed using target-group richness, abundance, the Shannon-Wiener diversity index (H'), Pielou's evenness index (E), and Simpson's dominance index (D) to describe station-level variation in diversity, evenness, and dominance. Diversity was classified as low when $H' < 1$, moderate when $1 < H' \leq 3$, and high when $H' \geq 3$. Evenness was considered low at $0 < E \leq 0.5$, moderate at $0.5 < E \leq 0.75$, and high at $0.75 < E \leq 1$. Dominance was interpreted as low at $0 < D < 0.5$ and high at $0.5 < D \leq 1$. Because the survey focused on selected Reef Check-oriented target macrozoobenthos groups rather than a complete inventory of all benthic invertebrates, all diversity metrics were interpreted as indicators of the target macrozoobenthos assemblage (Odum, 1971).

Environmental parameters, including temperature, salinity, dissolved oxygen, pH, total suspended solids, depth, and current velocity, were used to support the interpretation of macrozoobenthos and coral reef composition patterns. Descriptive statistics were applied to summarize biological and environmental variables among stations. Because the study used one transect per station and six stations in total, station-level variation was interpreted descriptively and cautiously rather than as evidence of statistically tested differences among stations (Gopal et al., 2020; Wakwella et al., 2020; Isdianto et al., 2023).

Spearman rank correlation was used to examine potential exploratory trends among macrozoobenthos indices, coral species richness, live coral cover as supporting habitat context, and water-quality variables. This non-parametric approach was selected because the dataset was based on a limited number of observation stations and did not meet the assumptions required for more complex parametric modelling. Principal Component Analysis was used as an exploratory ordination technique to visualize station-level patterns based on target macrozoobenthos groups, total abundance, target-group richness, ecological indices, and coral species richness as supporting habitat context. Variables included in the PCA were centred and scaled before analysis to reduce the influence of different measurement units. Because the analysis was based on six stations, PCA was interpreted only as an exploratory visualization rather than confirmatory evidence of ecological separation (Gopal et al., 2020).

Because the statistical analyses were based on six observation stations, the PCA and Spearman correlation results were interpreted cautiously as exploratory tendencies rather than confirmatory evidence of strong ecological relationships or causality (Gopal et al., 2020; Aulia et al., 2024). All analyses were conducted in WEB R version 4.4.1 using the Hmisc, corrplot, FactoMineR, factoextra, and ggplot2 packages, while Microsoft Excel was used for preliminary data organization.

Ethical and permit statement. This study was conducted as a non-destructive underwater visual survey within the Tanjung Palas Timur Marine Protected Area. No organisms were collected, handled, removed, or sacrificed during the survey. Field observations were limited to in situ visual census, underwater photographic documentation, and measurement of environmental parameters.

Results and Discussion

Macrozoobenthos assemblage composition and spatial distribution. A total of 62 individuals from five target macrozoobenthos groups were recorded across six observation stations in the core zone of the Tanjung Palas Timur Marine Protected Area (KKPTPT). The recorded groups consisted of *Diadema*/*Echinothrix* sea urchins, sea cucumbers, crown-of-thorns starfish, triton shells, and giant clams. Abundance was expressed as the number of individuals recorded within a 250 m² belt transect at each station. Target macrozoobenthos abundance varied among stations, with the highest

value at Station V and the lowest value at Station II (Table 1; Figure 2). This station-level pattern indicates spatial heterogeneity in the distribution of target macrozoobenthos within the KKPTPT core zone and may reflect differences in reef-associated habitat context, live coral cover, substrate composition, depth, and local environmental conditions (Gopal et al., 2020; Ariaz et al., 2024; Aulia et al., 2024).

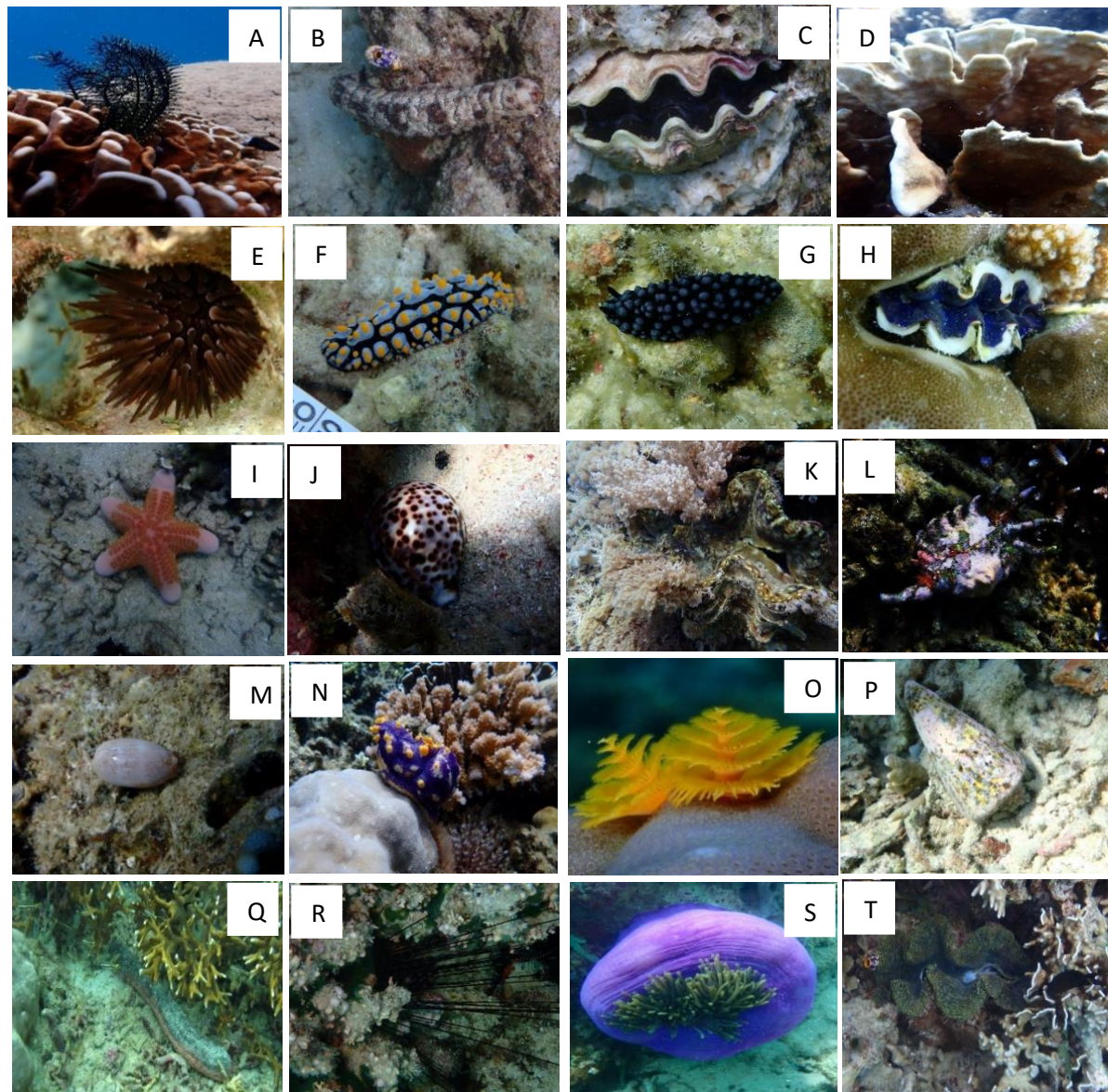


Figure 2. Representative reef-associated macrozoobenthos and benthic organisms documented during the underwater visual census in the KKPTPT core zone. A. *Anneissia bennetti*, B. *Pearsonothuria graeffei*, C. *Tridacna crosea*, D. *Tesseropora wireni*, E. *Echinometra mathaei*, F. *Phyllidia Varicosa*, G. *Phyllidiella nigra*, H. *Tridacna maxima*, I. *Choriaster granulatus*, J. *Cypraea tigris*, K. *Hippopus hippopus*, L. *Lambis millepeda*, M. *Luria isabella*, N. *Polycarpa aurata*, O. *Spirobranchus giganteus*, P. *Conus chaldaeus*, Q. *Holothuria edulis*, R. *Echinothrix diadema*, S. *Radianthus magnifica*, T. *Tridacna gigas*.

Stations located on reef-slope or hard-coral-dominated habitats, particularly Stations III and V, tended to support higher target-group richness, abundance, or more balanced assemblage structure than rubble- or sand-dominated stations. This pattern may reflect differences in habitat structure and substrate composition rather than directly measured microhabitat quality. Therefore, interpretations related to habitat complexity, shelter availability, or substrate stability are presented cautiously because rugosity, sediment grain size, three-dimensional complexity, and substrate stability were not directly quantified in this study. Reef-associated benthic assemblages are known to respond to

substrate condition, sediment exposure, hydrodynamic setting, and habitat structure, but such mechanisms require direct habitat measurements for confirmation (Richardson et al., 2017; Burns et al., 2019; Otaño-Cruz et al., 2019; Gopal et al., 2020; Mazzuco et al., 2020; Wakwella et al., 2020; Aulia et al., 2024). The recorded organisms were grouped into five target macrozoobenthos categories following a Reef Check-oriented approach: *Diadema*/*Echinothrix* sea urchins, sea cucumbers, crown-of-thorns starfish, triton shells, and giant clams (Table 1). This grouping provides an appropriate framework for baseline monitoring because these taxa represent ecologically relevant reef-associated invertebrates and can be consistently observed using underwater visual census (Hodgson et al., 2016).

Table 1

Counts of target macrozoobenthos groups recorded within a 250 m² belt transect at each observation station

Target macrozoobenthos group	Station I	Station II	Station III	Station IV	Station V	Station VI	Total
<i>Diadema</i> / <i>Echinothrix</i> sea urchins	1	1	0	2	3	1	8
Sea cucumbers	3	0	3	0	2	1	9
Crown-of-thorns starfish	0	0	1	0	1	0	2
Triton shells	0	0	1	0	0	0	1
Giant clams	8	3	8	7	10	6	42
Total individuals per 250 m ²	12	4	13	9	16	8	62

Note: Values represent total individuals recorded within one 250 m² belt transect at each station.

This grouping provides a clearer ecological interpretation because these organisms represent different functional roles in reef ecosystems. *Diadema* sea urchins are associated with grazing pressure and algal control; sea cucumbers contribute to detrital processing and sediment bioturbation; crown-of-thorns starfish indicate potential coral predation pressure; triton shells are important predators of crown-of-thorns starfish; and giant clams represent reef-associated bivalves that depend on suitable substrate, light availability, and relatively stable coral habitat conditions (Hodgson et al., 2016; Crespo & Pardal, 2020; Liu et al., 2021; Abdelmeneam et al., 2024).

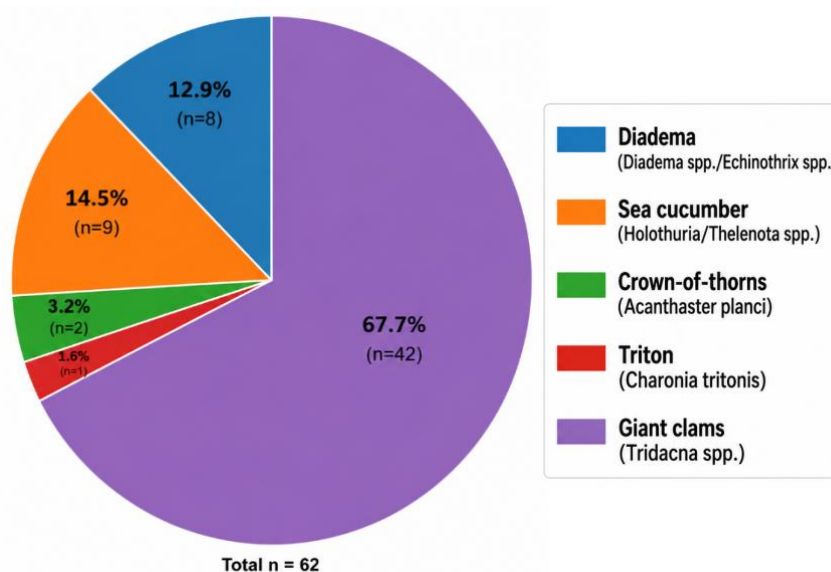


Figure 3. Relative abundance of target macrozoobenthos groups recorded across all observation stations.

Target macrozoobenthos abundance ranged from 4 to 16 individuals per 250 m² belt transect. Station V recorded the highest abundance (16 individuals per 250 m²), followed by Station III (13 individuals per 250 m²), Station I (12 individuals per 250 m²), Station IV (9 individuals per 250 m²), Station VI (8 individuals per 250 m²), and Station II (4 individuals per 250 m²). These values describe baseline station-level counts rather than statistically tested differences among stations because only one transect was surveyed at each station. Giant clams were the most abundant target group, contributing 42 individuals or approximately 67.7% of the total count. Their occurrence at all stations suggests that reef-associated substrates suitable for giant clams may remain available across parts of the KKPTPT core zone. However, their high proportional contribution also indicates an uneven target assemblage. Giant clams are ecologically important reef-associated bivalves that can contribute to reef functioning and provide settlement surfaces for other organisms, but their abundance should be interpreted together with richness, evenness, dominance, recruitment, size structure, and habitat condition rather than as a single indicator of reef health (Neo et al., 2015; Mehrotra et al., 2021; Mehrotra et al., 2022). Sea cucumbers were recorded at Stations I, III, V, and VI, while *Diadema/Echinothrix* sea urchins were recorded at five stations. Crown-of-thorns starfish occurred only at Stations III and V, and triton shells were recorded only at Station III. These occurrences provide useful baseline information for future monitoring of reef-associated target invertebrates. However, no strong inference on grazing pressure, coral predation, or predator-prey dynamics can be made from the present dataset because the counts were low and the survey represented a single sampling period.

Overall, the distribution of target macrozoobenthos in KKPTPT indicates station-level variation in reef-associated habitat context. Reef-slope stations generally supported higher abundance or broader target-group representation than rubble- or sand-dominated stations. However, the assemblage was numerically dominated by giant clams, indicating that abundance patterns should be interpreted together with richness, evenness, dominance, coral reef composition, and water-quality context. Such integration is important for newly designated marine protected areas because baseline monitoring should provide information not only on organism occurrence but also on the ecological setting that may influence station-level assemblage patterns.

Ecological indices and dominance patterns. The Shannon-Wiener diversity index (H') ranged from 0.53 to 1.04, indicating that target macrozoobenthos diversity remained low at most stations, with Stations III and V approaching the moderate category (Table 2). Evenness ranged from 0.67 to 0.81, while dominance ranged from 0.44 to 0.65. These values indicate that the assemblage was generally characterized by low diversity and uneven numerical representation among target groups.

Table 2

Ecological indices of target macrozoobenthos assemblages

<i>Index</i>	<i>Station I</i>	<i>Station II</i>	<i>Station III</i>	<i>Station IV</i>	<i>Station V</i>	<i>Station VI</i>
Target-group richness	3	2	4	2	4	3
Total abundance	12	4	13	9	16	8
Shannon diversity index (H')	0.82	0.56	1.03	0.53	1.04	0.74
Evenness index (E)	0.75	0.81	0.74	0.76	0.75	0.67
Dominance index (D)	0.51	0.63	0.44	0.65	0.45	0.59

Note: Indices were calculated using five target macrozoobenthos groups: *Diadema/Echinothrix* sea urchins, sea cucumbers, crown-of-thorns starfish, triton shells, and giant clams.

Stations III and V showed the highest diversity values, with H' values of 1.03 and 1.04, respectively. These stations also had lower dominance values ($D = 0.44$ - 0.45), indicating a comparatively more balanced target assemblage than the other stations. This pattern is consistent with their reef-slope habitat context and higher live coral cover, although direct habitat-complexity measurements were not available. Stations I, II, IV, and VI had lower diversity values, ranging from 0.53 to 0.82, and higher dominance values, ranging

from 0.51 to 0.65. Station IV showed the lowest diversity and highest dominance, whereas Station II showed low abundance and relatively high dominance. These patterns suggest a less even distribution of target groups at these stations. However, the interpretation is descriptive because the survey did not include replicate transects or direct measurements of substrate complexity. The low diversity values should be interpreted as an initial baseline rather than definitive evidence of ecological degradation. Macrozoobenthos diversity in reef-associated habitats can be influenced by habitat structure, sediment condition, hydrodynamic exposure, water quality, biological interactions, and sampling scale. Because the survey focused on selected target groups rather than a full inventory of all benthic invertebrates, the diversity values represent the structure of target macrozoobenthos assemblages and should be compared carefully with studies using different taxonomic scopes or sampling methods. Dominance patterns provide useful information for monitoring because they show whether the assemblage is evenly distributed or numerically controlled by a limited number of target groups. In this study, giant clams contributed strongly to total abundance, particularly at stations with low richness or low abundance of other groups. Therefore, total abundance should not be interpreted alone; richness, evenness, and dominance need to be evaluated together in future monitoring. The ecological index results support the use of target macrozoobenthos as one component of reef monitoring in KKPTPT. Macrozoobenthos can respond to substrate condition, sedimentation, hydrodynamic exposure, and water quality, making them useful indicators when interpreted together with habitat and environmental variables (Crespo & Pardal, 2020; Wang et al., 2022; Khasanah et al., 2024; Rabiyyanti et al., 2025).

Coral assemblage and habitat context. The related KKPTPT baseline survey documented 40 coral species across the same station framework (Table 3). In the present study, the coral dataset was used as supporting habitat context for interpreting target macrozoobenthos patterns. Coral species richness varied among stations, with the highest value at Station I and the lowest value at Station V (Table 3). This result indicates that coral species richness alone did not follow the same pattern as target macrozoobenthos abundance. For example, Station V had the highest target macrozoobenthos abundance but relatively low coral species richness.

Live coral cover provided an additional habitat context. Reef-slope stations, particularly Stations I, V, and III, had higher live coral cover than rubble- and sand-dominated stations based on the related KKPTPT baseline survey. This pattern may help explain why Stations III and V supported higher target macrozoobenthos abundance or more balanced assemblage structure. Nevertheless, coral cover was used as a contextual variable because direct measurements of rugosity, three-dimensional structural complexity, and substrate stability were not available. Coral species richness alone did not fully explain macrozoobenthos distribution. Station I had the highest coral species richness, whereas Station V had the highest target macrozoobenthos abundance. This contrast indicates that target macrozoobenthos distribution is likely influenced by multiple interacting factors, including live coral cover, substrate type, depth, food availability, and species-specific habitat requirements (Otaño-Cruz et al., 2019; Gopal et al., 2020; Wakwella et al., 2020; Ariaz et al., 2024).

Station II recorded the lowest target macrozoobenthos abundance and had low live coral cover. This pattern may reflect the coral-rubble habitat context recorded at this station. Rubble habitats can support benthic organisms, but their ecological role depends on consolidation, sediment cover, algal development, and hydrodynamic disturbance. Because these variables were not directly measured, the interpretation is limited to a cautious station-level explanation. Acropora was the most species-rich genus recorded across the station framework. This interpretation is more appropriate than referring to Acropora as the dominant genus because dominance requires quantitative abundance, frequency, or cover data by taxon. Coral assemblage composition, life-form structure, and live coral cover can influence reef habitat architecture, but habitat complexity is not determined by coral richness alone. Previous studies show that coral morphology, live cover, and substrate rugosity contribute to reef structural complexity and influence

associated reef organisms (Darling et al., 2017; Richardson et al., 2017; Burns et al., 2019). The relationship between coral reef composition and target macrozoobenthos was not uniform across stations. Coral richness, live coral cover, and macrozoobenthos abundance showed different station-level patterns. Therefore, coral and macrozoobenthos data should be interpreted as complementary ecological indicators, not interchangeable measures of reef condition (Gopal et al., 2020; Isdianto et al., 2023; Khasanah et al., 2024; RabiYanti et al., 2025).

Table 3

Distribution of coral species recorded at each observation station and used as supporting habitat context for the target macrozoobenthos assessment

No.	Genus	Species	Station I	Station II	Station III	Station IV	Station V	Station VI
1	<i>Acropora</i>	<i>Acropora cytherea</i>	–	–	+	–	–	+
2	<i>Acropora</i>	<i>Acropora digitifera</i>	–	–	–	+	–	–
3	<i>Acropora</i>	<i>Acropora gemmifera</i>	–	+	–	+	–	–
4	<i>Acropora</i>	<i>Acropora hyacinthus</i>	+	–	+	–	+	–
5	<i>Acropora</i>	<i>Acropora kimbeensis</i>	+	–	–	–	–	–
6	<i>Acropora</i>	<i>Acropora microphthalma</i>	+	–	–	–	–	–
7	<i>Acropora</i>	<i>Acropora millepora</i>	–	–	–	+	–	+
8	<i>Acropora</i>	<i>Acropora nasuta</i>	+	–	–	+	–	–
9	<i>Acropora</i>	<i>Acropora parilis</i>	+	–	+	–	–	–
10	<i>Acropora</i>	<i>Acropora secale</i>	–	–	+	–	–	–
11	<i>Acropora</i>	<i>Acropora spathulata</i>	–	–	–	+	–	–
12	<i>Acropora</i>	<i>Acropora subulata</i>	+	–	–	–	–	–
13	<i>Acropora</i>	<i>Acropora vermiculata</i>	+	–	–	–	–	–
14	<i>Echinopora</i>	<i>Echinopora lamellosa</i>	+	–	–	–	–	–
15	<i>Favia</i>	<i>Favia helianthoides</i>	–	+	–	–	–	–
16	<i>Favites</i>	<i>Favites flexuosa</i>	–	–	–	+	–	–
17	<i>Fungia</i>	<i>Fungia fungites</i>	–	–	+	–	–	–
18	<i>Galaxea</i>	<i>Galaxea fascicularis</i>	+	+	–	–	–	–
19	<i>Goniastrea</i>	<i>Goniastrea aspera</i>	+	–	–	–	–	–
20	<i>Goniastrea</i>	<i>Goniastrea favulus</i>	–	–	–	–	–	+
21	<i>Goniastrea</i>	<i>Goniastrea pectinata</i>	+	–	–	–	–	–
22	<i>Herpolitha</i>	<i>Herpolitha limax</i>	+	–	–	–	–	–
23	<i>Leptoria</i>	<i>Leptoria phrygia</i>	+	–	–	–	–	–
24	<i>Lobophyllia</i>	<i>Lobophyllia robusta</i>	+	–	–	–	–	–
25	<i>Montipora</i>	<i>Montipora capitata</i>	+	–	–	–	–	–
26	<i>Montipora</i>	<i>Montipora digitata</i>	–	–	+	+	–	–
27	<i>Montipora</i>	<i>Montipora porites</i>	–	+	–	–	–	–
28	<i>Montipora</i>	<i>Montipora samarensis</i>	–	–	–	+	–	–
29	<i>Montipora</i>	<i>Montipora stilosa</i>	–	+	–	–	–	–
30	<i>Oulophyllia</i>	<i>Oulophyllia levis</i>	–	–	+	–	–	–
31	<i>Pachyseris</i>	<i>Pachyseris rugosa</i>	–	–	+	–	–	+
32	<i>Pachyseris</i>	<i>Pachyseris speciosa</i>	+	–	–	–	+	–
33	<i>Pavona</i>	<i>Pavona maldivensis</i>	+	–	–	–	–	–
34	<i>Platygyra</i>	<i>Platygyra verweyi</i>	–	–	–	+	–	–
35	<i>Pocillopora</i>	<i>Pocillopora damicornis</i>	+	+	–	+	–	+
36	<i>Pocillopora</i>	<i>Pocillopora meandrina</i>	–	+	–	–	+	–
37	<i>Pocillopora</i>	<i>Pocillopora verrucosa</i>	+	–	+	–	–	–
38	<i>Porites</i>	<i>Porites cylindrica</i>	+	–	–	–	+	+
39	<i>Porites</i>	<i>Porites lobata</i>	+	+	+	+	+	–
40	<i>Porites</i>	<i>Porites lutea</i>	–	–	–	+	–	–
		Total species per station	21	8	10	12	5	6

Note: Coral species data were adopted from the related Biodiversitas baseline survey conducted using the same KKPTPT station framework. These data are used here as supporting habitat context. Source: Weliyadi et al., (2025).

Water-quality conditions. Water-quality parameters provided supporting environmental context for the macrozoobenthos survey. Station-level values are presented in Table 4 to improve clarity and avoid relying only on broad parameter ranges. The values presented in Table 4 represent station-level summary values recorded during the survey period. Temperature ranged from 30.6 to 30.8°C, salinity showed minimal station-level variation at approximately 36.0 ppt, dissolved oxygen ranged from 6.55 to 7.05 mg L⁻¹, pH ranged from 7.82 to 8.25, TSS ranged from 1.93 to 2.27 mg L⁻¹, and current velocity was approximately 0.2 m s⁻¹. These values indicate relatively stable short-term water-column conditions during the survey period. Dissolved oxygen and pH values were generally within ranges considered suitable for coral reef-associated organisms during the sampling period. TSS values were low during the survey, but this result should be interpreted as a short-term field condition. In coral reef systems, chronic sediment exposure can reduce light penetration, smother benthic organisms, limit coral recruitment, and alter benthic community structure (Rogers, 1990; Flores et al., 2012; Otaño-Cruz et al., 2019). Evidence from Indonesian reef systems also indicates that elevated suspended sediment can negatively affect coral cover and reef-associated benthic communities

Table 4

Station-level water-quality parameters

Parameter	Station I	Station II	Station III	Station IV	Station V	Station VI
Temperature (°C)	30.7	30.7	30.6	30.6	30.8	30.8
Salinity (ppt)	36.0	36.0	36.0	36.0	36.0	36.0
Dissolved oxygen (mg L ⁻¹)	7.05	6.75	6.70	6.80	7.05	6.55
pH	8.25	7.88	7.96	7.92	8.17	7.82
TSS (mg L ⁻¹)	1.93	2.05	2.27	1.97	2.26	2.19
Current velocity (m s ⁻¹)	0.2	0.2	0.2	0.2	0.2	0.2

Note: Station-level water-quality data were used as supporting environmental context for the macrozoobenthos analysis.

Although measured water-quality parameters showed relatively narrow variation during the survey, station-level differences in habitat type, substrate condition, depth, and live coral cover may still influence macrozoobenthos assemblages. In reef-margin ecosystems, benthic organisms may respond not only to water-column conditions but also to substrate stability, sediment deposition, and habitat structure (Otaño-Cruz et al., 2019; Gopal et al., 2020; Wakwella et al., 2020; Aulia et al., 2024). Depth ranged from approximately 3 to 8 m, with reef-slope stations generally deeper than rubble- and sand-dominated stations. Depth may influence light availability, hydrodynamic exposure, and benthic habitat structure; however, in this study, depth was interpreted as part of the broader station-level habitat context rather than as an independent driver.

Exploratory relationships among macrozoobenthos, coral habitat, and environmental variables. PCA summarized station-level variation in target macrozoobenthos assemblages, coral species richness, and ecological indices (Figure 4). The first two axes explained 76.99% of the total variation, with PC1 explaining 60.57% and PC2 explaining 16.41%. PC1 was mainly aligned with total individuals, target-group richness, Shannon diversity, giant clams, sea cucumbers, and crown-of-thorns starfish, while dominance showed an opposite direction. Stations III and V were positioned on the positive side of PC1, indicating comparatively higher abundance, richness, or more balanced assemblage structure. Coral species richness was more strongly aligned with PC2 and did not closely follow total target macrozoobenthos abundance. Because the analysis was based on six stations, the PCA was interpreted only as an exploratory visualization.

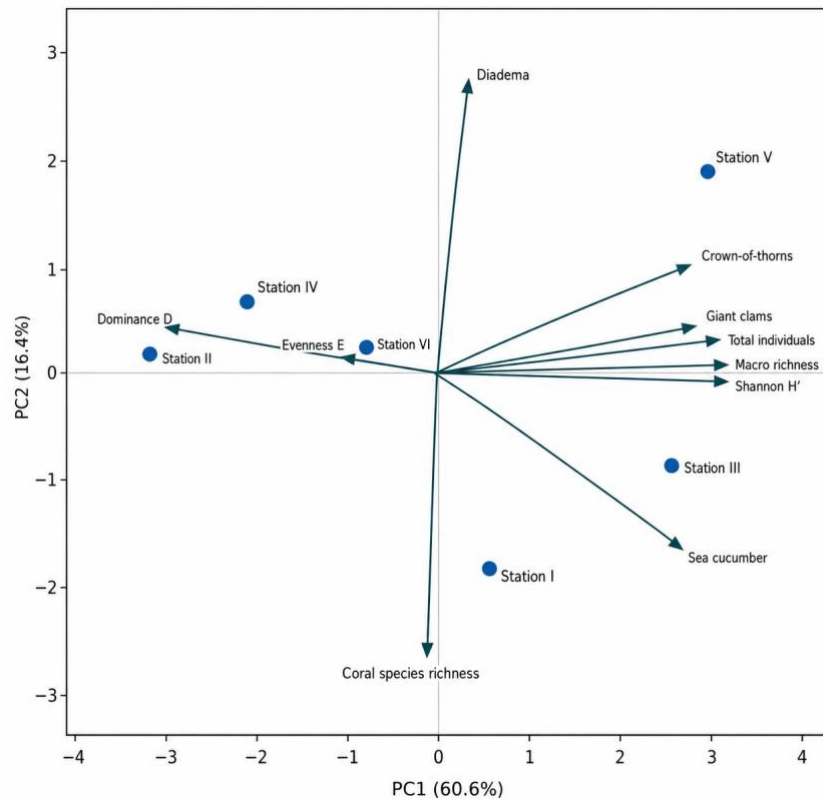


Figure 4. Principal Component Analysis (PCA) biplot showing station-level associations among target macrozoobenthos assemblages, coral species richness, and ecological indices in KKPTPT.

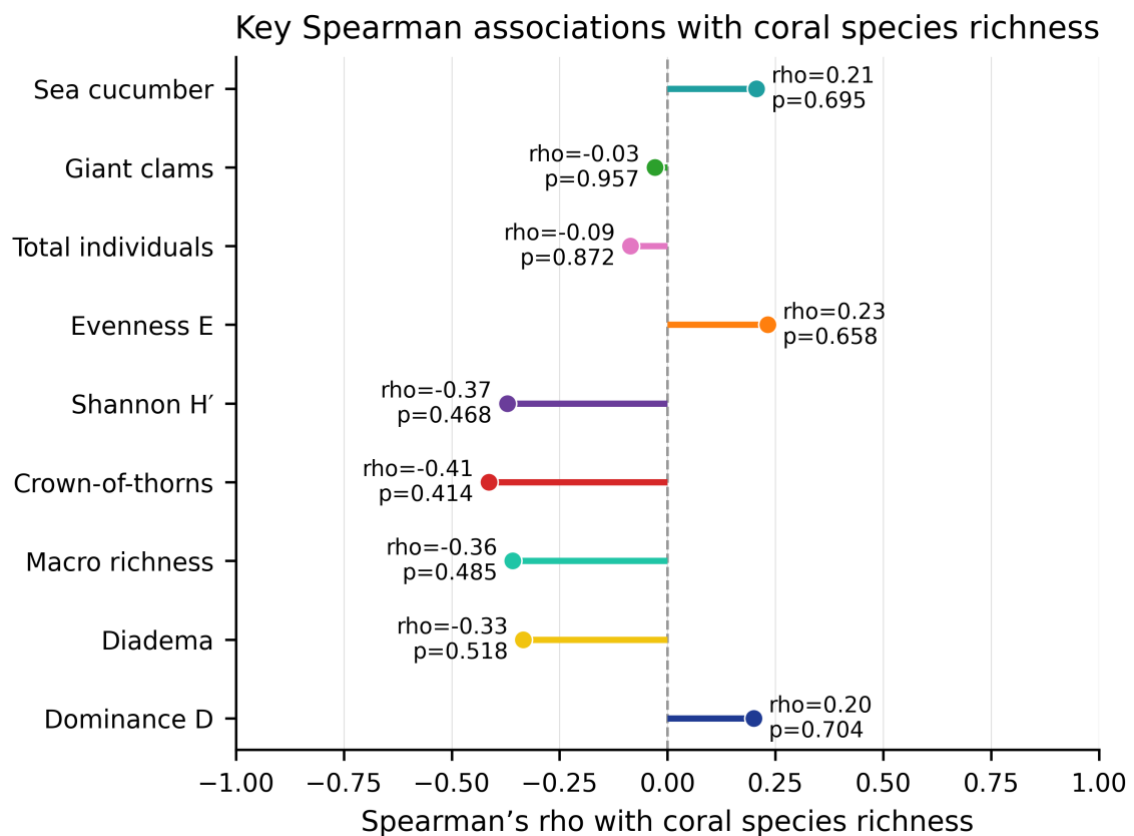


Figure 5. Spearman rank correlations between coral species richness and selected biological and ecological variables. All relationships were interpreted as exploratory station-level tendencies.

Stations II, IV, and VI were positioned closer to the negative side of PC1 and corresponded with higher dominance or lower target macrozoobenthos abundance. This pattern is consistent with their rubble- or sand-dominated habitat context. However, the ordination should not be interpreted as evidence of causal habitat effects because substrate stability, rugosity, and sediment characteristics were not measured directly. Spearman rank correlation analysis was used to explore station-level tendencies between coral species richness and selected biological and ecological variables (Figure 5). None of the tested relationships was statistically significant at $\alpha = 0.05$. Therefore, the results were interpreted only as exploratory tendencies and were not used to infer direct ecological relationships between coral richness and target macrozoobenthos assemblage structure. The small number of stations reduced statistical power and increased uncertainty in correlation estimates. (Gopal et al., 2020).

The correlation results do not support detailed ecological interpretation of relationships between coral richness and individual macrozoobenthos groups. Future studies should test these relationships using more stations, replicate transects, repeated sampling, and direct habitat-complexity measurements.

Integrated ecological interpretation. Overall, the results indicate that target macrozoobenthos assemblages in KKPTPT varied across reef-associated habitat types. Reef-slope stations generally showed higher live coral cover and were associated with higher target macrozoobenthos abundance or more balanced assemblage structure. In contrast, rubble- and sand-dominated stations tended to show lower abundance or higher dominance. These patterns should not be interpreted as evidence that coral richness directly controls macrozoobenthos assemblage structure. The corrected coral dataset showed that Station I had the highest coral richness, whereas Station V had the highest target macrozoobenthos abundance. This contrast indicates that macrozoobenthos distribution is likely influenced by multiple interacting factors, including live coral cover, substrate type, depth, food availability, and species-specific habitat requirements. The dominance of giant clams is ecologically relevant because tridacnids are conspicuous reef-associated bivalves with important conservation value in Indo-Pacific reef systems. Their broad occurrence provides useful baseline information, but future monitoring should assess population size structure, recruitment, and habitat condition to determine whether the observed abundance reflects stable population status. The low occurrence of crown-of-thorns starfish and triton shells provides baseline information for future monitoring. Their abundance was too low to support strong inference on predator-prey dynamics, but both groups should remain part of repeated reef monitoring because changes in their abundance may have implications for coral reef condition. From a conservation-monitoring perspective, the findings provide a station-level baseline for adaptive management in KKPTPT. Stations I, III, and V are important reference locations because they represented reef-slope habitats with higher live coral cover and comparatively stronger target macrozoobenthos assemblage attributes. Stations II, IV, and VI should remain in the monitoring design because they represent rubble- and sand-dominated habitats that may respond differently to sedimentation, substrate instability, or reef degradation. Future monitoring should include replicate transects, seasonal surveys, direct habitat-complexity measurements, sediment characterization, and size-structure assessment for key taxa such as giant clams. These improvements would strengthen the use of macrozoobenthos data for evaluating reef condition, fisheries habitat quality, and adaptive management in the marine protected area. In summary, the integrated assessment shows that KKPTPT supports a measurable but uneven target macrozoobenthos assemblage associated with variable reef-associated habitat context and relatively stable short-term water-quality conditions. The findings provide an initial ecological baseline for interpreting station-level patterns in abundance, richness, diversity, evenness, and dominance, and can support future conservation monitoring, zoning evaluation, and adaptive management of the Tanjung Palas Timur Marine Protected Area.

Conclusions. This study provides an initial ecological baseline for target macrozoobenthos assemblages in the core zone of the Tanjung Palas Timur Marine Protected Area, North Kalimantan, Indonesia. The assemblage was unevenly structured and numerically dominated by giant clams, suggesting that suitable reef-associated substrates may remain available in parts of the surveyed area, although this should be confirmed through future population and habitat assessments. Reef-slope stations generally supported higher target macrozoobenthos abundance or more balanced assemblage structure than rubble- and sand-dominated stations, indicating that habitat context is important for interpreting benthic assemblage patterns. Coral species data and water-quality parameters provided supporting environmental context, but coral richness alone did not fully explain macrozoobenthos distribution. Overall, the findings offer a useful reference for future conservation monitoring in KKPTPT and highlight the need for replicate transects, seasonal surveys, direct habitat-complexity measurements, sediment characterization, and size-structure assessment of key taxa such as giant clams.

Acknowledgment. The authors would like to express their sincere gratitude to the Marine and Fisheries Service of North Kalimantan Province, the Kelompok Masyarakat Penggerak Konservasi (KOMPAK) diving group, and local conservation heroes for their valuable support and assistance during the field activities of this study.

Authors Contributions. Conceptualization: EW; Methodology: EW, SA, H, and S; Formal analysis: EW, MN, and FA; Investigation: EW, MN, and FA; Data curation: AABK and MYY; Writing - original draft: MFA; Writing - review & editing: MFA and BI; Supervision: EW, MN, and FA.

Conflict of Interest. The authors declare that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Funding. This research was supported through the Indonesian Education Scholarship (Beasiswa Pendidikan Indonesia, BPI) Program administered by the Center for Higher Education Financing and Assessment (Pusat Pembiayaan dan Asesmen Pendidikan Tinggi, PPAPT), Ministry of Higher Education, Science, and Technology of the Republic of Indonesia, under Decision Letter No. 010838/PPAPT.1.2/BPI.06/02/2025.

References

- Abdelmeneam, B., Madkour, F., Ismail, M., Dosoky, M., & Hanafy, M. (2024). Zooxanthellae densities within the fluted giant clam *Tridacna squamosa* (Lamarck, 1819) from the southern coast of Egypt's Red Sea. *Egyptian Journal of Aquatic Biology and Fisheries*, 28(6), 241-258. <https://doi.org/10.21608/ejabf.2024.392222>
- Ariaz, P. A., Zulkifli, Z., & Efriyeldi, E. (2024). Macrozoobenthos community structure at Teluk Marunggai Beach, Nagari Sungai Nyalo, Pesisir Selatan District, West Sumatera Province. *Tropical Marine Environmental Sciences*, 2(2), 42-50. <https://doi.org/10.31258/tromes.2.02.42-50>
- Aulia, E. D., Park, J., Lee, S.-K., & Khim, J. S. (2024). Revealing macrozoobenthos diversity of Java coral reefs, Indonesia: A review on research trends and species assemblages. *Frontiers in Marine Science*, 11, 1387984. <https://doi.org/10.3389/fmars.2024.1387984>
- Burns, J. H. R., Fukunaga, A., Pascoe, K. H., Runyan, A., Craig, B. K., Talbot, J., Pugh, A. R., & Kosaki, R. K. (2019). 3D habitat complexity of coral reefs in the Northwestern Hawaiian Islands is driven by coral assemblage structure. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W10, 61-67. <https://doi.org/10.5194/isprs-archives-XLII-2-W10-61-2019>

- Crespo, D., & Pardal, M. Â. (2020). Ecological and economic importance of benthic communities. In W. Leal Filho, A. M. Azul, L. Brandli, A. L. Salvia, & T. Wall (Eds.), *Life below water* (pp. 1-11). Springer International Publishing. https://doi.org/10.1007/978-3-319-71064-8_5-1
- Darling, E. S., Graham, N. A. J., Januchowski-Hartley, F. A., Nash, K. L., Pratchett, M. S., & Wilson, S. K. (2017). Relationships between structural complexity, coral traits, and reef fish assemblages. *Coral Reefs*, 36(2), 561-575. <https://doi.org/10.1007/s00338-017-1539-z>
- Flores, F., Hoogenboom, M. O., Smith, L. D., Cooper, T. F., Abrego, D., & Negri, A. P. (2012). Chronic exposure of corals to fine sediments: lethal and sub-lethal impacts. *PLOS ONE*, 7(5), e37795. <https://doi.org/10.1371/journal.pone.0037795>
- Gopal, A., Abdul Jaleel, K. U., Parameswaran, U. V., Sanjeevan, V. N., Saramma, A. V., Vijayan, A., Saravanane, N., Gupta, G. V. M., & Sudhakar, M. (2020). Distinctive community patterns with exceptional diversity of polychaetes around a tectonically active archipelago in the tropical Indian Ocean. *Frontiers in Marine Science*, 7, 710. <https://doi.org/10.3389/fmars.2020.00710>
- Hodgson, G., Hill, J., Kiene, W., Maun, L., Mihaly, J., Liebeler, J., Shuman, C., & Torres, R. (2016). *Reef Check instruction manual: a guide to Reef Check coral reef monitoring* (2006 ed., revised 2016). Reef Check Foundation.
- Isdianto, A., Kurniawan, A., Wicaksono, A. D., Taufik, M. Z., Putri, B. M., Fathah, A. L., Setyanto, A., Luthfi, O. M., Pratiwi, D. C., & Harahab, N. (2023). Assessment of community structure of macroinvertebrates, coral cover and water quality in Sempu Strait, Malang Regency, East Java. *Journal of Ecological Engineering*, 24(12), 99-111. <https://doi.org/10.12911/22998993/172353>
- Khasanah, S., Riani, E., Zairion, & Sulistiono. (2024). Community structure of macrozoobenthos as a water quality indicator at Margagiri-Grenyang coastal waters, Banten Bay. *IOP Conference Series: Earth and Environmental Science*, 1400(1), 012012. <https://doi.org/10.1088/1755-1315/1400/1/012012>
- Kohler, K. E., & Gill, S. M. (2006). Coral Point Count with Excel extensions (CPCe): A Visual Basic program for the determination of coral and substrate coverage using random point count methodology. *Computers & Geosciences*, 32(9), 1259-1269. <https://doi.org/10.1016/j.cageo.2005.11.009>
- Liu, C.-S., Wu, C.-L., Li, X.-B., Liu, C., Wang, A.-M., Gu, Z.-F., & Lü, B. (2021). Distribution and the influence of substrate on its mantle color of giant clam *Tridacna noae* in coastal waters of Sanya. *Acta Hydrobiologica Sinica*, 45(3), 645-651. <https://doi.org/10.7541/2021.2020.045>
- Mazzuco, A. C. A., Stelzer, P. S., & Bernardino, A. F. (2020). Substrate rugosity and temperature matters: patterns of benthic diversity at tropical intertidal reefs in the SW Atlantic. *PeerJ*, 8, e8289. <https://doi.org/10.7717/peerj.8289>
- Mehrotra, R., Allchurch, A., Monchanin, C., & Scott, C. M. (2021). Assessment of spatiotemporal variability of giant clam populations (Cardiidae: *Tridacna*) from 11 years of monitoring at Koh Tao, Thailand. *Journal of Molluscan Studies*, 87(4), eyab042. <https://doi.org/10.1093/mollus/eyab042>
- Mehrotra, R., Allchurch, A., Monchanin, C., & Scott, C. M. (2022). Recruitment of hard coral communities on giant clam shells (Cardiidae: *Tridacna*) differ from surrounding reef habitats at a tourist destination in the Gulf of Thailand. *Journal of Molluscan Studies*, 88(4), eyac031. <https://doi.org/10.1093/mollus/eyac031>
- Mellin, C., MacNeil, M. A., Cheal, A. J., Emslie, M. J., & Caley, M. J. (2016). Marine protected areas increase resilience among coral reef communities. *Ecology Letters*, 19(6), 629-637. <https://doi.org/10.1111/ele.12598>
- Neo, M. L., Eckman, W., Vicentuan, K., Teo, S. L.-M., & Todd, P. A. (2015). The ecological significance of giant clams in coral reef ecosystems. *Biological Conservation*, 181, 111-123. <https://doi.org/10.1016/j.biocon.2014.11.004>
- Odum, E. P. (1971). *Fundamentals of ecology* (3rd ed.). W. B. Saunders.
- Otaño-Cruz, A., Montañez-Acuña, A. A., García-Rodríguez, N. M., Díaz-Morales, D. M., Benson, E. P., Cuevas, E., Ortiz-Zayas, J. R., & Hernández-Delgado, E. A. (2019). Caribbean near-shore coral reef benthic community response to changes on

- sedimentation dynamics and environmental conditions. *Frontiers in Marine Science*, 6, 551. <https://doi.org/10.3389/fmars.2019.00551>
- Rabiyanti, I., Asriansyah, A., Sulistiono, Yulianda, F., Samosir, A. M., Rastina, & Hestiranoto, T. (2025). Community structure of macrozoobenthos molluscs in several coastal waters of Banten Bay, Java. *IOP Conference Series: Earth and Environmental Science*, 1512(1), 012014. <https://doi.org/10.1088/1755-1315/1512/1/012014>
- Richardson, L. E., Graham, N. A. J., Pratchett, M. S., & Hoey, A. S. (2017). Structural complexity mediates functional structure of reef fish assemblages among coral habitats. *Environmental Biology of Fishes*, 100(3), 193-207. <https://doi.org/10.1007/s10641-016-0571-0>
- Rogers, C. S. (1990). Responses of coral reefs and reef organisms to sedimentation. *Marine Ecology Progress Series*, 62, 185-202. <https://doi.org/10.3354/meps062185>
- Wakwella, A., Mumby, P. J., & Roff, G. (2020). Sedimentation and overfishing drive changes in early succession and coral recruitment. *Proceedings of the Royal Society B: Biological Sciences*, 287(1941), 20202575. <https://doi.org/10.1098/rspb.2020.2575>
- Wang, Y., Li, B.-L., Zhu, J.-L., Feng, Q., Liu, W., He, Y.-H., & Wang, X. (2022). Assessment of heavy metals in surface water, sediment and macrozoobenthos in inland rivers: a case study of the Heihe River, Northwest China. *Environmental Science and Pollution Research*, 29(23), 35253-35268. <https://doi.org/10.1007/s11356-022-18663-8>
- Weliyadi, E., Anggoro, S., Haeruddin, Saputra, S. W., Najib, M., Amaliah, F., Kase, A. A. B., Yusuf, M. Y., & Akhmadi, M. F. (2025). Baseline assessment of coral and fish assemblage relationships in Tanjung Palas Timur Marine Protected Area, North Kalimantan, Indonesia. *Biodiversitas*, 26(10), 5303-5313. <https://doi.org/10.13057/biodiv/d261043>

Received: 25 May 2026. Accepted: 05 August 2026. Published online: 14 September 2026.

Authors:

Encik Weliyadi (EW), Aquatic Resources Management Doctoral Study Program, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, 50275 Semarang, Central Java Province, Indonesia; e-mail: weliyadianwar098@gmail.com

Sutrisno Anggoro (SA), Aquatic Resources Management Doctoral Study Program, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, 50275 Semarang, Central Java Province, Indonesia, e-mail: sutrisno.anggoro@yahoo.co.id.

Haeruddin (H), Aquatic Resources Management Doctoral Study Program, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, 50275 Semarang, Central Java Province, Indonesia, e-mail: haeruddindaengmile@lecturer.undip.ac.id.

Suradi (S), Aquatic Resources Management Doctoral Study Program, Department of Aquatic Resources Management, Faculty of Fisheries and Marine Science, Universitas Diponegoro, Tembalang, 50275 Semarang, Central Java Province, Indonesia, e-mail: suradiwsaputra@yahoo.co.id.

Muhammad Najib (MN), Head of Marine Spatial Management, Ministry of Maritime Affairs and Fisheries, North Kalimantan, 77123 Tarakan, Indonesia,

Fahyuni Amaliah (FA), Marine and Coastal Ecosystem Management, Ministry of Maritime Affairs and Fisheries, North Kalimantan, 77123 Tarakan, Indonesia,

Ardy Andreas Bernard Kase (AABK), Department of Aquatic Resource Management, Faculty of Fisheries and Marine Sciences, University of Borneo Tarakan, 77123 Tarakan, North Kalimantan, Indonesia,

Muhammad Yusfi Yusuf (MY), Department of Aquatic Resource Management, Faculty of Fisheries and Marine Sciences, University of Borneo Tarakan, 77123 Tarakan, North Kalimantan, Indonesia,

Burhanuddin Ihsan (BI), Department of Aquaculture, Faculty of Fisheries and Marine Science, Borneo University, 77123 Tarakan, North Kalimantan, Indonesia,

Mohammad Fadnan Akhmadi (MFA), Department of Fisheries Product Technology, Faculty of Fisheries and Marine Science, Borneo University, 77123 Tarakan, North Kalimantan, Indonesia, e-mail:

adnan_ub@borneo.ac.id

This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

How to cite this article:

Weliyadi, E., Anggoro, S., Haeruddin, Suradi, Najib, M., Amaliah, F., Kase, A. A. B., Yusuf, M. Y., Ihsan, B., & Akhmadi, M. F. (2026). Baseline assessment of target macrozoobenthos assemblages in the Tanjung Palas Timur Marine Protected Area, Indonesia. *AACL Bioflux* 19(5):2149-2164.