INDO PAC J OCEAN LIFE
Volume 9, Number 1, June 2025
Pages: 26-35

P-ISSN: 2775-1961
E-ISSN: 2775-1953
DOI: 10.13057/oceanlife/o090103

Short Communication: Spatial distribution and diversity of intertidal crustaceans in karstic beaches of southern Java, Indonesia

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[2]Department of Biology, Faculty of Science, Universiti Putra Malaysia. 43400 UPM Serdang, Selangor, Malaysia
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Manuscript received: 14 July 2024. Revision accepted: 26 March 2025.

Abstract. *Hartono DAN, Widowati D, Saputra EF, Wicaksono FR, Pramadaningtyas PS, Yap CK, Setyawan AD. 2025. Short Communication: Spatial distribution and diversity of intertidal crustaceans in karstic beaches of southern Java, Indonesia. Indo Pac J Ocean Life 9: 26-35.* Karstic coastal systems in tropical regions are often overlooked in biodiversity assessments despite their ecological complexity and vulnerability. This study investigates the species composition, diversity, and environmental drivers of intertidal crustacean communities across five karstic beaches in Gunungkidul, Indonesia. A total of 18 crustacean species were recorded, with *Coenobita scaevola* emerging as the most dominant and widely distributed taxon. Species richness and the Shannon-Wiener diversity index (H′) varied significantly among sites, with Ngrenehan Beach exhibiting the highest diversity (H′=2.18) and Ngrawah the lowest (H′=1.23). Among the measured abiotic parameters, dissolved oxygen (DO) showed the strongest positive correlation with H′ ($r=0.92$, $p<0.05$), indicating its critical role in structuring crustacean assemblages. Cluster analysis revealed two distinct site groups, reflecting spatial heterogeneity in species composition likely shaped by microhabitat features. The findings underscore the importance of karstic intertidal habitats as localized biodiversity reservoirs and emphasize the need for site-specific conservation strategies and long-term ecological monitoring in tropical coastal regions.

Keywords: Bray-Curtis similarity, *Coenobita scaevola*, crustacean diversity, dissolved oxygen, Gunungkidul, karst beach

INTRODUCTION

Indonesia, as a vast archipelagic nation, possesses one of the richest marine biodiversities in the world. The intertidal zone, located at the interface between terrestrial and marine ecosystems, is a dynamic and ecologically significant habitat that supports diverse assemblages of marine organisms, including crustaceans. These organisms play essential ecological roles in nutrient cycling, sediment turnover, and as prey for higher trophic levels (Snelgrove et al. 2016; Söderhäll 2016). Among the varied coastal geomorphologies in Indonesia, karstic beaches—characterized by limestone cliffs, narrow tidal flats, and rocky substrates—form unique habitats with high environmental heterogeneity yet remain poorly studied in terms of their faunal communities.

Crustaceans, particularly decapods such as crabs and hermit crabs, are prominent and ecologically significant members of intertidal communities. Their distribution and diversity are influenced by a suite of abiotic factors, including temperature, pH, salinity, substrate type, and dissolved oxygen levels (Mokhtari et al. 2015; Semprucci et al. 2019). These variables not only affect species occurrence but also shape ecological interactions and habitat preferences. Moreover, crustaceans have varying degrees of mobility and adaptability to habitat disturbances, making them useful bioindicators for monitoring coastal ecosystem health (Handayani et al. 2016; Marin and Tiunov 2023).

Despite their ecological importance, intertidal crustacean communities in karstic coastal zones of Java, especially in Gunungkidul District, remain understudied. Previous studies in Indonesian waters have mostly focused on mangrove or estuarine systems (Paujiah et al. 2020; Rahmawati et al. 2021), while rocky intertidal habitats in remote and difficult-to-access karst areas have received limited scientific attention. These beaches often exhibit steep geomorphological features and variable exposure to waves, potentially affecting crustacean assemblages in ways that are distinct from those in other coastal settings.

Environmental gradients, particularly abiotic stressors such as low dissolved oxygen or fluctuating pH, can act as filters that structure intertidal communities. For instance, some crustaceans exhibit physiological adaptations to hypoxic conditions or morphological traits suited for burrowing in compact substrates (Bezuidenhout et al. 2021). Karst beaches, with their mix of sandy pockets, coral rubble, and rock platforms, may harbor niche-specialized species whose presence reflects fine-scale environmental variability. Understanding how crustacean communities respond to these gradients is essential for anticipating shifts due to climate change, habitat degradation, or tourism development.

In addition to ecological drivers, human activities increasingly impact intertidal habitats in Gunungkidul. Coastal development, unmanaged tourism, and pollution can alter substrate conditions and water quality, thereby threatening sensitive intertidal species (El-Naggar et al. 2022). However, most management efforts in the region have focused on coral reefs and fisheries conservation, often overlooking intertidal invertebrates. Establishing a baseline of species composition and environmental conditions in these underexplored beaches can inform local conservation strategies and contribute to national biodiversity monitoring goals.

This study investigates the spatial distribution and species diversity of intertidal crustaceans across five karstic beaches in the southern coastal area of Yogyakarta Special Region, Indonesia. We aimed to: (i) document the species richness and community composition of crustaceans in these sites; (ii) evaluate the ecological diversity indices, including Shannon-Wiener diversity, Margalef richness, and evenness; and (iii) examine how environmental variables such as pH, temperature, and dissolved oxygen correlate with crustacean abundance and diversity. By addressing these objectives, we seek to fill a critical knowledge gap in tropical rocky intertidal ecology and provide empirical data relevant to coastal biodiversity conservation.

The findings of this research are expected to contribute to a broader understanding of biotic responses to abiotic stress in tropical intertidal zones and highlight the ecological value of karstic coastal ecosystems. Furthermore, the documentation of crustacean species from relatively undisturbed or minimally studied locations can serve as a valuable reference for long-term monitoring, particularly in the face of anthropogenic pressures and climate variability. Ultimately, this study provides insights into how environmental heterogeneity drives biodiversity patterns in intertidal crustacean assemblages within a unique karst landscape.

MATERIALS AND METHODS

Study area

This study was conducted at five karstic beach locations situated along the southern coast of Gunungkidul District, Yogyakarta Special Region, Indonesia: Pringjono, Torohudan, Ngrawah, Dadap Ayam, and Ngrenehan Beaches (Figure 1). All sites lie within Kanigoro Village, Saptosari Subdistrict, and are part of a unique limestone coastal system characterized by narrow intertidal zones, rocky platforms, and steep cliff backdrops (Nurcahyo et al. 2024). These beaches are generally less accessible than more developed tourist beaches (Fadin et al. 2023), offering relatively undisturbed ecological settings suitable for intertidal biodiversity studies.

Each beach differs in terms of geomorphology and human accessibility. Pringjono Beach is the most isolated, located west of Nguyahan Beach and accessible only by footpaths through rocky terrain and vegetated hills. Torohudan and Ngrawah Beaches lie adjacent to agricultural fields and can only be reached by walking across narrow, unpaved paths. Dadap Ayam Beach, named after the local medicinal tree *Erythrina variegata* (*dadap ayam*), is accessible via steep stone steps through coastal scrub and forest. Ngrenehan Beach is the most developed, serving as a fishing port and tourism site, with well-maintained access and public facilities.

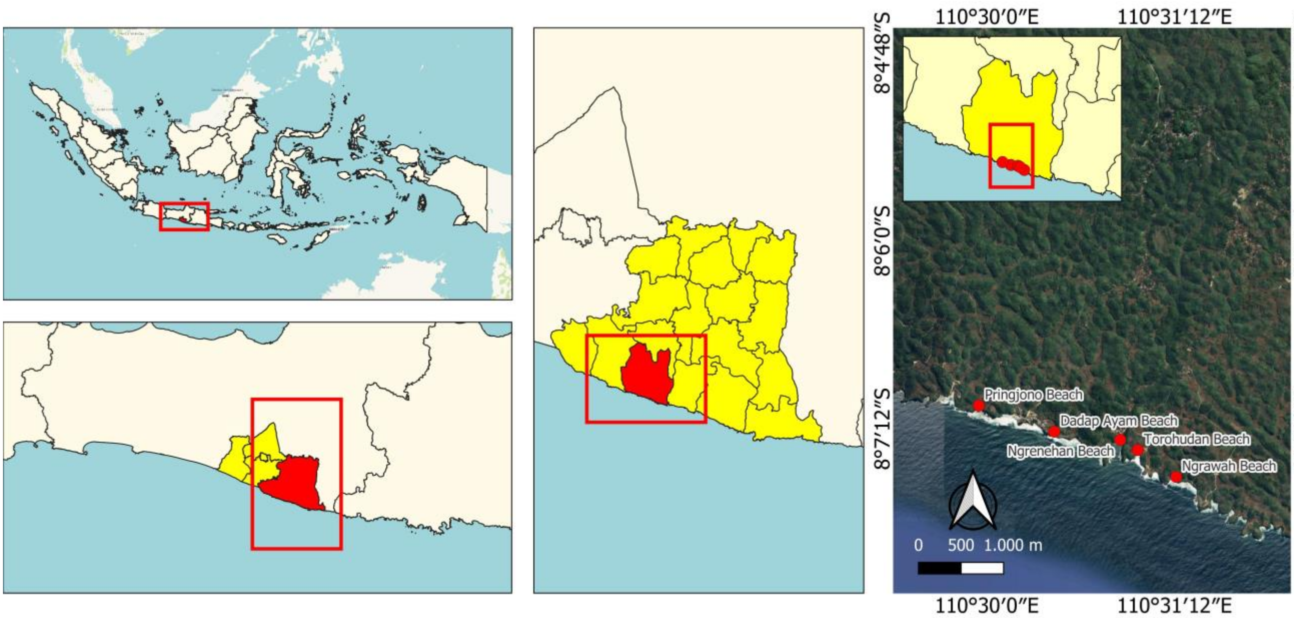

Figure 1. Map showing the location of five karstic beach study sites (Pringjono, Torohudan, Ngrawah, Dadap Ayam, and Ngrenehan) in Saptosari Sub-district, Gunungkidul District, Yogyakarta Special Region, Indonesia

All five beaches are located within a tropical monsoon climate zone, receiving 1,500-2,000 mm of rainfall annually and experiencing average daily temperatures ranging from 26°C to 31°C. The tidal regime is semi-diurnal with moderate amplitude, creating regular cycles of exposure and submersion that define the intertidal zone structure (Furlani et al. 2020). Variations in abiotic conditions such as pH, temperature, salinity, and dissolved oxygen occur spatially across the sites due to differential wave exposure, substrate type, and human impact levels (Hartati et al. 2024).

Sampling design and data collection

Crustacean survey and identification

Field sampling was conducted at each of the five beach locations during low tide in March 2024. A belt transect method was employed to systematically survey crustaceans along a 50-m shoreline segment at each site (Shofi 2021). Within each transect, five square plots of 10×10 m were established to capture habitat variation, including sandy, rocky, and coral-rubble microhabitats.

Crustaceans observed within each plot were collected manually using hand tools, such as small nets, plastic jars, and shovels for burrowing individuals. Only specimens found within the plot boundary during standardized 30-minute search sessions were recorded. To ensure consistency, all sampling was performed during the same tidal phase and time window (08:00-12:00 local time) across all beaches.

Specimens were preserved in 70% ethanol and identified in the laboratory based on morphological characteristics, including carapace shape and texture, coloration, cheliped structure, and body size. Identification referred to field guides and taxonomic keys (Rustikasari et al. 2021), as well as the World Register of Marine Species (WoRMS) online database. When identification to the species level was uncertain, the specimens were assigned to the closest possible genus and marked with "cf." Voucher specimens were not retained due to logistical and ethical limitations, but photographic documentation was archived for all unique morphotypes.

Measurement of abiotic parameters

Abiotic data collection was conducted simultaneously with crustacean sampling to assess local environmental conditions that may influence species distribution. Parameters measured included pH, surface water temperature, and dissolved oxygen (DO) concentration. Measurements were taken at three random points within each transect using portable instruments: a waterproof digital pH meter, a thermometer, and a DO meter (Lutron DO-5510).

Instruments were calibrated prior to each sampling session, and readings were recorded on-site. DO values were cross-validated using the Winkler titration method, particularly in locations where digital readings indicated extremely low oxygen levels. Salinity measurements were excluded due to the minimal variation observed across the study sites.

These abiotic parameters were selected due to their known importance in shaping intertidal community structure. pH influences physiological processes such as carapace formation, while temperature and oxygen availability affect metabolic activity, mobility, and reproductive success in crustaceans (Semprucci et al. 2019; Hartati et al. 2024). Variation in these parameters was later analyzed to explore potential correlations with crustacean diversity patterns.

Biodiversity indices and ecological analysis

Three ecological indices were calculated to evaluate the structure of crustacean communities across the five karstic beaches: the Shannon-Wiener diversity index (H′), Margalef's richness index (Dmg), and Pielou's evenness index (E). These indices provide complementary metrics for assessing species composition, abundance distribution, and community balance within each site (Fachrul 2007; Kusumaningsih and Hendrarto 2015).

The Shannon-Wiener index (H') was calculated using the formula:

$$H' = -\sum(pi \times \ln pi)$$

where *pi* is the proportion of individuals belonging to the *i*-th species. Interpretation followed the scale proposed by Fachrul (2007):

$H'<1$: low diversity
$1 \le H' \le 3$: moderate diversity
$H'>3$: high diversity

Margalef's species richness index (Dmg) was computed as:

$$Dmg = (S - 1) / \ln(N)$$

where *S* is the number of species and *N* is the total number of individuals observed at a site. According to Kamaluddin et al. (2019):

$Dmg<2.5$: low richness
$2.5 \le Dmg \le 4$: moderate richness
$Dmg>4$: high richness

Pielou's evenness index (E) was calculated to assess the equitability of individual distribution among species:

$$E = H' / \ln(S)$$

Classification followed Pielou (1977):
$E<0.31$: low evenness
$0.31 \le E \le 1$: moderate evenness
$E>1$: high evenness

All indices were calculated using Microsoft Excel and validated with PAST version 4.11. Species counts and ecological indices were then compared across beach sites to detect spatial trends. Additionally, index values were later correlated with abiotic factors to explore possible environmental influences on community structure (Semprucci et al. 2019; Rahmadhani and Martuti 2023).

Data processing and statistical procedures

All raw data, including species counts, ecological indices, and abiotic parameters, were compiled, cleaned, and organized using Microsoft Excel. Descriptive statistics were used to summarize the number of species, individuals, and values of pH, temperature, and dissolved oxygen at each study site. Results were tabulated and visualized to facilitate inter-site comparisons and pattern interpretation.

To explore the relationship between environmental factors and crustacean diversity, Pearson's correlation analysis was conducted. Shannon-Wiener diversity index (H′) values were treated as the dependent variable, while pH, temperature, and dissolved oxygen served as independent predictors. Correlation coefficients (*r*) and significance values (*p*) were calculated using SPSS version 25, with a significance level set at α=0.05.

In addition, hierarchical cluster analysis was applied to examine community similarity among beach sites based on species composition and relative abundance. The Bray-Curtis similarity index was used to generate a dissimilarity matrix, and dendrograms were constructed using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) in PAST version 4.11 (Semprucci et al. 2019). This analysis allowed the visual grouping of sites with similar crustacean assemblages and facilitated the ecological interpretation of spatial patterns.

All data visualizations—including diversity index plots, abiotic parameter distributions, and dendrograms—were prepared using a combination of PAST, SPSS, and Adobe Illustrator for publication quality. All statistical procedures followed standard assumptions regarding normality and independence; where these assumptions were not met, results were interpreted with caution and noted accordingly.

RESULTS AND DISCUSSION

Species composition and abundance

A total of 18 crustacean species from 14 families were recorded across five karstic beaches in Gunungkidul, Indonesia (Table 1). Species richness and total abundance varied substantially among sites, with Ngrenehan Beach exhibiting the highest diversity (8 species, 98 individuals), and Ngrawah the lowest (4 species, 24 individuals). The most frequently encountered species was *Coenobita scaevola* (long-armed hermit crab), present at all beaches and accounting for 96 individuals or 42.5% of total abundance.

Other abundant taxa included *Xantho cf. poressa* (27 individuals), *Hemigrapsus sanguineus* (21 individuals), and *Coenobita brevimanus* (18 individuals), each with more restricted spatial distributions. Notably, *C. scaevola* showed consistent dominance at Pringjono, Torohudan, Ngrawah, and Dadap Ayam, while *X. cf. poressa* was strongly localized at Ngrenehan (Figure 2).

Several species were rare, being recorded only once across all sites—namely *Platypodia granulosa* (granular reef crab), *Plagusia chabrus* (red rock crab), *Carpilius maculatus* (seven-eleven crab), and *Ozius cf. rugulosus* (tentatively identified as wrinkled rock crab). Their rarity may indicate specialized habitat requirements or low population density within the sampled zones. Figure 2 illustrates the relative abundance of the five most dominant species, namely *C. scaevola*, *X. cf. poressa*, *H. sanguineus*, *Grapsus albolineatus* (lined shore crab), and *C. brevimanus* (giant land hermit crab).

These findings reveal notable inter-site variation in species composition, likely driven by differences in substrate type, tidal exposure, and microhabitat heterogeneity. While Ngrenehan had the highest richness and total individuals, several species occurred exclusively at other beaches, underscoring the importance of localized environmental conditions over a simple spatial gradient (Figure 3).

Diversity indices supported these patterns. The highest Shannon-Wiener index (H′=2.18) was observed at Ngrenehan, and the lowest (H′=1.23) at Ngrawah. Margalef's richness index mirrored this trend, confirming the relatively higher diversity structure at Ngrenehan (Figure 4).

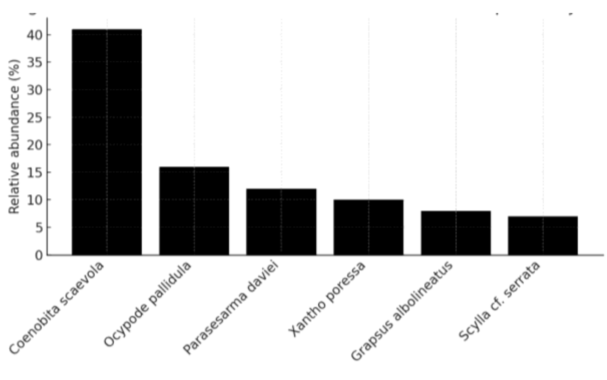

Figure 2. Relative abundance of dominant crustacean species across five karstic beaches in Gunungkidul, Yogyakarta, Indonesia

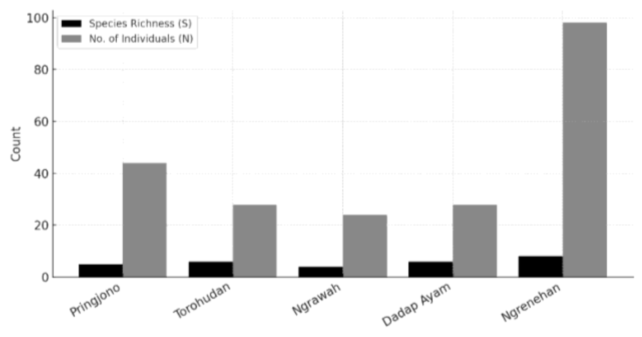

Figure 3. Species richness and number of individuals per beach in Gunungkidul, Yogyakarta, Indonesia

Table 1. Occurrence and abundance of crustacean species across five karstic beaches in Gunungkidul, Indonesia

Scientific name	Common name	Family	I	II	III	IV	V	IUCN status
Etisus dentatus (Herbst, 1785)	Toothed reef crab	Xanthidae	-	3	-	-	1	LC
Carpilius maculatus (Linnaeus, 1758)	Seven-eleven crab	Carpiliidae	-	-	-	1	-	NE
Cardisoma carnifex (Herbst, 1796)	Purple land crab	Gecarcinidae	-	-	-	-	3	LC
Grapsus albolineatus Latreille, 1812	Lined shore crab / Sally lightfoot crab	Grapsidae	-	1	5	-	12	LC
Plagusia chabrus (Linnaeus, 1758)	Red rock crab	Plagusiidae	-	-	-	1	-	LC
Discoplax hirtipes (Dana, 1851)	Hairy land crab	Gecarcinidae	-	-	-	1	-	LC
Hemigrapsus sanguineus (De Haan, 1835)	Asian shore crab	Varunidae	-	-	-	-	21	LC
Hyastenus diacanthus (De Haan, 1839)	Spider decorator crab	Epialtidae	4	-	-	-	-	LC
Ocypode pallidula Hombron & Jacquinot, 1846	Pale ghost crab	Ocypodidae	7	3	-	-	-	LC
Ocypode cordimanus Latreille, 1818	Shore ghost crab	Ocypodidae	-	-	-	2	-	LC
Ozius cf. rugulosus	Wrinkled rock crab (tentative)	Oziidae	-	-	-	-	1	NE
Parasesarma daviei Shahdadi, Schubart & Mendoza, 2021	Davie's mangrove crab	Sesarmidae	8	-	-	-	-	LC
Platypodia granulosa (Rüppell, 1830)	Granular reef crab	Xanthidae	1	-	-	-	-	LC
Schizophrys aspera (H.Milne Edwards, 1831)	Rough spider crab	Majidae	-	2	-	-	-	LC
Scylla cf. serrata	Giant mud crab	Portunidae	-	-	5	-	-	LC
Xantho poressa (Olivi, 1792)	Jaguar round crab	Xanthidae	-	-	-	-	27	LC
Coenobita scaevola (Forskål, 1775)	Long-armed hermit crab	Coenobitidae	24	18	11	16	25	LC
Coenobita brevimanus Dana, 1852	Giant land hermit crab	Coenobitidae	-	1	3	6	8	LC

Note: I: Pringjono Beach, II: Torohudan Beach, III: Ngrawah Beach, IV: Dadap Ayam Beach, V: Ngrenehan Beach. -: Absence of the species at the site. Species marked as *cf.* indicate tentative identification based on morphology and ecological distribution. LC: Least Concern, NE: Not Evaluated

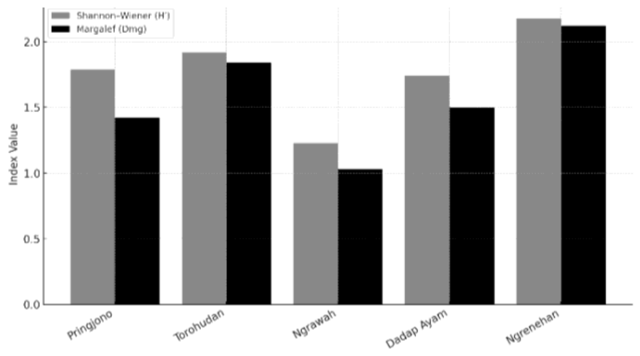

Figure 4. Shannon-Wiener and Margalef's richness indices across beach sites

Morphological variation of key species

Several crustacean species recorded in this study exhibited distinct morphological traits that facilitated both field identification and ecological interpretation (Table 2). The most abundant species, *Coenobita scaevola* (long-armed hermit crab), possessed a small, asymmetrical body adapted for shell-dwelling, with a light brown to pale gray exoskeleton, short eyestalks, and a conspicuously enlarged left chela. It was easily distinguishable from *Coenobita brevimanus* (giant land hermit crab), which exhibited a darker body coloration, shortened walking legs, and a more robust, laterally compressed left chela (Hazlett 1981).

The large-bodied portunid *Scylla cf. serrata* (giant mud crab) was identified based on its broad, polygonal carapace with pronounced frontal lobes and stout, spiny chelae. Although members of *Scylla* are typically associated with mangrove estuaries, the individuals observed in this study were found inhabiting semi-enclosed tidal pools adjacent to rocky platforms, consistent with known ecological plasticity within this genus (Keenan et al. 1998).

Xantho cf. poressa, a xanthid crab restricted to Ngrenehan Beach, featured a reddish-brown, moderately convex carapace with fine granulations and black-tipped chelae. This morphology aligns with xanthid species commonly found on sheltered, rocky intertidal substrates in the Indo-Pacific region (Ng et al. 2008).

Other taxa, such as *Grapsus albolineatus* (lined shore crab) and *Parasesarma daviei* (Davie's mangrove crab), were identified based on general coloration patterns and habitat associations described in existing literature. *G. albolineatus* is recognized by its agility, slender body form, and vivid coloration, often observed darting across rock surfaces. In contrast, *P. daviei* was typically associated with moist rock crevices, and exhibited a squared, maroon carapace with shallow lateral grooves, consistent with previous descriptions of sesarmid morphology (Ng et al. 2008).

Crustacean diversity indices

The diversity of crustacean communities varied across the five study sites, as reflected in the calculated values of the Shannon-Wiener diversity index (H′), Pielou's evenness index (E), and Margalef's species richness index (Dmg). These metrics offer complementary insights into the composition, distribution, and balance of species within each assemblage (Fachrul 2007).

Ngrenehan Beach exhibited the highest diversity (H′=2.18), indicating both relatively high species richness and a balanced distribution of individuals among species (Table 3). In contrast, Ngrawah Beach recorded the lowest diversity (H′=1.23), likely due to a combination of low species number and dominance by one or two taxa.

Pielou's evenness index (E) ranged from 0.56 to 0.97, reflecting variation in species dominance patterns across sites. The highest evenness was observed at Dadap Ayam (E=0.97), suggesting that individuals were evenly distributed among six species, with no single taxon dominating numerically. Conversely, Ngrawah's low evenness (E=0.56) suggests community imbalance, consistent with its lower species richness.

Margalef's richness index (Dmg) also showed inter-site variation, with the highest value at Ngrenehan (2.12), indicating moderate species richness based on classification thresholds. The lowest Dmg was observed at Ngrawah (1.03). After correcting the species count at Dadap Ayam from five to six, its updated richness value (Dmg=1.50) and evenness (E=0.97) reflect a more structured and balanced community than previously assumed.

Figure 4 illustrates the site-specific differences in diversity and richness indices, reinforcing the pattern that structurally complex and oxygen-rich sites tend to support more diverse crustacean assemblages.

Abiotic environmental parameters

Environmental conditions varied among the five study sites, particularly in terms of water temperature and dissolved oxygen (DO)-two key abiotic factors known to influence the structure and function of intertidal communities (Semprucci et al. 2019). As summarized in Table 4, water temperature ranged from 27.4°C at Dadap Ayam to 30.2°C at Pringjono, with Ngrenehan and Torohudan displaying intermediate and relatively stable values (~28.5°C). Ngrawah was slightly warmer (29.1°C), potentially reflecting its more exposed location and limited vegetation cover.

pH levels were relatively uniform across all sites, ranging from 7.4 to 7.8, typical of marine-influenced intertidal environments. Dadap Ayam was the most alkaline (pH 7.8), while Pringjono and Torohudan exhibited slightly lower values (pH 7.4-7.5). These conditions fall within a physiologically favorable range for crustaceans, particularly with regard to exoskeletal calcification and molting processes (Rahmadhani and Martuti 2023).

Dissolved oxygen (DO) levels exhibited the greatest spatial variation, with Dadap Ayam recording the highest average concentration (7.1 mg/L) and Ngrawah the lowest (4.3 mg/L). These differences suggest that microhabitat oxygen availability may play a key role in supporting or limiting species presence, especially in more enclosed or stagnant zones. The low DO at Ngrawah may indicate mild hypoxic conditions, which could contribute to its reduced species richness and evenness. Figure 5 visualizes the spatial gradients of temperature, pH, and DO across the five sites, highlighting the potential ecological implications of abiotic variability in shaping crustacean community patterns.

Table 2. Morphological features of representative crustacean species found at five karstic beaches in Gunungkidul, Indonesia

Species	Body size (mm)	Carapace coloration	Chela morphology	Habitat type	Diagnostic features
Coenobita scaevola (Forskål, 1775)	12-28	Pale brown to gray	Asymmetrical; left larger	Rocky and sandy intertidal	Short eyestalks, shell-dwelling, terrestrial tendency
Coenobita brevimanus Dana, 1852	25-35	Dark brown to black	Flattened, thick chelae	Sheltered rock crevices	Short antennae, stout body, reduced mobility
Scylla cf. serrata	60-110	Dark green to bluish	Large, spiny, robust	Tidal pools, brackish edge	Broad frontal lobe, polygonal carapace
Xantho poressa (Olivi, 1792)	30-50	Reddish-brown	Short, black-tipped	Rocky substrate	Convex carapace, granulated surface
Parasesarma daviei Shahdadi, Schubart & Mendoza, 2021	18-32	Maroon or deep red	Narrow, curved	Moist rock crevices	Square carapace, lateral grooves

Table 3. Diversity indices of crustacean communities at 5 karstic beaches in Gunungkidul, Indonesia

Beach	No. of Species (S)	No. of Individuals (N)	Shannon-Wiener (H′)	Pielou's Evenness (E)	Margalef's Richness (Dmg)
Pringjono	5	44	1.79	0.71	1.42
Torohudan	6	28	1.92	0.72	1.84
Ngrawah	4	24	1.23	0.56	1.03
Dadap Ayam	6	28	1.74	0.97	1.50
Ngrenehan	8	98	2.18	0.70	2.12

Relationship between abiotic factors and crustacean diversity

The relationship between abiotic parameters and crustacean diversity was examined using Pearson's correlation analysis between the Shannon-Wiener diversity index (H′) and three key environmental variables: temperature, pH, and dissolved oxygen (DO). As presented in Table 5, DO exhibited a strong positive correlation with H′ ($r=0.92$, $p<0.05$), indicating that higher oxygen availability is closely associated with increased species diversity. This suggests that DO is a critical factor shaping the composition and richness of intertidal crustacean assemblages in karstic environments.

By contrast, temperature showed a weak negative correlation with diversity ($r=-0.46$), which may reflect a modest inhibitory effect on species richness or evenness, possibly due to thermal stress, reduced oxygen solubility, or disrupted physiological processes. Although the result was not statistically significant, it may hold ecological relevance under scenarios of rising coastal temperatures associated with climate change.

The correlation between pH and H′ was minimal ($r=0.10$), suggesting that the narrow pH range observed across sites (7.4-7.8) exerted little influence on overall diversity. This aligns with previous findings that moderate pH variation rarely impacts adult crustaceans in stable marine-influenced intertidal systems.

These trends are visualized in Figure 6, which presents scatterplots of H′ against each environmental variable. The clear linear association between DO and diversity underscores the ecological importance of oxygen availability in maintaining species-rich crustacean communities along the karstic shoreline.

Community similarity among beaches

Cluster analysis using Bray-Curtis similarity was performed to evaluate the degree of overlap in crustacean species composition across the five karstic beach sites. The resulting dendrogram (Figure 7) revealed two primary clusters: the first consisting of Pringjono, Dadap Ayam, and Torohudan, and the second comprising Ngrenehan and Ngrawah.

The grouping of Pringjono, Dadap Ayam, and Torohudan indicates a shared species assemblage, likely resulting from similar microhabitat features such as rocky intertidal substrates, moderate wave exposure, and limited anthropogenic disturbance. These sites were consistently inhabited by generalist species, including *Coenobita scaevola*, *Ocypode pallidula*, and *Parasesarma daviei*, which are known for their ecological flexibility and ability to occupy both sandy and rocky microhabitats.

Table 4. Summary of abiotic parameters measured at 5 karstic beaches, Gunungkidul, Indonesia

Beach	Temperature (°C)	pH	Dissolved oxygen (mg/L)
Pringjono	30.2	7.4	5.2
Torohudan	28.6	7.5	6.0
Ngrawah	29.1	7.6	4.3
Dadap Ayam	27.4	7.8	7.1
Ngrenehan	28.5	7.7	6.4

Table 5. Pearson correlation matrix between Shannon-Wiener index (H′) and abiotic parameters

Variable	H′	Temperature (°C)	pH	DO (mg/L)
H′	1.00	-0.46	0.10	0.92
Temperature	-0.46	1.00	-0.20	-0.68
pH	0.10	-0.20	1.00	0.31
DO	0.92	-0.68	0.31	1.00

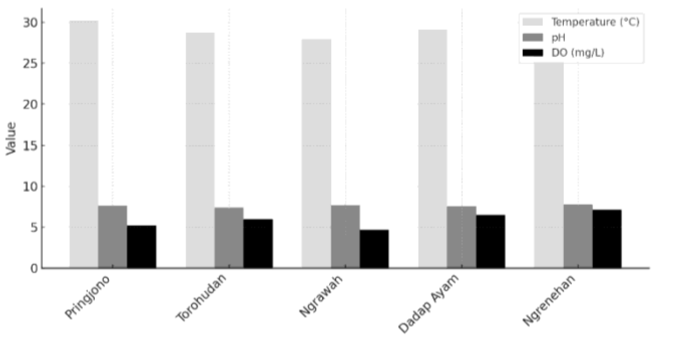

Figure 5. Variation in temperature, pH, and dissolved oxygen (DO) across 5 karstic beaches in Gunungkidul, Indonesia

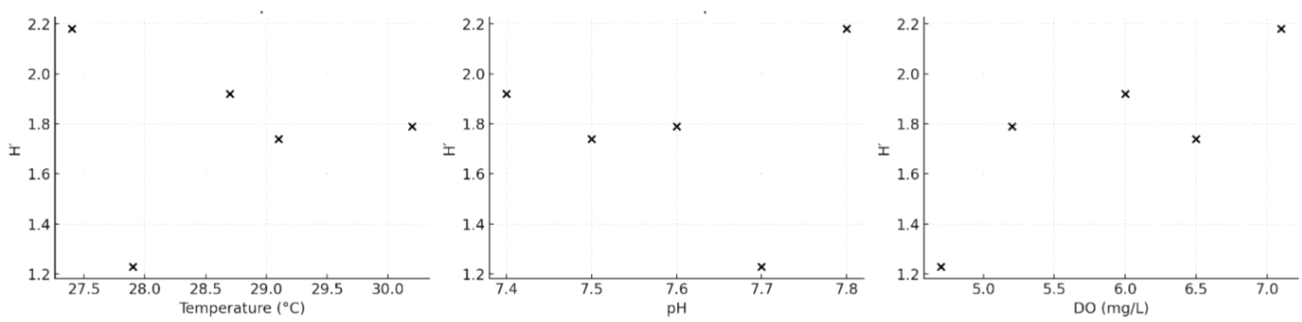

Figure 6. Scatterplots showing the relationship between Shannon-Wiener index (H′) and A. Temperature, B. pH, and C. Dissolved oxygen across five beach sites, Gunungkidul, Indonesia

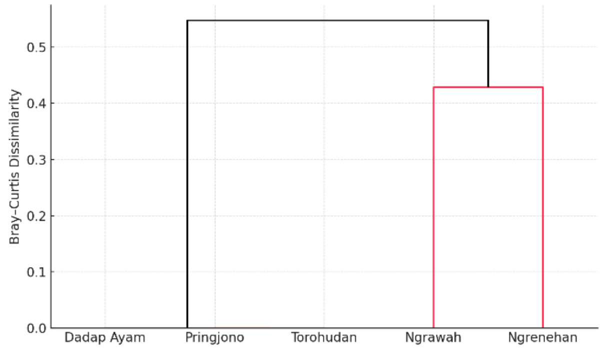

Figure 7. Cluster dendrogram showing similarity in crustacean species composition among five karstic beach sites based on Bray-Curtis similarity index

In contrast, Ngrenehan and Ngrawah formed a distinct cluster, characterized by the localized dominance of *Xantho cf. poressa* and *Scylla cf. serrata*. The limited species overlap with other sites suggests that these beaches harbor more specialized assemblages, shaped by unique environmental conditions. For instance, Ngrenehan's higher DO levels and more stable rock pools, along with Ngrawah's isolated and enclosed habitats, may support species less tolerant of fluctuating or disturbed conditions.

The spatial structuring revealed by the dendrogram highlights the ecological heterogeneity of karstic intertidal systems, even within a confined geographic area. These findings emphasize that each site contributes uniquely to the regional species pool, reinforcing the importance of site-specific conservation approaches that account for localized ecological dynamics and habitat variability.

Discussion

Species diversity and site-level patterns

The study revealed a moderate level of crustacean diversity across the five karstic beach sites, with Ngrenehan exhibiting the highest Shannon-Wiener index (H′=2.18) and Ngrawah the lowest (H′=1.23). This spatial variation highlights the influence of localized habitat conditions in shaping species assemblages. Beaches characterized by greater microhabitat complexity—including shaded crevices, tidal pools, and heterogeneous substrates, as seen at Ngrenehan and Dadap Ayam—tended to support higher species richness and evenness. In contrast, simpler and more physically exposed shores, such as Ngrawah, were associated with reduced diversity. This pattern aligns with previous findings in intertidal zones, where structural heterogeneity is known to enhance niche availability and reduce interspecific competition (Bertness 1999; Geng et al. 2020).

Among the recorded species, *Coenobita scaevola* was the most abundant and widely distributed, occurring at all sites and accounting for over 40% of total individuals. Its ecological success likely reflects its broad environmental tolerance and semi-terrestrial adaptations, which enable it to occupy both sandy and rocky habitats under varying intertidal conditions (Hazlett 1981; Emery et al. 2022). In contrast, taxa such as *Xantho cf. poressa*, *Scylla cf. serrata*, and *Grapsus albolineatus* exhibited more restricted distributions, generally confined to one or two sites. For instance, *X. cf. poressa* was found almost exclusively at Ngrenehan, likely due to its preference for shaded rock pools and moderate hydrodynamic conditions. This habitat specificity is consistent with previous observations of xanthid crabs in Indo-Pacific and Mediterranean rocky shores (Ng et al. 2008).

Notably, species richness (S) and total abundance (N) did not display a linear relationship across sites. Ngrawah, for example, harbored a moderate number of individuals (N=24) but only four species, suggesting the presence of ecological filters or the seasonal absence of less dominant taxa. Conversely, Ngrenehan supported both high richness (S=8) and abundance (N=98), reinforcing its role as a relatively stable habitat. Additionally, the updated data for Dadap Ayam revealed six species with relatively balanced abundances, reflecting a more equitable community structure than initially assumed. These findings emphasize the importance of microhabitat heterogeneity and abiotic moderation—such as oxygen availability and substrate diversity—in sustaining intertidal biodiversity in fragmented karst systems (Semprucci et al. 2019; Ord et al. 2024).

Environmental drivers of crustacean assemblages

Among the environmental variables measured, dissolved oxygen (DO) showed the strongest and most significant positive correlation with the Shannon-Wiener diversity index ($r=0.92$, $p<0.05$), indicating its critical role in structuring crustacean communities in karstic intertidal zones. High DO levels, such as those observed at Dadap Ayam and Ngrenehan, support aerobic metabolism and enhance survival and foraging activity, particularly for taxa sensitive to hypoxic conditions (Horn et al. 2021). In contrast, lower DO levels at Ngrawah likely restricted the number of viable species, contributing to the observed lower diversity.

Temperature exhibited a weak negative correlation with diversity ($r=-0.46$), suggesting that elevated surface temperatures, such as the 30.2°C recorded at Pringjono, may impose thermal stress on certain crustacean taxa. Prolonged exposure to high intertidal temperatures can limit species presence by affecting osmoregulation, molting cycles, or behavioral thermoregulation strategies (Stillman and Somero 2000; Rahmadhani and Martuti 2023). However, the relatively narrow temperature range observed in this study (27.4-30.2°C) may not have been extreme enough to impact the assemblage structure drastically.

The effect of pH was minimal ($r=0.10$), likely due to the narrow and near-neutral range (7.4-7.8) measured across sites. While ocean acidification is known to influence calcification and larval development in marine crustaceans (Kurihara 2008), the relatively stable pH conditions observed in these intertidal pools did not appear to be a major limiting factor for adult crustaceans during the sampling period. This aligns with findings from other tropical rocky shores where pH is less variable and rarely falls below critical thresholds (Geng et al. 2020).

Overall, the findings underscore DO as the most ecologically significant parameter influencing crustacean diversity in these karst beach ecosystems. Elevated DO enhances crustacean larval recruitment and aerobic performance, particularly in species with limited gill surface area (Marochi et al. 2021). Future studies should investigate diurnal DO fluctuations, sediment oxygen demand, and the role of primary producers such as macroalgae in modulating oxygen availability.

Ecological implications of community similarity

Cluster analysis based on Bray-Curtis similarity revealed two distinct groups of beach sites, reflecting differences in crustacean community composition likely shaped by microhabitat conditions. The grouping of Pringjono, Torohudan, and Dadap Ayam into a single cluster suggests these beaches share similar environmental and structural features—such as moderate wave exposure, patchy rocky substrates, and partial shading—that support comparable species assemblages. All three sites harbored core taxa like *Coenobita scaevola*, *Ocypode pallidula*, and *Parasesarma daviei*, which are known for their ecological generalism and remarkable ability to occupy both rocky and sandy microhabitats (Hazlett 1981; Ng et al. 2008).

In contrast, Ngrenehan and Ngrawah formed a separate cluster, characterized by more distinct and site-specific species such as *Xantho poressa* and *Scylla cf. serrata*. The exclusivity of these taxa to the Ngrenehan–Ngrawah cluster may result from specialized habitat features such as tidal pools, crevice-rich platforms, and relative isolation from anthropogenic disturbance. For instance, *X. poressa* is typically associated with shaded rocky substrates and may be sensitive to desiccation, restricting its occurrence to sites with stable microclimates (Simanullang et al. 2024). Similarly, *S. cf. serrata* requires semi-enclosed saline water pockets for foraging and refuge, which were more prevalent at Ngrawah.

This spatial structuring supports the hypothesis that crustacean assemblages in karst coastal systems are highly influenced by microhabitat heterogeneity rather than broad-scale geographic proximity. The results align with studies in other tropical coastal systems, where even small variations in substrate type, moisture retention, and tidal inundation can produce marked community differences (Bertness 1999; Ord et al. 2024).

These findings have implications for conservation planning, emphasizing that each site contributes uniquely to the regional species pool. Conservation strategies should, therefore, consider protecting multiple representative microhabitats rather than assuming ecological redundancy across adjacent coastal locations.

Methodological considerations and limitations

This study provides a baseline understanding of crustacean diversity in karstic beach ecosystems; however, several methodological limitations should be acknowledged. Sampling was conducted over a short temporal window and did not account for seasonal or tidal fluctuations, which may affect species detectability and abundance, particularly for migratory or cryptic taxa. Identification was based solely on external morphology, and while most specimens could be assigned to species or genus level, certain taxa (e.g., *Scylla cf. serrata*, *Ozius cf. rugulosus*) could not be confirmed without molecular or morphometric verification. In addition, abiotic parameters were measured only once per site, limiting the ability to capture diel or weather-related variability. Future research should include repeated sampling across multiple seasons and incorporate genetic tools to improve taxonomic resolution and ecological inference.

Implications for conservation and future research

The findings underscore the ecological importance of karstic beach ecosystems as reservoirs of intertidal crustacean biodiversity, encompassing both generalist species and habitat specialists. Ubiquitous taxa such as *Coenobita scaevola* contribute to habitat connectivity and ecological resilience, while more localized species like *Xantho poressa* and *Scylla cf. serrata* highlight the critical role of specific microhabitat features—such as crevices, shaded pools, and dissolved oxygen-rich substrates—in sustaining unique assemblages. The presence of diverse and spatially structured communities, even in narrow coastal zones, affirms the conservation value of tropical karst landscapes.

Effective management should prioritize the protection of microhabitat diversity across multiple beach sites rather than emphasizing single-site conservation. Strategies may include restricting unsustainable tourism development, controlling coastal pollution, and preserving natural hydrodynamics that promote substrate complexity and oxygenation. Given the patchy nature of karstic shorelines, site-specific approaches tailored to local environmental and biological conditions are essential. In this context, community-based initiatives involving local stakeholders—such as fishers, guides, and eco-tourism operators—can enhance stewardship and align conservation goals with sustainable use (Semprucci et al. 2019; Balata and Williams 2020; Evans et al. 2023).

Future research should incorporate temporal replication to account for seasonal and tidal variability in crustacean assemblages, including larval recruitment and reproductive timing. The integration of molecular tools, such as DNA barcoding, alongside stable isotope analysis and spatial modeling, will enable more accurate assessments of species identity, trophic relationships, and habitat use. These approaches are especially crucial in the face of accelerating anthropogenic pressures and climate change, which threaten the persistence of small-scale biodiversity hotspots in tropical coastal ecosystems.

In conclusion, this study documents the diversity and ecological patterns of intertidal crustaceans across five karstic beach sites in Gunungkidul, Indonesia. A total of 18 species were identified, with community structure varying notably between sites. Ngrenehan Beach showed the highest diversity and richness, while *Coenobita scaevola* emerged as the most widespread and dominant species. Dissolved oxygen was positively correlated with species diversity, underscoring its importance as a key environmental driver. Cluster analysis revealed two distinct site groups, highlighting the role of habitat heterogeneity in shaping assemblages. These findings emphasize the conservation value of karst coastal systems and the need for habitat-specific management strategies. Future research should incorporate seasonal monitoring, broader taxonomic resolution, and integrate local ecological knowledge for more effective biodiversity assessment and protection.

ACKNOWLEDGEMENTS

The authors express their sincere appreciation to local communities and coastal volunteers in Gunungkidul District, Central Java, Indonesia, for their support and assistance during fieldwork. We also thank the academic staff and students of Universitas Sebelas Maret, Surakarta, Indonesia, for logistical support and field identification. Technical guidance provided by regional marine biology experts is gratefully acknowledged.

REFERENCES

Balata F, Williams C. 2020. The role of coastal communities in the sustainable management of marine protected areas. In: Humphreys J, Clark RWE (eds). Marine Protected Areas: Science, Policy and Management. Elsevier, Amsterdam. DOI: 10.1016/B978-0-08-102698-4.00006-X.

Bertness MD. 1999. The Ecology of Atlantic Shorelines. Sinauer Associates, Sunderland, MA.

Bezuidenhout K, Nel R, Schoeman DS, Hauser L. 2021. Historic dispersal barriers determine genetic structure and connectivity in a supratidal sandy-beach brooder. Mar Ecol Prog Ser 674: 1-13. DOI: 10.3354/meps13839.

El-Naggar HA, Salem ESS, El-Kafrawy SB, Bashar MA, Shaban WM, El-Gayar EE Ahmed HO, Ashour M, Abou-Mahmoud ME. 2022. An integrated field data and remote sensing approach for impact assessment of human activities on epifauna macrobenthos biodiversity along the western coast of Aqaba Gulf. Ecohydrology 15 (3): e2400. DOI: 10.1002/eco.2400.

Emery KA, Kramer VR, Schooler NK, Michaud KM, Madden JR, Hubbard DM, Miller RJ, Dugan JE. 2022. Habitat partitioning by mobile intertidal invertebrates of sandy beaches shifts with the tides. Ecosphere 13 (2): e3920. DOI: 10.1002/ecs2.3920.

Evans LS, Buchan PM, Fortnam M, Honig M, Heaps L. 2023. Putting coastal communities at the center of a sustainable blue economy: A review of risks, opportunities, and strategies. Front Polit Sci 4: 1032204. DOI: 10.3389/fpos.2022.1032204.

Fachrul MF. 2007. Metode Sampling Bioekologi. Bumi Aksara, Jakarta. [Indonesian]

Fadin DIN, Gustiarti PO, Nisa ANK. 2023. The charm of Kanigoro Beach: Student tourism trends and social media effects. J Tour Sci 1 (3): 116-124. DOI: 10.62885/toursci.v1i3.153.

Geng X, Michael HA, Boufadel MC, Molz FJ, Gerges F, Lee K. 2020. Heterogeneity affects intertidal flow topology in coastal beach aquifers. Geophys Res Lett 47 (17): e2020GL089612. DOI: 10.1029/2020GL089612.

Handayani OT, Ngabekti S, Martuti NKT. 2016. Keanekaragaman Crustacea di ekosistem mangrove wilayah tapak Kelurahan Tugurejo Kota Semarang. Life Sci 5 (2): 100-107. [Indonesian]

Hartati R, Widianingsih W, Zainuri M, Wardianto Y. 2024. Using macrobenthic community structure and biotic indices to assess the ecological status of Wulan Estuary, Demak, Indonesia. Biodiversitas 25 (7): 3073-3087. DOI: 10.13057/biodiv/d250729.

Hazlett BA. 1981. The behavioral ecology of hermit crabs. Ann Rev Ecol Syst 12: 1-22. DOI: 10.1146/annurev.es.12.110181.000245.

Horn KM, Fournet ME, Liautaud KA, Morton LN, Cyr AM, Handley AL, Dotterweich MM, Anderson KN, Zippay ML, Hardy KM. 2021. Effects of intertidal position on metabolism and behavior in the acorn barnacle, *Balanus glandula*. Integr Org Biol 3 (1): obab010. DOI: 10.1093/iob/obab010.

Kamaluddin A, Winarno GD, Dewi DBS. 2019. Diversity of avifauna at the Elephant Training Center Way Kambas National Park. Jurnal Sylva Lestari 7 (1): 10-21. DOI: 10.23960/jsl1710-21.

Keenan CP, Davie PJF, Mann DL. 1998. A revision of the genus *Scylla* de Haan, 1833 (Crustacea: Decapoda: Portunidae). Raffles Bull Zool 46 (1): 217-245.

Kurihara H. 2008. Effects of CO_2-driven ocean acidification on the early developmental stages of invertebrates. Mar Ecol Progr Ser 373: 275-284. DOI: 10.3354/meps07802.

Marin IN, Tiunov AV. 2023. Terrestrial crustaceans (Arthropoda, Crustacea): Taxonomic diversity, terrestrial adaptations, and ecological functions. ZooKeys 1169: 95-162. DOI: 10.3897/zookeys.1169.97812.

Marochi MZ, Castellano GC, Freire CA, Masunari S. 2021. Carrying eggs in a semi-terrestrial environment: Physiological responses to water deprivation of mothers and embryos of the tree-climbing crab *Aratus pisonii*. J Exp Mar Biol Ecol 540: 151547. DOI: 10.1016/j.jembe.2021.151547.

Mokhtari H, Shahi S, Janani M, Reyhani MF, Zonouzi HRM, Rahimi S, Kheradmand HRS. 2015. Evaluation of apical leakage in root canals obturated with three different sealers in presence or absence of smear layer. Iran Endod J 10: 131-134.

Ng PKL, Guinot D, Davie PJF. 2008. Systema Brachyurorum: Part I. An annotated checklist of extant Brachyuran crabs of the world. Raffles Bull Zool 17: 1-286.

Nurcahyo FD, Zen HM, ‘Azizah HPN, Nugroho GD, Ramdhun D, Yap CK, Indrawan M, Setyawan AD. 2024. The community structure of Echinodermata (Echinoidea and Holothuroidea) on seagrass ecosystem in Gunungkidul, Yogyakarta, Indonesia. Biodiversitas 25 (11): 4561-4571. DOI: 10.13057/biodiv/d251155.

Ord TJ, Surovic EA, Vaz DF, Irisarri I. 2024. Abiotic factors that prompt major ecological transitions: Are fish on land to escape an intolerable aquatic environment? Funct Ecol 38 (12): 2648-2664. DOI: 10.1111/1365-2435.14672.

Paujiah E, Cahyanto T, Sariningsih I, Setya W, Zulfahmi I. 2020. Density of mollusks community from a rocky intertidal zone in Karang Papak Coastal, West Java, Indonesia. J Phys: Conf Ser 1467 (1): 012011. DOI: 10.1088/1742-6596/1467/1/012011.

Pielou EC. 1977. Mathematical Ecology. Wiley, New York.

Rahmadhani GW, Martuti NKT. 2023. Keanekaragaman makrozoobentos di sekitar alat pemecah ombak wilayah pesisir Kota Semarang sebagai data awal upaya konservasi. Indones J Math Nat Sci 46 (2): 74-82. [Indonesian]

Rahmawati YF, Putri RA, Prakarsa TBP, Muflihaini MA, Aliyani YP. 2021. Diversity and distribution of molluscs in the intertidal zone of Nglambor Beach, Gunung Kidul, Yogyakarta. BIO Web Conf 33: 01002. DOI: 10.1051/bioconf/20213301002.

Rustikasari I, Paransa DSJ, Kaligis EY, Ompi M, Pelle WE, Pratasik SB. 2021. Identifikasi kepiting secara morfologi di daerah pantai pesisir berbatu di Teluk Manado. Jurnal Ilmiah PLATAX 9 (2): 210-216. [Indonesian]

Semprucci F, Facca C, Ferrigno F, Balsamo M, Sfriso A, Sandulli R. 2019. Biotic and abiotic factors affecting seasonal and spatial distribution of meiofauna and macrophytobenthos in transitional coastal waters. Estuar Coast Shelf Sci 219: 328-340. DOI: 10.1016/j.ecss.2019.02.008.

Shofi S. 2021. Struktur komunitas *Uca* spp. (Crustacea: Decapoda: Ocypodidae) di kawasan hutan mangrove Desa Banyuurip, Kabupaten Gresik. [Undergraduate thesis]. Universitas Islam Negeri Maulana Malik Ibrahim, Malang. [Indonesian]

Simanullang DR, Bengen DG, Natih NM, Zamani NP. 2024. Spatial distribution and association of gastropods in mangrove ecosystem in the coast of Nusa Lembongan and Perancak Bali. Biodiversitas 25 (6): 2382-2392. DOI: 10.13057/biodiv/d250607.

Snelgrove PVR, Berghe EV, Miloslavich P et al. 2016. Global Patterns in Marine Biodiversity. In: United Nations (eds). The First Global Integrated Marine Assessment World Ocean Assessment I. Cambridge University Press, Cambridge.

Söderhäll I. 2016 Crustacean Hematopoiesis. Dev Comp Immunol 58: 129-141. DOI: 10.1016/j.dci.2015.12.009.

Stillman JH, Somero GN. 2000. A comparative analysis of the upper thermal tolerance limits of eastern Pacific porcelain crabs, genus *Petrolisthes*: influences of latitude, vertical zonation, acclimation, and phylogeny. Physiol Biochem Zool 73: 200-208. DOI: 10.1086/316738.