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EPIFAUNAL GASTROPODS DIVERSITY IN SMALL ISLAND WATERS OF BATAM CITY BORDER REGION

KEANEKARAGAMAN *GASTROPODA* EPIFAUNA DI PERAIRAN PULAU-PULAU KECIL DI DAERAH PERBATASAN KOTA BATAM

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Abstract

This research examines gastropod epifauna diversity across ten small islands in Batam City, which directly borders international shipping lanes. Data collection was occurred in rocky intertidal zones using sweep sampling. The inventory revealed 12 gastropod species from 8 families, with a total abundance of 7,913 individuals. *Nerita undata*, *Trochus marmoratus*, and *Euchelus atratus* species dominated, contributing 56.80% to the total individuals found. The Shannon-Wiener index (H') values ranged from 1.458 to 2.103, indicating moderate diversity with moderate ecological pressure. The relatively high evenness index (E) (0.762–0.921) shows an even distribution of individuals between islands, while the low dominance index (C) (0.147–0.371) confirms the absence of genuinely dominant species. Pearson correlation analysis reveals that water clarity significantly correlated with diversity ($P < 0.05$), whereas salinity and current velocity influence species distribution. Anthropogenic activities manifest through TDS and pH value variations affecting gastropod community stability, particularly in shipping and shipbuilding industries. These results emphasize the importance of environmental quality monitoring and implementation of sustainable conservation programs in Batam City's border areas. Future research should highlight population genetic dynamics and adaptive responses of gastropods to habitat changes. A holistic approach involving stakeholders becomes necessary to maintain biodiversity conservation and ecosystem sustainability.

Keywords: Anthropogenic activities; Biodiversity; Environmental quality; Gastropods epifauna

Abstrak

Penelitian ini bertujuan mengkaji keanekaragaman Gastropoda epifauna di sepuluh pulau kecil Kota Batam, yang berbatasan langsung dengan jalur pelayaran internasional. Pengumpulan data dilakukan pada zona intertidal berbatu dengan metode sweep sampling. Sebanyak 12 spesies Gastropoda dari 8 famili berhasil diinventarisasi, dengan total kelimpahan 7.913 individu. Spesies Nerita undata, Trochus marmoratus, dan Euchelus atratus mendominasi dan berkontribusi 56,80% terhadap total individu yang ditemukan. Nilai indeks Shannon-Wiener (H') berkisar antara 1,458 hingga 2,103, mengindikasikan keanekaragaman sedang dengan tingkat tekanan ekologis moderat. Indeks keseragaman (E) yang relatif tinggi (0,762–0,921) menunjukkan distribusi individu yang cukup merata antarpulau, sedangkan indeks dominansi (C) yang rendah (0,147–0,371) menegaskan tiadanya spesies yang benar-benar mendominasi. Analisis korelasi Pearson menunjukkan bahwa kecerahan perairan berhubungan signifikan dengan keanekaragaman ($P < 0,05$), sementara salinitas dan kecepatan arus memengaruhi distribusi spesies. Aktivitas antropogenik, terutama pelayaran dan industri perkapalan, terindikasi melalui variasi nilai TDS dan pH yang memengaruhi stabilitas komunitas Gastropoda. Hasil ini menekankan pentingnya pemantauan kualitas lingkungan serta pelaksanaan program konservasi berkelanjutan di kawasan perbatasan Kota Batam. Penelitian lanjutan diharapkan dapat menyoroti dinamika genetika populasi dan respon adaptif Gastropoda terhadap perubahan habitat. Pendekatan holistik, melibatkan pemangku kepentingan, diperlukan untuk menjaga kelestarian keanekaragaman hayati dan keberlanjutan ekosistem.

***Kata Kunci**: Aktivitas antropogenik; Gastropoda epifauna; Keanekaragaman hayati; Kualitas lingkungan*

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INTRODUCTION

Gastropods represent one of the mollusk groups that have evolved since the Paleozoic era and continue to play vital roles in marine ecosystems (Frýda, 2013). High adaptability allows gastropods to inhabit various habitats, such as sandy, muddy, and rocky beaches (Dharma, 2005). Based on habitat preferences, gastropods are classified into epifauna living on substrate surfaces and infauna living within substrates in intertidal regions (Raiba et al., 2022). Benthic epifauna includes animals living on or attaching to the seabed. The majority, approximately 80%, of large animals found in benthic regions fall into this category (Walag, 2022). This high adaptability makes gastropods one of the most diverse groups in marine ecosystems (Persulessy & Arini, 2018).

Despite its limited area, the intertidal zone has high environmental variability supporting significant biodiversity (Katili, 2011). Recent studies show that gastropod abundance and morphology in this area strongly depend on ecological dynamics (Gemelli et al., 2020). For example, Southeast Asian research demonstrates that changes in environmental parameters such as temperature, salinity, and pH significantly affect intertidal gastropod distribution and abundance (Mawardi et al., 2023). High-density species demonstrate better adaptation abilities in occupying space and thriving in dynamic environments (Rahmawati, 2014).

Anthropogenic pressure has become a primary concern in gastropod conservation in coastal regions. Recent studies reveal that human activities affect native species composition and drive non-native species invasion (Nurinsiyah & Hausdorf, 2019). The sessile characteristics and slow movement of gastropods make them effective bioindicators for assessing aquatic ecosystem quality (Andriati & Syamsul, 2020). Ecologically, gastropods are crucial in food chains as detritivores that decompose organic litter and circulate suspended matter in waters (Ira et al., 2015; Jamil et al., 2016). Benthic organisms such as gastropod groups show high sensitivity to environmental pollution activities, both domestic waste and chemical waste, from oil and lubricant spills due to ship and fishing boat activities (Mawardi et al., 2023). Animals living on seabed substrates with low mobility face relatively more exposure and accumulate pollutants from the environment (Stewart et al., 2021). Pollutants from household waste and ship oil spills accumulate as hazardous metal sources in the environment, affecting various animal species, including humans, who depend on marine resources for daily needs (Akpoghelie et al., 2021). Disturbances arising from various anthropogenic activities can lead to habitat loss and ecological niches as well as the existence of gastropod communities as one of the key species in their environment (Purnama et al., 2024a; Purnama et al., 2024b).

Water physicochemical parameters serve as key factors affecting gastropod distribution and abundance. Research shows gastropods can survive in temperature ranges of 0–48 °C and salinity of 25–35‰ (Raiba et al., 2022; Siswansyah & Kuntjoro, 2023; Wahida et al., 2024), with optimal pH between 6.5–7.5 (Raiba et al., 2022). However, drastic changes in these parameters can affect gastropod survival and reproduction.

The research location encompasses uninhabited small islands in Batam City's border waters, where the study area directly borders the Philip Strait International shipping lane. This strategic position subjects these waters to various high anthropogenic pressures, including domestic waste, the shipbuilding industry, oil spills, ports, anchor laying, tourism activities, and hospitality, which rapidly develop in Batam City's coastal areas. Despite the strategic location, no comprehensive studies have examined epifaunal gastropod diversity in this region. This research fills this knowledge gap by conducting an inventory and diversity analysis of epifaunal gastropods in the intertidal zone. The research results should serve as baseline data for invasive species management and future environmental quality biomonitoring program development.

MATERIALS AND METHODS

The research took place from September to November 2024 across ten uninhabited small islands in Batam City's border area, including Kajang Island, Piring Island, Layang Island, Manek Island, Catur Island, Kapal Besar Island, Kapal Kecil Island, Mersim Island, Meriam Island, and Subar Island. Administratively, the research location falls within Sekanak Raya Village, Belakang Padang District, Batam City (Figure 1).

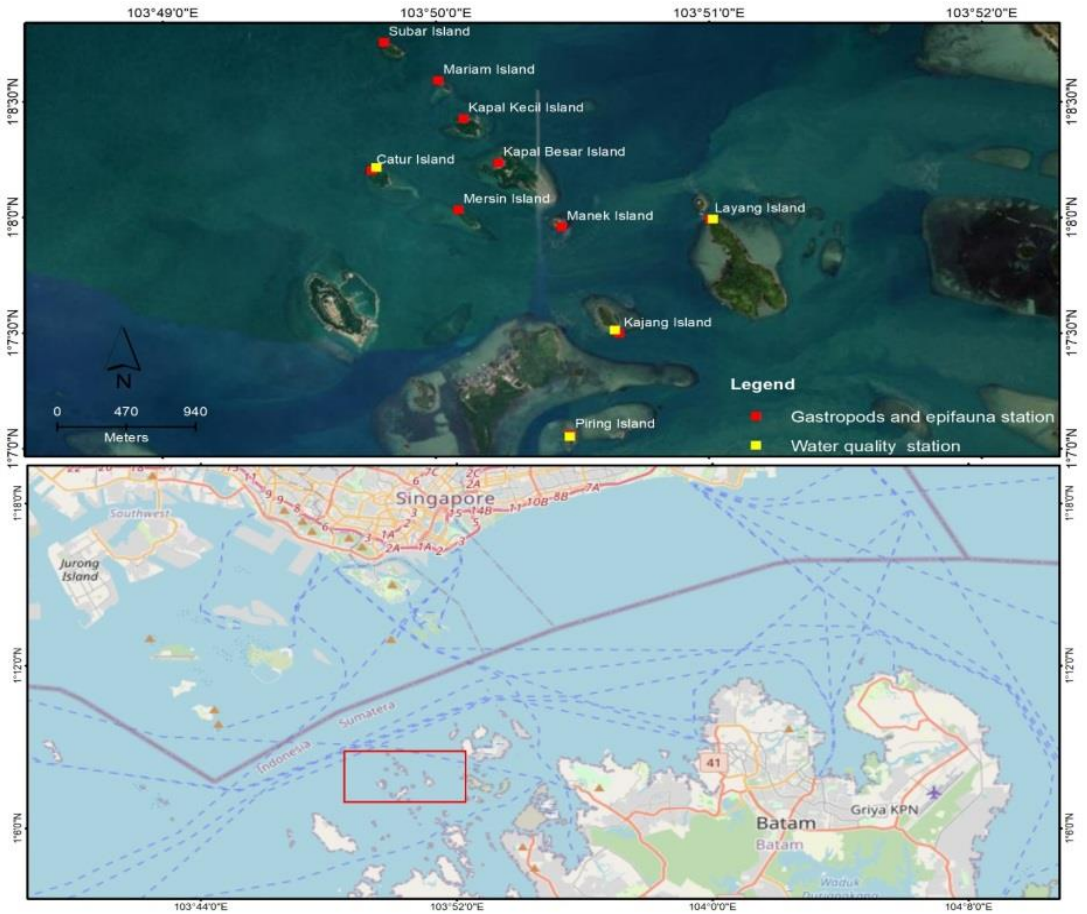

Figure 1. Map of sampling locations and water quality measurement sites

Data Collection

Epifaunal gastropod sampling occurred in rocky intertidal zones during low tide using a sweep sampling technique following protocols developed by Underwood and Chapman (2013). The collection process included gathering all discovered gastropods, grouping them by morphology, counting individual numbers, and recording discovery locations. Specimens from each discovered species were preserved using 70% ethanol and transported to the Coastal Waters Ecology Laboratory, Universitas Riau Kepulauan, for further identification.

Species Identification

Gastropod identification utilized Dharma's (1988) identification key and the General Shell Portal Since 1993 version "No.3" updated 2020 database http://idscaro.net/sci/index.htm. Identification verification involved comparing specimen morphological characteristics with descriptions and illustrations from recent Indo-Pacific gastropod literature (Tan & Clements, 2008; Abbott & Dance, 2020), MolluscaBase (2020) World Register of Marine Species. http://www.marinespecies.org and Global Biodiversity Information Facility (GBIF) (2023) https://www.gbif.org

Environmental Parameters

Water physicochemical parameters underwent in-situ measurement concurrent with gastropod sampling to obtain environmental condition profiles at each observation location. Water temperature measurement utilized a digital thermometer in degrees Celsius (°C), while acidity level (pH) measurement employed a portable pH meter. Water salinity measurement used a refractometer in parts per mil units (‰), while dissolved oxygen (DO) measurement utilized a meter in milligrams per liter (mg/L). Total dissolved solids (TDS) measurement employed a TDS meter in milligrams per liter (mg/L). Water clarity measurement utilized a Secchi disk in meters (m), and current velocity measurement used a current meter in meters per second (m/s). These environmental parameter

measurements occurred at each observation station to obtain representative data about water physicochemical conditions that might affect gastropod distribution and abundance.

Data Analysis

Species Composition

Species composition calculation uses the formula according to Brower and Zar (1990), Kj= (∑ni)/N × 100%. Where Kj= species composition (%); ∑ni= number of individuals of species i; and N= total number of individuals at each station.

Shannon-Wiener Diversity Index (H')

Species diversity calculation uses the Shannon-Wiener index (Shannon, 1948), H'= ∑ Pi ln Pi. Where H'= Shannon-Wiener diversity index (diversity index); Pi= number of individuals of species i per total number of individuals (ni/N); ni= number of individuals of species i; N= total number of individuals.

According to Krebs (1985), species diversity levels are categorized into three levels based on Shannon-Wiener index values (H'). H' values less than 1 indicate low species diversity. Species diversity falls into the moderate category when H' values range between 1 and 3. Meanwhile, H' values greater than 3 indicate high species diversity. This categorization reflects community stability, where higher H' values demonstrate more stable communities. H'>3= high species diversity (stable).

Dominance Index

The dominance index (C) measures the extent to which one biota group dominates other groups. Substantial dominance leads to unstable or stressed communities. The dominance index calculation uses Simpson's dominance index formula (Odum, 1993), $C= \sum(pi)^2$. Where C= Simpson's dominance index; ni= number of individuals per species; and N= total number of individuals across all species.

Evenness Index

Evenness is calculated using Pielou's index (Pielou, 1975), E= H'/ln S. Where E= Simpson's dominance index; H'= number of individuals of each species; and S= total number of individuals of all species. According to Krebs (1999), evenness index values (E) are classified into three categories reflecting community stability levels. Evenness falls into the low category when E values range from over 0 to 0.5, indicating stressed communities with uneven distribution of individuals among species. E values ranging from over 0.5 to 0.75 show moderate evenness, characterizing communities in unstable conditions. Meanwhile, E values ranging from over 0.75 to 1 indicate high evenness, depicting stable communities with relatively even distribution of individuals among species.

RESULTS

Composition and Abundance

Based on the research results in Table 1, the study found 12 epifaunal gastropod species belonging to 8 families, with a total abundance of 7,913 individuals across ten small islands of Batam City. The discovered species include *Euchelus atratus* (Gmelin, 1791), *Nerita (Linnerita) polita* (Linnaeus, 1758), *Nerita undata* (Linnaeus, 1758), *Reishia bitubercularis* (Lamarck, 1822), *Gyrineum natator* (Röding, 1798), *Mauritia arabica* (Linnaeus, 1758), *Turbo (Lunatica) marmoratus* (Linnaeus, 1758), *Planaxis sulcatus* (Born, 1778), *Nerita (Argonerita)* ocellata (Le Guillou, 1841), *Tectus niloticus* (Linnaeus, 1767), *Trochus maculatus* (Linnaeus, 1758), and *Pictocolumbella ocellata* (Link, 1807).

N. undata represents the species with the highest composition at 1,832 individuals (23.15%), followed by *T. marmoratus* with 1,492 individuals (18.86%), and *E. atratus* with 1,170 individuals (14.79%). These three species dominate with total contribution reaching 56.80% of total individuals found. The species with the lowest abundance appears to be *M. arabica* with only 3 individuals (0.04%) found in Piring Island (1 individual) and Layang Island (2 individuals). Low abundance also characterizes *T. maculatus* with 30 individuals (0.38%) and *R. bitubercularis* with 39 individuals (0.49%). These three species together contribute only 0.91% of total individuals found.

Table 1. Composition and abundance of epifaunal gastropods in ten small islands of Batam City

Species	Local name	1	2	3	4	5	6	7	8	9	10	Total	(%)
Euchelus atratus	*Siput sanggul*	58	47	236	43	56	175	172	214	72	97	1,170	14.79
Nerita polita	*Siput nonam*	24	0	36	7	186	150	0	0	0	0	403	5.09
Nerita undata	*Siput batu*	94	19	765	149	112	72	156	252	111	102	1,830	23.15
Reishia bitubercularis	*Siput duri*	0	6	2	5	2	1	5	7	3	8	39	0.49
Gyrineum natator	*Siput cokoh*	0	0	0	57	86	66	41	129	96	23	498	6.29
Mauritia arabica	*Siput kucing*	0	1	2	0	0	0	0	0	0	0	3	0.04
Turbo marmoratus	*Siput bulan*	206	46	358	145	170	86	210	157	56	58	1,490	18.86
Planaxis sulcatus	*Siput wangi*	0	0	0	136	56	71	129	210	14	129	745	9.42
Nerita ocellata	*Siput nyiru*	0	0	0	115	125	57	127	47	186	211	868	10.97
Tectus niloticus	*Siput lola*	11	13	146	0	0	0	0	0	0	0	170	2.15
Trochus maculatus	*Siput dara*	0	5	7	2	0	5	0	0	2	9	30	0.38
Pictocolumbella ocellata	*Siput rantai*	0	0	0	105	96	72	11	75	89	215	663	8.38
Total		393	137	1,552	764	889	755	851	1,091	629	852	7,913	100

Note: 1= Kajang Island; 2= Piring Island; 3= Layang Island; 4= Manek Island; 5= Kapal Besar Island; 6= Kapal Kecil Island; 7= Mersim Island; 8= Catur Island= 9= Meriam Island; 10= Subar Island

From a spatial distribution perspective, interesting variations exist among observation locations. Layang Island recorded the highest abundance with 1,552 individuals, dominated by *N. undata* (765 individuals) and *T. marmoratus* (358 individuals). Conversely, Piring Island showed the lowest abundance with only 137 individuals. Several species, including *E. atratus*, *N. undata*, and *T. marmoratus* ware present at all observation locations, indicating high adaptability to various environmental conditions. The spatial distribution pattern also reveals specific habitat preferences for several species. *P. sulcatus*, *N. ocellata*, and *P. ocellata* appeared only in specific locations, particularly in the eastern islands of the research area. Meanwhile, *T. niloticus* limited its distribution to three western islands (Kajang Island, Piring Island, and Layang Island) with 170 individuals. This pattern indicates environmental factors affecting this species's distribution.

Ecological Indices

Ecological index calculations show value variations across research locations (Table 2). Ecological index values vary across ten research locations. The Shannon-Wiener diversity index (H') at all locations falls within the moderate diversity category with values ranging from 1.458–2.103. The highest H' value appears in Manek Island (2.103), while the lowest value occurs in Kajang Island (1.458). The average H' value equals 1.852 ± 0.215, indicating that gastropod communities in the research area maintain relatively stable diversity levels.

Table 2. Ecological indices of epifaunal gastropods in ten small islands of Batam City

Location	Number of species	Number of individuals	H'	E	C
Kajang Island	5	393	1.458	0.906	0.371
Piring Island	7	137	1.729	0.889	0.225
Layang Island	8	1552	1.584	0.762	0.316
Manek Island	10	764	2.103	0.913	0.156
Catur Island	9	889	2.024	0.921	0.147
Kapal Besar Island	10	755	2.067	0.898	0.162
Kapal Kecil Island	8	851	1.897	0.912	0.178
Mersim Island	8	1091	1.816	0.873	0.195
Meriam Island	9	629	1.893	0.862	0.183
Subar Island	9	852	1.947	0.886	0.169
Average ± Stdev.	8.3 ± 1.5	791.3 ± 388.2	1.852 ± 0.215	0.882 ± 0.045	0.210 ± 0.077

Pielou's evenness index (E) shows high value across all locations, ranging from 0.762–0.921, with the highest value appearing on Catur Island (0.921) and the lowest on Layang Island (0.762). The average E value of 0.882 ± 0.045 indicates an even distribution of individuals among species and

reflects stable community conditions. Simpson's dominance index (C) supports this with relatively low values, ranging from 0.147–0.371, averaging 0.210 ± 0.077. The highest dominance value occurs on Kajang Island (0.371) and the lowest on Catur Island (0.147), indicating no strong dominance by particular species at research locations. The number of species found varies across locations, ranging from 5–10. Manek Island and Kapal Besar Island contain the highest number of species (10 species), while Kajang Island shows the lowest (5 species). The average number of species equals 8.3 ± 1.5, showing moderate variation in species richness across locations. Individual numbers also show considerable variation, ranging from 137–1,552 individuals, averaging 791.3 ± 388.2 individuals per location. The highest individual abundance appears in Layang Island (1,552 individuals) and the lowest in Piring Island (137 individuals).

Environmental Parameter

Effects waters physicochemical parameter measurements at research locations show site variations (Table 3). Dissolved oxygen (DO) levels range between 8.0–9.8 mg/L with an average of 8.90 ± 0.82 mg/L, where the highest value occurs in Layang Island and the lowest in Catur Island. These values indicate good water conditions supporting gastropod life.

Table 3. Water physicochemical parameters at research locations

Parameters	Unit	Kajang Island	Piring Island	Layang Island	Catur Island	Average ± Stdev.
Dissolved oxygen (DO)	mg/L	8.4	9.4	9.8	8	8.90 ± 0.82
Temperature	°C	30	30	31	30	30.25 ± 0.50
Total dissolved solids (TDS)	mg/L	31.07	73.04	42.16	62.82	52.27 ± 19.17
pH	-	8.56	8.6	8.8	8.5	8.62 ± 0.13
Salinity	‰	31	26	29	30	29.00 ± 2.16
Current velocity	m/s	2.39	5.42	6.83	3.85	4.62 ± 1.93
Brightness	m	2	3	3	3	2.75 ± 0.50

Water temperature remains relatively stable across all locations, ranging from 30–31 °C, averaging 30.25 ± 0.50 °C. This slight temperature variation indicates uniform thermal conditions in the research area. Total dissolved solids (TDS) show considerable variation across locations ranging from 31.07–73.04 mg/L with an average of 52.27 ± 19.17 mg/L. The highest TDS value occurs in Piring Island, while the lowest appears in Kajang Island. Water acidity level (pH) falls within the alkaline range at 8.50–8.80 with an average of 8.62 ± 0.13, showing relatively uniform conditions across locations. Water salinity varies between 26–31‰ with an average of 29.00 ± 2.16‰, with the highest value on Kajang Island and the lowest on Piring Island. Current velocity shows significant variation across locations ranging from 2.39–6.83 m/s with an average of 4.62 ± 1.93 m/s, where the strongest currents occur in Layang Island and the weakest in Kajang Island. Water clarity levels remain relatively uniform across most locations, ranging from 2–3 m, with an average of 2.75 ± 0.50 m. Kajang Island shows the lowest clarity (2 m), while other locations show equal values (3 m). Water physicochemical parameters at research locations remain within supporting ranges for gastropod life despite value variations across locations that might affect species distribution and abundance.

Table 4. Pearson correlation coefficients between environmental parameters and gastropod abundance and diversity

Environmental parameters	Diversity index (H')	Evenness index (E)	Dominance index (C)
Dissolved oxygen (mg/L)	-0.312	-0.584	0.467
Temperature (°C)	0.577	-0.333	-0.333
Total dissolved solids (TDS) (mg/L)	0.236	-0.127	-0.156
pH	-0.095	-0.612	0.442
Salinity (‰)	-0.718*	0.218	0.289
Current velocity (m/s)	-0.156	-0.645*	0.512
Water clarity (m)	0.845*	-0.067	-0.378

Note: *= significant correlation

Table 4 shows the correlations between environmental parameters and gastropod abundance and diversity: pH values were negatively correlated with evenness (r= -0.612) and positively correlated with dominance (r= 0.442). Dissolved oxygen showed a positive correlation with dominance (r= 0.467), while TDS values showed a weak positive correlation with diversity (r= 0.236). Water temperature was positively correlated with diversity (r= 0.577).

DISCUSSION

Gastropod Community Characteristics

Distribution patterns and abundance of epifaunal gastropods across ten small islands of Batam City show distinctive characteristics of rocky intertidal zone communities. The dominance of *N. undata* (23.15%) and *T. marmoratus* (18.86%) indicates the high adaptation capabilities of these two species to intertidal environmental conditions. This aligns with Tan and Clements (2008) findings reporting *Nerita* genus dominance in rocky intertidal zones across Southeast Asia, where morphological and behavioral adaptation capabilities allow survival in fluctuating environmental conditions. *N. undata* (*Neritidae*) represents small to medium-sized euryhaline gastropods widely distributed from marine to freshwater habitats (Tudu et al., 2017). These herbivores inhabit middle to upper intertidal zones (Fukumori & Kano, 2014; Islamy & Hasan, 2020). Heavy shells function to withstand drying and protect from predators. *Nerita* snails grow to 10 mm; ecological records show they developed through the free-swimming veliger (Fukumori & Kano, 2014).

Gastropod spatial distribution patterns at research locations show significant variation, from widespread species like *E. atratus*, *N. undat*a, and *T. marmoratus*, to those limited to specific locations like *M. arabica* and *T. niloticus*. According to Williams and Morritt (1995), such distribution patterns commonly occur in intertidal gastropods, where species show broader tolerance to environmental variations while others demonstrate more specific habitat preferences. This pattern might relate to habitat preferences and utilization pressure mainly for *T. niloticus*, which is found only in three western islands, considering this species holds economic value (Setiawan et al., 2019). Ideal environments and abundant food supply significantly influence animal populations in an area (Fitriadi et al., 2023; Kudratov et al., 2023).

Species dominance at research locations depends on several factors. *N. undata* and *T. marmoratus*, dominating most locations, demonstrate strong adaptive characteristics, including strong attachment ability to rocky substrates and tolerance to temperature and salinity variations (Krug et al., 2021). Conversely, the low abundance of *M. arabica* (0.04%) might relate to specific habitat preferences and sensitivity to anthropogenic disturbances, as Mawardi et al. (2023) reported in gastropod habitat characteristic studies in Indonesia. Compared to similar research in Southeast Asia, the species composition found (12 species) appears relatively lower than Tan and Clements's (2008) findings in Singapore (19 species) and Printrakoon et al. (2008) in Thailand (47 species). This difference might relate to anthropogenic pressure intensity in Batam City's border area, which serves as an international shipping lane. Nurinsiyah and Hausdorf (2019) report that shipping activities and coastal development can affect gastropod species richness through habitat quality changes and alien species introduction. Habitat characteristics of rocky substrate with measured environmental parameter variations contribute to observed species composition patterns. Specifically, high current velocity in Layang Island (6.83 m/s) correlates with the highest abundance (1,552 individuals), showing gastropod community adaptation to strong hydrodynamic conditions. This aligns with Ishida's (2001) research finding that some intertidal gastropod species thrive in locations with strong currents due to increased availability of food and oxygen.

The highest H' value appears in Manek Island (2.103) yet remains lower than Tan and Clements (2018) records in Singapore waters (H'= 2.89). Nevertheless, this H' range exceeds Ishida's (2001) report in Tokyo port (H'= 0.98–1.45), experiencing very intensive anthropogenic pressure. H' value ranges at research locations reflect gastropod communities under moderate ecological pressure. The evenness index (E) in this research ranges from 0.762 to 0.921, with the lowest value on Layang Island (0.762) and the highest on Catur Island (0.921). Low E in Layang Island coincides with the dominance of *N. undata* (765 individuals) and *T. marmoratus* (358 individuals), creating an uneven

distribution of individuals among species. According to Chemello and Milazzo (2002), the dominance of several species in intertidal communities typically relates to superior adaptation capabilities against environmental pressure and competition.

Gastropod community stability across these ten small islands is still classified as moderate. Eight out of ten islands show E values in the mild category ($0.5<E\leq0.75$). These findings align with the study of Amini-Yekta et al. (2019), who stated that E values in such range commonly occur in port areas or shipping lanes, where anthropogenic disturbances arise regularly. However, gastropod communities still maintain relatively stable structures. Comparisons with similar research show that ecological index values at this location reflect characteristics commonly found in tropical port gastropod communities. Halim et al. (2019) documented H' ranges of 0.34–1.21 in Penang Island, Malaysia, while Ocampo et al. (2014) recorded H' values of 1.1–1.4 in Manila waters. These similar value ranges indicate adaptation patterns among epifaunal gastropod communities in Southeast Asian port areas, particularly when facing various anthropogenic pressures, such as shipping activities, coastal infrastructure development, and marine pollution.

Environmental Parameter Effects

Pearson correlation analysis between environmental parameters and ecological indices (Table 4) reveals several significant relationships affecting gastropod community structure at research locations. Water clarity shows a strong positive correlation with the diversity index ($r= 0.845$, $P <0.05$), indicating the critical role of light penetration in supporting primary productivity that indirectly affects food availability for gastropods. This aligns with Afwanuddin et al.'s (2019) findings, which reported significant effects of water clarity on gastropod distribution in Aceh coastal waters. Salinity shows a strong negative correlation with diversity ($r= -0.718$, $P <0.05$), indicating that salinity increases usually decrease species diversity. This condition is explained by different osmotic tolerance limits in each gastropod species (Halim et al., 2019). Current velocity correlates negatively with evenness ($r= -0.645$, $P <0.05$), showing that strong currents usually create uneven species distribution. Veiga et al. (2015) found that only species with special morphological adaptations can survive in strong current conditions.

The main limiting factors at research locations reflect pH values showing a negative correlation with evenness ($r= -0.612$) and a positive correlation with dominance ($r= 0.442$). pH variations exceeding optimal gastropod tolerance ranges can cause physiological stress and affect shell formation (Barclay et al., 2019). Dissolved oxygen shows a positive correlation with dominance ($r= 0.467$), indicating that good oxygenation conditions can support the dominance of certain species with broader physiological tolerance. Anthropogenic activities in the research area, particularly from shipping and coastal industry activities, reflected in TDS value variations showing a weak positive correlation with diversity ($r= 0.236$). Despite a weak correlation, Olson and Hawkins (2017) research shows that long-term TDS increases can affect gastropod survival and reproduction. Water temperature positively correlates with diversity ($r= 0.577$). However, extreme temperature fluctuations due to anthropogenic activities can threaten gastropod communities. Conservation implications from these findings point to the importance of water quality management, particularly in controlling key parameters such as clarity, salinity, and current velocity. Limiting activities that can decrease water clarity and routine environmental parameter monitoring become priorities for maintaining gastropod community stability.

Research Implications

This research's ecological significance provides a fundamental understanding of gastropod community dynamics in port areas. Strong correlations between water clarity and diversity ($r= 0.845$) and salinity with diversity index ($r= -0.718$) indicate the importance of maintaining water quality to preserve ecosystem stability. Slightly polluted environments can receive tolerance from various species, particularly bottom-dwelling, and sessile biota (El-Gendy et al., 2021). These findings strengthen Lamine et al. (2023) research results showing that gastropods can be effective bioindicators for assessing coastal ecosystem health. A 12 gastropod species with different habitat

preferences demonstrate the complexity of interaction between biotic and abiotic factors in shaping community structure.

This research opens opportunities for more comprehensive follow-up studies. Presley and Willig (2023) suggest the importance of long-term research to understand the cumulative impacts of anthropogenic activities on gastropod communities. Studies about gastropod reproduction and recruitment aspects in port areas can provide a better understanding of population dynamics. Population genetic analysis is also necessary to assess inter-population connectivity and the potential for adaptation to environmental pressures. Long-term monitoring programs need development with a focus on key environmental parameters showing a significant correlation with ecological indices. Khatun et al. (2023) recommend seasonal monitoring to identify temporal patterns in gastropod community dynamics. The development of standardized monitoring protocols involving regular physicochemical parameter measurements and biota sampling will help detect early ecosystem changes. Collaboration with port managers and relevant stakeholders also becomes essential to ensure monitoring program sustainability.

CONCLUSION

This research reveals that epifaunal gastropod communities across ten small islands of Batam City show dominance by *Nerita undata*, *Trochus marmoratus*, and *Euchelus atratus*, collectively contributing over half of the total individuals found. Shannon-Wiener diversity index (H') values range from 1.458 to 2.103, placing communities in the moderate diversity category. A relatively high evenness index (E) (0.762–0.921) indicates a reasonably even distribution of individuals among species, while a low dominance index (C) (0.147–0.371) shows the absence of genuinely dominant species. Environmental parameter variations such as current velocity, salinity, and water clarity significantly influence gastropod community structure, indicating specific adaptations from each species to rocky intertidal habitat conditions in Batam City's border area. Gastropod community conditions in the research area are categorized as stable with moderate ecological pressure. However, anthropogenic activity influences such as shipping, domestic waste, and shipyard industry manifest through water physicochemical parameter variations. A 12 epifaunal gastropod species reflects interaction complexity between biotic and abiotic factors in shaping communities. These findings emphasize the need for coastal environmental management to prioritize water quality monitoring, particularly in maintaining clarity, salinity stability, and water pollution control. Further research examining reproduction aspects, recruitment, population genetics, and invasive gastropod species is recommended to enrich baseline data for biodiversity management in tropical port areas and dense intercontinental shipping lanes (border areas). Additionally, sustainable biomonitoring program development becomes a priority to detect early ecosystem changes and ensure gastropod community preservation.

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