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Spatial distribution and association of mangrove snails (Gastropoda: Mollusca) in mangrove ecosystems on the coast of Nusa Lembongan and Perancak, Bali, Indonesia

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Abstract. *Simanullang DR, Bengen DG, Natih NMN, Zamani NP. 2024. Spatial distribution and association of mangrove snails (Gastropoda: Mollusca) in mangrove ecosystems on the coast of Nusa Lembongan and Perancak, Bali, Indonesia. Biodiversitas 25: 2382-2392.* Nusa Lembongan and Perancak are two areas located in Bali Province that have mangrove ecosystems that are utilized as ecotourism areas, with different geomorphologies. This study was conducted with the aim to determine the density and spatial distribution of gastropods, as well as their relationship with environmental characteristics using a multivariate analysis approach, namely Correspondence Analysis (CA) and Principal Component Analysis (PCA). Sampling used a purposive sampling method consisting of 3 zones based on distance from the sea, namely the sea, middle and land zones. The results showed that a total of 22 gastropod species were found in Nusa Lembongan where 17 species were found in the marine zone with the most gastropod species *Pyrene ocellata* (43,48%), while in Perancak 17 gastropod species were found in all zones and the most gastropod species were found in the middle zone, which 13 with the most gastropod species *Sphaerasiminea miniate* (63,17%). Environmental characteristics such as temperature, pH, ORP, salinity and dissolved oxygen still support the survival of gastropods. In general, 12 mangrove species were found in Nusa Lembongan and Perancak, *Rhizophora stylosa*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora lamarckii*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Avicennia marina*, *Avicennia alba*, *Avicennia rumphiana*, *Avicennia officinalis*, *Sonneratia alba*, and *Xylocarpus granatum.*

Keywords: Community structure, ecological characteristics, mangrove zones

INTRODUCTION

Mangrove forests are one of the natural resources with special properties that can live along the coast, rivers and estuaries in the tropics and subtropics with distinct and tangled roots arising from mud with a distinctive ecological role as a link between the ocean and land and has a high potential economic value (Sudhir et al. 2022; Dharmawan and Siregar 2008). Mangrove ecosystems have a very important role as protecting coastal areas, fortrees from influence of floods originating from land, a natural wave breaker, preventing erosion and abrasion on the beach, as a sediment trap, retaining saltwater intrusion and as a breeding ground for aquatic biota. Bali Province is a tourism destination that requires many supporting facilities to complement tourism supporting facilities and infrastructure such as hotels, restaurants, and villas and housing (Karimah 2017; Hasidu et al. 2020; Eryani 2014). Nusa Lembongan has a mangrove forest area of 202 ha and Perancak with a mangrove forest area of 178.6 ha, which is an area that is used as an ecotourism area with different geomorphology. Nusa Lembongan has a hilly topography, less fertile soil conditions, has no river flow so that there is no freshwater flow entering the sea (Sundra 2018), While Perancak Bali has a river flow so that it is influenced by seawater intrusion and freshwater from rivers that flow in it such as the Sowan river, Loloan river, Ijo Gading river, Samblong river and Yeh Kuning river (Hastuti et al. 2016), the estuary area is clay mixed with mud with organic matter (Kartikasari and Sukojo 2015). The rapid development in Nusa Lembongan and Perancak, especially those that lead to coastal areas, especially development in economic interests, such as development in the tourism sector (hotels, restaurants), as well as in the fisheries sector (ponds), and other agricultural businesses (seaweed land development) that are not controlled so that a lot of logging is done in mangrove forests which have an impact on mangrove damage (Sundra 2018).

The existence of various activities that occur in the mangrove ecosystem will change the condition of the mangrove environment and vulnerable to pollution (Ernanto et al. 2010; Wulansari and Kuntjoro 2018). The occurrence of changes in the mangrove ecosystem has an impact on benthic organisms that live in mangrove ecosystems such as gastropods and bivalves (Saleky et al. 2016). The existence of gastropods and bivalves in the mangrove ecosystem forms an association with a complex process between organisms and the environment, which has

an important role as a link between the food chain and the condition of the aquatic ecosystem. So that the presence of gastropods and bivalves is used as an ecological bioindicator of a water body (Katukdoan et al. 2018).

The living habits of gastropods that tend to settle at the bottom of the waters make the existence of gastropods highly influenced by the activities that take place in the ecosystem that is the living environment of gastropods, such as pollution or other disturbances (Tetelepta 2019). Mangrove ecosystems become habitats, shelters, spawning grounds and food sources that can support the sustainability of organisms. In the mangrove ecosystem, the food chain that plays a role is the detritus food chain originating from mangroves in the form of mangrove leaves and twigs that have fallen and have undergone a decay process. So, the presence of gastropods, which are organisms whose lives are very sensitive to changes in water quality, can be used as bioindicators to measure water quality (Afwanudin et al. 2019).

Based on the explanation above, it is necessary to conduct research on the distribution of gastropod species and conditions in mangrove ecosystems on the coast of Nusa Lembongan and Perancak which aims to identify the distribution of gastropod species and association relationships with mangrove ecosystems, where these two locations have different characteristics to know the condition of mangrove ecosystems in both locations.

MATERIALS AND METHODS

Study area

This research was conducted from August to October 2023 in mangrove ecosystem of Nusa Lembongan (8°40'07"S-8°41'30" S, 115°27'08"E-115°27'05"E) and Perancak coast (8°24'02"S-8º23'15" S, 114°36'40"E-114º37'35"E). Three zones on Nusa Penida and Perancak were selected based on distance from the sea: sea zone, middle zone and land zone. Each zone devide into three 10x10 m plots (Figure 1).

Gastropods data sampling and analysis

Under low tide conditions, gastopods sampling was conducted using purposive sampling method by handpicking from substrate, mangrove trunks and leaves, with three zonations (land, middle, and sea) in mangrove vegetation. The boundary of the gastropod sampling area was sampled using a 1x1 m quadrant plot within each 10x10 meter plot of mangrove vegetation. The obtained gastropod samples were put into plastic samples and preserved using alcohol for further identification by using the book *"Recent & Fossil Indonesian Shells"* by Bunjamin Dharma, *"Encyclopedia of Marine Gastropods"* by Alain Robin and *"The Complete Encyclopedia of Shells"* by R. H De Bruyne. Using Shannon-Wiener to analyzed gastropods abundance and community structure.

Environmental parameters

Soil and water were analyzed for environmental parameters. Soil samples were obtained for pH testing with a Lutron pH meter 212. One hundred grams of soil were desiccated at 70°C for 48 hours to constant weight for Total Organic Matter (TOM). The temperature, pH water, salinity and Oxidation-Reduction Potential (ORP) were testing directly in location.

Data analysis

We used Correspondence Analysis (CA) to see the correlation of gastropods associations with mangroves. Principal Correspondence Analysis (PCA) to analyze varation of environmental characteristics. All analyses were conductes utulizing XLSTAT version 2023.3.1.

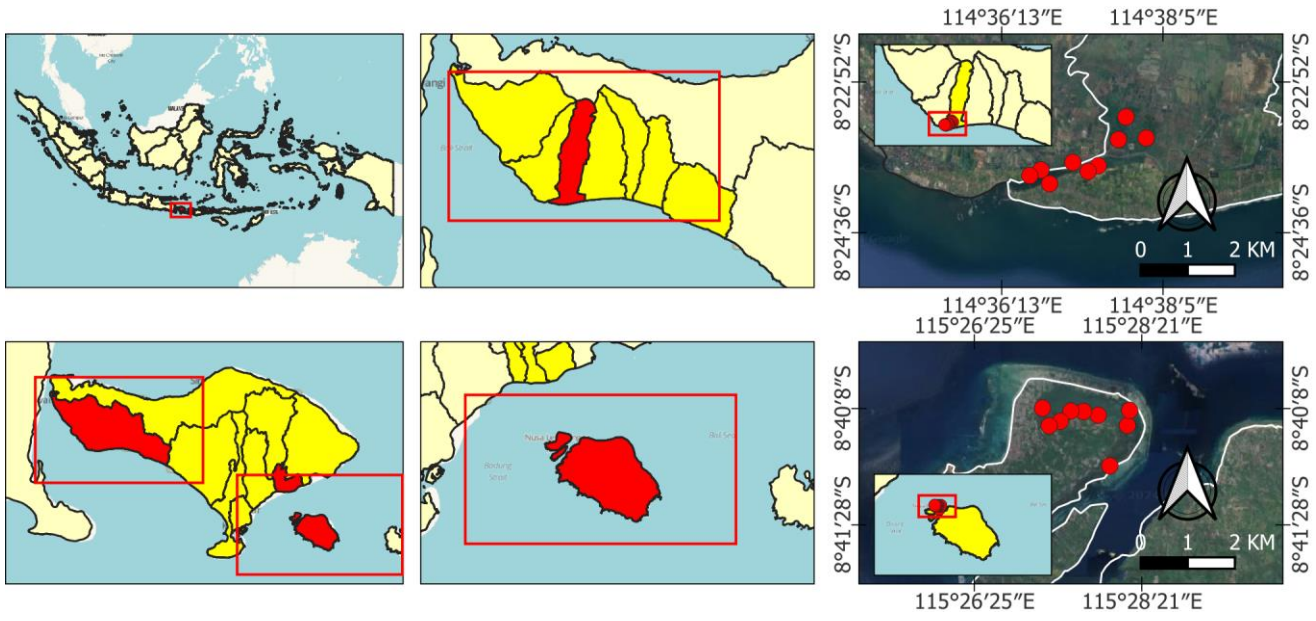


Figure 1. Distribution of sampling plots of each mangrove zone in Lembongan lsland and Perancak, Bali, Indonesia

RESULTS AND DISCUSSION

Gastropod abundance and composition

Gastropods found in Nusa Lembongan totaled 22 species and in Perancak totaled 18 species, based on the zonation of mangrove habitat distance to the sea. Gastropod species in Nusa Lembongan were mostly found in the sea zone with 17 species, in the middle zone 3 species were found and the land zone found 2 species with each type of gastropod not found in other zones. Gastropod species in Perancak was almost evenly distributed in all zones, which 11 species were found in sea zone, 13 species were found in the middle zone and 12 species were found in the land zone. Gastropods found in Nusa Lembongan and Perancak coast are very diverse in mangrove ecosystems. When compared to research conducted by Imamsyah et al. (2020) found 11 species in the area of Ngurah Rai Forest Park Bali, Wiraatmaja et al. (2022) found 25 species in mangrove ecosystem in Pacitan District, while research conducted by Ambeng (2023) found 13 species in the mangrove ecosystem on Pannikiang Island. Environmental characteristics such as salinity, temperature, substrate, and pH can affect differences in gastropod diversity at each location. It should also be noted that differences in the number of species found can occur based on the sampling techniques used, timing of year, and placement of sampling points in the mangrove ecosystem can cause these differences.

The highest abundant gastropod species in Nusa Lembongan was *P. ocellata* with a total abundance for all zonations of 130 individuals/m², followed by *L. scabra* with a total abundance of 83 individuals/m², *Cassidula sulculosa* with a total abundance of 24 individuals/m², and *L. carinifera* with a total abundance of 20 individuals/m². The highest abundance of gastropod species in Perancak coastal zone for all zones was *S. miniata* with a total abundance of 731 individuals/m², followed by *Cerithidea cingulata* with a total abundance of 121 individuals/m², *L. scabra* with a total abundance of 74 individuals/m² and *L. pallescens* with a total abundance of 65 individuals/m² (Table 1).

Figure 2. Mangrove gastropod in Nusa Lembongan and Perancak. A. *L. melanostoma* (24 mm); B. *L. scabra* (27 mm); C. *L. carinifera* (19 mm); D. *P. ocellata* (16 mm); E. *E. margariticola* (22 mm); F. *C. vespaceum* (25 mm); G. *C. atratum* (20 mm); H. *M. califera* (13 mm); I. *M. fasciatus* (10 mm); J. *C. sulculosa* (11 mm); K. *N. polita* (20 mm); L. *H. biconical* (12 mm); M. *C. alata* (20 mm); N. *P. fasciata* (28 mm); O. *C. punctatum* (19 mm); P. *C. capunicus* (38 mm); Q. *N. signata* (18 mm); R. *M. granulate* (30 mm); S. *T. Telescopium* (100 mm); T. *T. palustris* (62 mm); U. *T. sulcata* (25 mm); V. *L. angulifera* (30 mm); W. *N. olivaria* (13 mm); X. *S. nodosa* (20 mm); Y. *S. miniate* (2 mm); Z. *C. cingulate* (19 mm); ab. *C. quardrata* (30 mm); ac. *N. planospira* (22 mm); ad. *C. nucleus* (18 mm); ae. *C. aurisfelis* (20 mm); af. *M. castaneus* (12 mm); ag.*V. turrita* (30 mm)

Pyrene ocellata species were found in sea zone of Nusa Lembongan on rock and sand substrates. This species is generally found in rocky coastal areas with sand substrates in *R. stylosa* mangrove vegetation. This is in line with research conducted by Kalay and Lewerissa (2022) which shows the results of research that *P. ocellata* species are found in substrates with rocky sand, sandy stone categories. The abundance of *S. miniata* species in Perancak was found in all zones in muddy substrates in *R. mucronata* and *A. alba* mangrove vegetation. This is in line with research conducted by Febrita (2015) which shows that *S. miniata* species are found in groups in litter piles and really like areas with muddy substrates or sandy mud containing lots of detritus and algae.

The composition of gastropods observed was in the mangrove ecosystem on the substrate, mangrove trunks, and mangrove leaves. The dominating gastropod species in Nusa Lembongan were *P. ocellata* on the substrate (67%), *L. scabra* (69%) on mangrove trunks, and *L. carinifera* (65%) on the mangrove leaves. Meanwhile, the dominating gastropod species in Perancak were *S. miniata* (73%) on substrate, *C. quardrata* (28%) on mangrove trunks, and *L. scabra* (47%) on the mangrove leaves. The difference in substrate gives a difference in the dominance of gastropod species such as in Nusa Lembongan in sea zone dominated by *P. ocellata*, in middle zone dominated by *C. sulculosa* and in land zone dominated by *T. sulcata*, while Perancak sea zone and land zone dominated by *Sphaerasiminea miniata* gastropod species, and in middle zone dominated by *S. miniate* and *C. alata*. Gastropod species that dominate in mangrove trunks in Nusa Lembongan are dominated by *L. scabra* in sea zone, and *C. sulculosa* in middle zone, in Perancak dominated by *L. carinifera* in marine zone, *C. quardrata* in middle zone and land zone. On leaves of mangroves in Nusa Lembongan dominated by *L. carinifera* in sea zone, and in Perancak dominated by *L. scabra* and *L. pallescens* in sea zone, and *L. scabra* in middle zone (Figure 2).

Table 1. Gastropods abundance (individuals/m²) in Nusa Lembongan and Perancak, Bali, Indonesia

Species	Nusa Lembongan			∑	%	Perancak			∑	%
	Sea	Middle	Land			Sea	Middle	Land		
Littoraria scabra	83	0	0	83	27.76	54	16	4	74	4.97
Cerithium atratum	1	0	0	1	0.33	0	0	0	0	0
Pyrene ocellata	130	0	0	130	43.48	0	0	0	0	0
Nerita signata	2	0	0	2	0.67	0	0	0	0	0
Morula granulata	2	0	0	2	0.67	0	0	0	0	0
Habromorula biconica	4	0	0	4	1.34	0	0	0	0	0
Littoraria melanostoma	3	0	0	3	1.00	0	0	0	0	0
Littoraria carinifera	20	0	0	20	6.69	37	11	7	55	3.70
Monilea callifera	1	0	0	1	0.33	0	0	0	0	0
Pyrene fasciata	1	0	0	1	0.33	0	0	0	0	0
Nerita polita	2	0	0	2	0.67	0	0	0	0	0
Cerithium punctatum	1	0	0	1	0.33	0	0	0	0	0
Littoraria angulifera	1	0	0	1	0.33	4	0	0	4	0.27
Semiricinula nodosa	1	0	0	1	0.33	0	0	0	0	0
Nerita olivaria	1	0	0	1	0.33	0	0	0	0	0
Ergalatax margariticola	2	0	0	2	0.67	0	0	0	0	0
Cymatium vespaceum	1	0	0	1	0.33	0	0	0	0	0
Cassidula sulculosa	0	24	0	24	8.03	0	0	0	0	0
Chicoreus capunicus	0	1	0	1	0.33	0	0	0	0	0
Melampus fasciatus	0	4	0	4	1.34	4	2	2	8	0.54
Telescopium telescpium	0	0	1	1	0.33	0	2	1	3	0.20
Terebralia sulcata	0	0	13	13	4.35	43	8	1	52	3.49
Nerita planospira	0	0	0	0	0	3	4	7	14	0.94
Sphaerasiminea miniata	0	0	0	0	0	463	235	242	940	63.17
Terebralia palustris	0	0	0	0	0	17	0	0	17	1.14
Cassidula nucleus	0	0	0	0	0	1	8	23	32	2.15
Cerithidea alata	0	0	0	0	0	0	25	0	25	1.68
Cerithidea quardrata	0	0	0	0	0	0	19	23	42	2.82
Cassidula aurisfelis	0	0	0	0	0	0	4	29	33	2.22
Melampus castaneus	0	0	0	0	0	0	1	1	2	0.13
Vittina turrita	0	0	0	0	0	0	0	1	1	0.07
Littoraria pallescens	0	0	0	0	0	55	10	0	65	4.37
Cerithidea cingulata	0	0	0	0	0	69	17	35	121	8.13
Total	256	29	14	299		750	362	376	1488	

Gastropods community structure

The structure of the gastropod community in Nusa Lembongan and Perancak showed diversity value ranging from 0,55-1,56 which is classified as low diversity, based on the Shannon Wiener diversity index which states that if the value of H'<1 then the diversity is small, 1<H'3 is in the medium diversity category and H'>3 is in the high diversity category. The lowest diversity value was found in middle zone and land zones of Nusa Lembongan. The uniformity index of gastropods in Nusa Lembongan and Perancak ranged from 0,48-0,69 in the category of depressed uniformity, based on Pielou's uniformity index which states that if 0.00<E≤0.50 then it is categorized as depressed, 0.50<E≤0.75 is categorized as unstable and 0.75<E≤1.00 is categorized as stable. The dominance index of gastropods in Nusa Lembongan and Perancak Coast ranges from 0,34-0,71 which is categorized as low. This is based on the dominance index with the Margalef formula which states 0.00<C≤0.50 is categorized as low, 0.50<C≤0.75 is categorized as medium and 0.75<C≤1.00 is categorized as high. The lowest dominance index was found in middle zone of Perancak which was 0.34 and the highest in middle zone of Nusa Lembongan (Table 2).

The total of species and individuals found in abundance has an impact on the high value of diversity and uniformity (Janwar et al. 2022). The uneven distribution of the number of individuals of each species and the tendency of dominance of a species causes the value of diversity to be low.Environment changes, pressures, food availability, predation, and competition can also affect distribution of individuals of each species and differencesin gastropod structure (Galgani et al. 2023; Wintah et al. 2021).

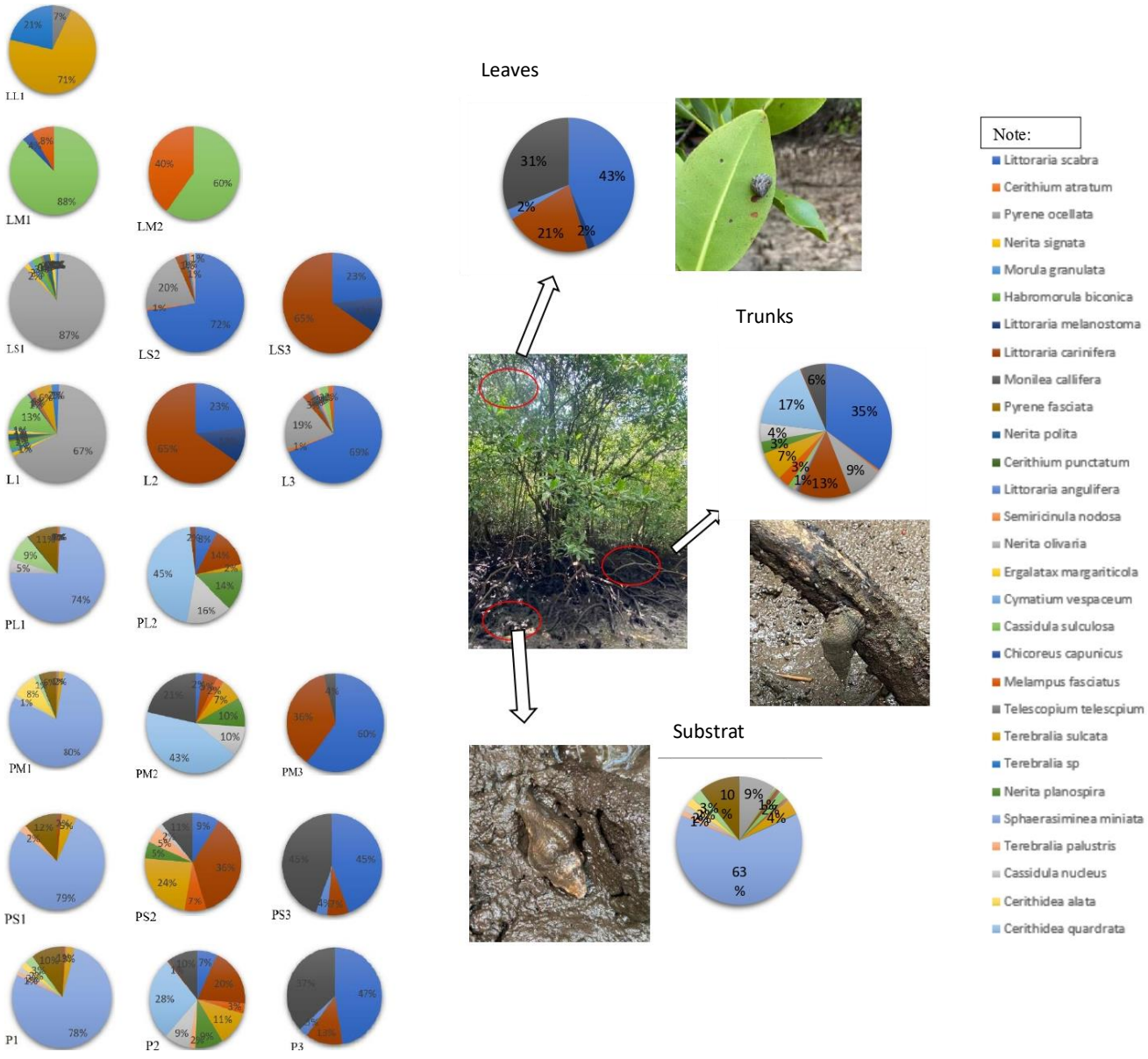


Figure 2. Gastropod species composition in all media (1: substrate, 2: trunks, 3: leaves) and mangrove zone (LL: Land Lembongan, LM: Middle Lembongan, LS: Sea Lembongan, L: Lembongan, PL: Land Perancak, PM: Middle Perancak, PS: Sea Perancak, P: Perancak)

Table 2. Average value and index criteria of gastropod diversity, uniformity, and dominance in Nusa Lembongan and Perancak, Bali, Indonesia

Station	Zone	Diversity (H')	Uniformity (E)	Dominance (C)
Nusa Lembongan	Sea	1.35	0.48	0.37
	Middle	0.55	0.50	0.71
	Land	0.76	0.69	0.56
Perancak	Sea	1.38	0.58	0.41
	Middle	1.56	0.61	0.34
	Land	1.33	0.52	0.44

According to Supriharyono (2009) and Candri et al. (2020), gastropod food is quite specific, such as some types of gastropods that like *Avicennia* mangrove leaves cannot be replaced with other types of mangrove leaves. In addition, species diversity is also influenced by the structure, composition and height of mangroves (Ariyanto et al. 2018) which is related to the amount of litter produced. Mangroves with seedling categories produce more litter than tree categories, even with the same mangrove type (Piranto et al. 2019).

Mangrove density and physicochemical characteristic

The composition of mangrove vegetation in Nusa Lembongan and Perancak in general found 12 species from 3 families, namely *Rhizophora stylosa*, *Rhizophora apiculata*, *Rhizophora mucronata*, *Rhizophora lamarckii*, *Bruguiera gymnorrhiza*, *Ceriops tagal*, *Avicennia marina*, *Avicennia alba*, *Avicennia rumphiana*, *Avicennia officinalis*, *Sonneratia alba*, and *Xylocarpus granatum* (Table 3).

Based on Table 3, the density of mangrove vegetation in Nusa Lembongan and Perancak for tree criteria ranges from 9.3 ind/100m² to 49.5 ind/100m². The highest mangrove vegetation density in Nusa Lembongan in sea zone was 37.6 ind/100m² dominated by *R. stylosa*, middle zone was 36.7 ind/100m² dominated *B. gymnorrhiza*, and land zone was 25.7 ind/100m² which in each zone was dominated by *A. marina*. In Perancak, the highest mangrove vegetation density was in land zone at 49.5 ind/100m² dominated by *R. mucronata*, middle zone at 41.2 ind/100m² dominated by *R. apiculata*, and sea zone at 9.3 ind/100m² dominated by *S. alba*.

Based on the results obtained, the dominating mangrove species in Nusa Lembongan is *R. stylosa*, while in Perancak the dominating mangrove species is *R. mucronata*. Soil conditions in Nusa Lembongan which are mostly sand-textured soil is a suitable habitat for *R. stylosa*. This is supported by the results of research conducted by Palguna et al. (2017) that the results of soil analysis in Nusa Lembongan in the front, middle to back zone are mostly composed of sand, sandy loam texture although in some places the texture is dusty loam but the sand content is still there. In addition to soil conditions suitable as *R. stylosa* mangrove habitat, environmental factors such as high salinity also support the growth of *R. stylosa* mangroves. *R. mucronata* dominate the Perancak estuary can be caused by environmental conditions in the form of mud with organic matter content. Research conducted by Kartikasari and Sukojo (2015) states that mangrove forests in the Perancak estuary grow on soil conditions in the form of clay mud mixed with organic matter without coral fragments. Environmental conditions in mangrove ecosystems in Nusa Lembongan and Perancak can be described by several environmental parameters (Table 4).

The water temperature in Nusa Lembongan and Perancak ranged from 26.02 to 29.51°C. This temperature range indicates that Nusa Lembongan waters are normal for gastropod survival. The lowest temperature was found in Nusa Lembongan in sea zone with 26.02°C and the highest temperature was found in Nusa Lembongan in land zone. Water temperature is one of important abiotic factors because it has a fundamental role for the life of aquatic organisms (Li et al. 2022). Temperature greatly affects the metabolic process and reproduction of gastropods, the higher the temperature in a body of water will cause a decrease in dissolved oxygen content which will result in the death of gastropods and other aquatic organisms (Persulessy et al. 2018). The temperature range of 25-32°C is the ideal range for gastropod growth and reproduction (Antsari et al. 2020).

Table 3. Mangrove density in Nusa Lembongan and Perancak (ind/m²)

Category	Species	Nusa Lembongan			Density	Perancak			Density
		Sea	Middle	Land		Sea	Middle	Land	
Tree	*Rhizophora stylosa*	45	25	18	88	-	24	-	24
	Rhizophora apiculata	16	-	-	16	1	29	20	50
	Rhizophora mucronata	-	-	-	0	-	20	63	83
	Rhizophora lamarckii	-	7	1	8	-	-	-	0
	Bruguiera gymnorrhiza	-	32	-	32	-	-	10	10
	Ceriops tagal	-	-	-	0	-	-	-	0
	Avicennia marina	-	12	35	47	4	-	-	4
	Avicennia rumphiana	-	1	-	1	-	-	-	0
	Avicennia officinalis	-	-	-	0	-	9	12	21
	Avicennia alba	-	-	-	0	6	6	-	12
	Sonneratia alba	18	-	-	18	9	1	2	12
	Xylocarpus granatum	-	-	4	4	-	-	3	3
	∑	79	77	54	210	20	89	107	216
	%	37.6	36.7	25.7		9.3	41.2	49.5	

Table 4. Physicochemical characteristic in Nusa Lembongan and Perancak, Bali, Indonesia (ind/m²)

Parameter	Nusa Lembongan			Perancak		
	Sea	Middle	Land	Sea	Middle	Land
Temperature (°C)	26.02	29.23	29.51	29.49	28.82	26.7
Salinity (‰)	24	29	27	24	27	14
Soil pH	7.30	6.17	6.18	6.26	4.98	4.93
Water pH	7.80	6.68	6.81	7.34	6.03	5.68
Dissolved oxygen (mg/L)	4.29	2.05	1.70	1.83	1.90	1.96
Total Organic Matter (%)	5.08	9.32	17.77	31.98	33.53	19.12
Sand (%)	92.71	42.55	52.63	33.60	37.52	42.54
Silt (%)	4.76	20.09	17.26	29.39	24.54	17.68
Clay (%)	2.53	37.36	30.11	37.02	37.94	39.78

Salinity in the waters of Nusa Lembongan and Perancak is in the range of 14 to 29‰. The lowest salinity is found in land zone of Perancak and the highest salinity is found in middle zone of Nusa Lembongan. The difference in salinity content in Nusa Lembongan and Perancak is caused by differences in geomorphology where in Nusa Lembongan there is no potential surface water (Harmayani et al. 2015) so that the flow of the estuary is directly related to the ocean, while in Perancak the condition of the water body is influenced by sea water and fresh water sourced from the river that empties into it (Kartikasari and Sukojo 2015), this causes the process of dilution of the salt content contained in the waters.

The results of soil pH measurements in Nusa Lembongan and Perancak were in the range of 4.93 to 7.30. The low content of soil pH at the research site is thought to be due to the decomposition process of organic matter contained in mangrove sediments which resulted in acidic sediments. According to Hossain and Nuruddin (2016), pH level of mangrove soils can be low as 5, but some mangrove soils can be also be alkaline (Dookie et al. 2023).

Water pH measurements in Nusa Lembongan and Perancak ranged from 5.68 to 7.70. The pH range of 5-9 still supports the survival of gastropods and aquatic life. However, waters with a pH range of less than 4 can kill gastropod organisms and a pH range of more than 9.5 makes waters unproductive (Zakia et al. 2022).

Dissolved oxygen content in the waters of Nusa Lembongan and Perancak ranged from 1.70 to 4.29 mg/L. Dissolved oxygen in Perancak tends to be lower when compared to dissolved oxygen in Nusa Lembongan. The low content of dissolved oxygen in Perancak is thought to be due to the form of mangrove sediments in the form of mud that is rich in organic matter content contained therein. The condition of the aquatic environment with thick mud can result in low dissolved oxygen content which can make the waters anoxic due to the use of excess oxygen by aerobic bacteria (Sipayung and Poedjirahajoe 2021). The accumulation of organic matter has an impact on the oxygen demand of bacteria to carry out the process of decomposing organic matter (Pinontoan et al. 2023). Although the dissolved oxygen content is relatively low below the minimum limit of dissolved oxygen in coastal areas, namely 4 ppm, this condition still supports the life of gastropods depending on the resilience, liveliness and water temperature Suwondo (2005) in Maturbongs et al. (2017). Gastropods have higher adaptation ability in environmental changes (Pacyao and Marquez 2022).

The organic matter content in Nusa Lembongan ranges from 5.08 to 17.77% which is classified as medium and in Perancak it ranges from 19.12 to 33.53% which is classified as high. The organic matter content in Nusa Lembongan is lower than in Perancak, this can be caused by the location of Nusa Lembongan directly adjacent to the sea and affected by tides. This is also supported by the research of Amin et al. (2022) that organic matter content tends to be lower in areas that experience a stirring process due to tidal activity, this is because organic matter from the sediment substrate is lifted into the water body as a result of its small size when the tide occurs. In addition to the stirring process from tidal activity that causes low organic matter content, high salinity levels also reduce nutrient content for organisms (Kho et al. 2020). The high content of organic matter in Perancak can be caused by its location that is not directly adjacent to the sea and also mangrove vegetation that is still natural and the form of sediment in the form of mud. Sediments in the form of mud found in mangrove ecosystems contain a lot of organic matter as a food source for macrozoobenthos deposit feeders Merly and Pane (2021). Litter derived from dead plant parts such as leaves, twigs, flowers, bark, and roots that fall on the ground becomes a source of nutrients for marine biota such as bacteria, algae, and fungi in the decomposition process (Selviani et al. 2024). Decomposition will stimulate the presence and biodiversity of mollusks, bivalves, gastropods (Baderan et al. 2019).

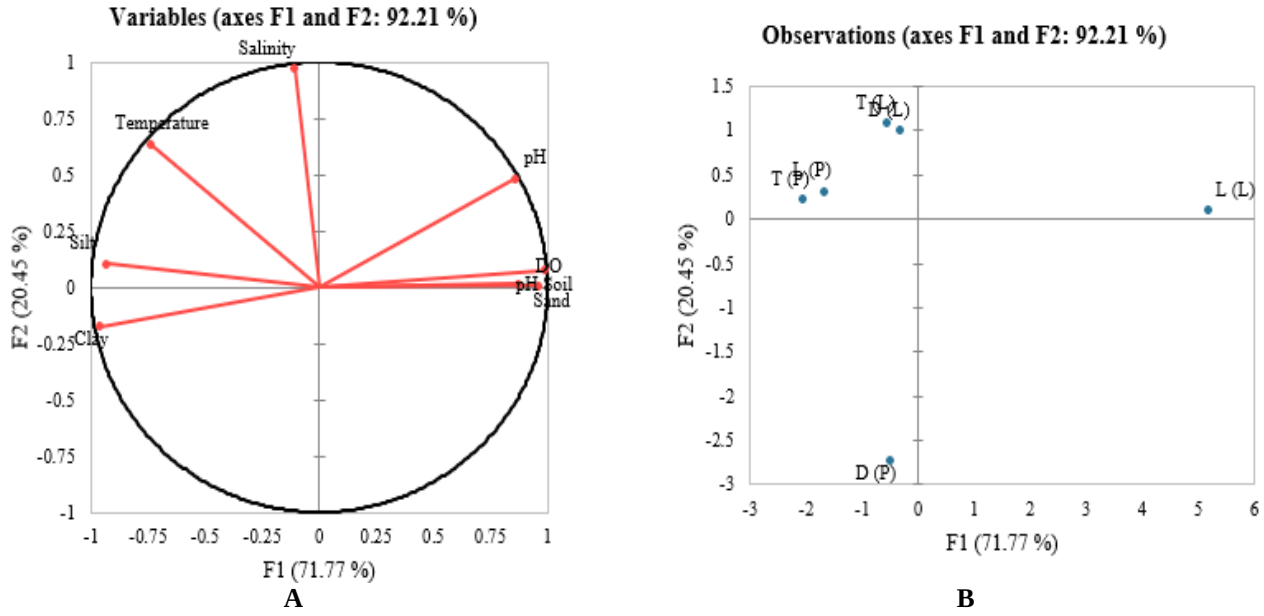
Distribution of physicochemical characteristics and spatial distribution of gastropods

Principal Component Analysis (PCA) results provide information on environmental quality at the research site on the F1 axis providing information on data diversity of 71.77% and F2 with data diversity of 20.45%, so that the total diversity of F1 and F2 is 92.21% (Figure 3).

The correlation pie chart of the intersection of the F1 and F2 axes shows a positive correlation between the parameters of water pH, soil pH, dissolved oxygen and sand-fraction sediments that contribute to forming a positive F1 axis. Sediment dust, clay and temperature fractions contribute positively forming a negative F1 axis. Salinity parameters contribute positively, forming a positive F2 axis (Figure 3.A).

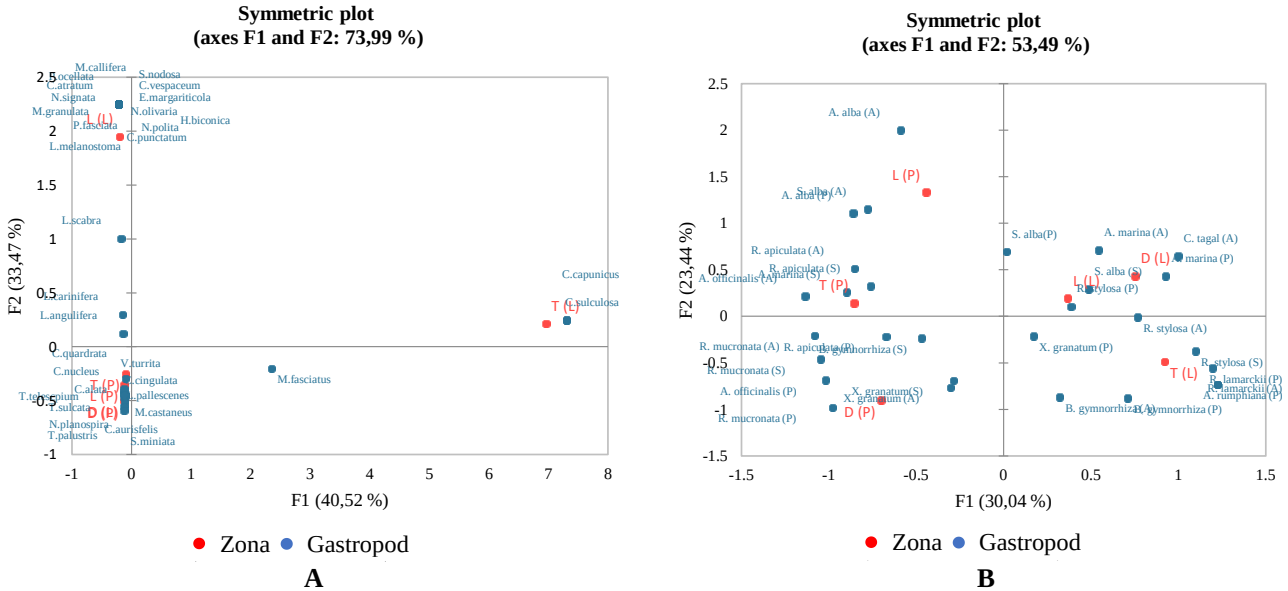
The representation diagram of zone distribution in relation to environmental parameters on the F1 and F2 axes shows that the Lembongan sea zone (L(L)) forms a positive F1 axis, while the Perancak sea zone (L(P)), Perancak middle (T(P)) forms a negative F1 axis. Furthermore, the Lembongan middle zone (T(L)) and Lembongan land zone (D(L)) form a positive F2 axis. In contrast, the Perancak land zone (D(P)) forms a negative F2 axis (Figure 3.B).

Based on the distribution of environmental parameters, the Lembongan sea zone is characterized by high water pH, soil pH, dissolved oxygen and sand-fraction sediments. The Perancak sea zone and Perancak central zone are characterized by dust and clay fraction sediments with high temperatures. The Lembongan central and Lembongan land zones are characterized by high salinity, while the Perancak land zone is not characterized by identical environmental characteristics. The sand-fractioned sediments in Lembongan zone are related to the movement of seawater where the Lembongan sea zone is located on the coastline. Tidal currents, waves and wind cause sediment transport.



A **B**

Figure 3. PCA analysis results. (A) Ordination of environmental parameters on F1 and F2 axes. (B) Representation of zone distribution based on environmental parameters on F1 and F2 axes



A **B**

Figure 4. Correspondence analysis results. A. Correspondent analysis between zonation and gastropod individual abundance. B. Correspondent analysis between zonation and mangrove density

Figure 5. Chicken footprints (*left*) and remote photos of chickens (*right*) found in land zone of Nusa Lembongan

According to Muskananfola et al. (2021), the type of sediment in the form of fine and coarse sand which is white to brownish in color, and partly in the form of gravel indicates that the sediment comes from the sea which undergoes a transportation process and is deposited as sediment. The sandy sediment type helps the water exchange process so that the dissolved oxygen content tends to be high. This is in accordance with the statement of Husen et al. (2020) that sandy susbtrates have air pores that allow more intensive mixing with the water above.

Based on the results of the correspondent analysis between gastropods and mangroves, it can be seen that in Lembongan sea zone were found gastropod species *L. scabra*, *C. atratum*, *P. ocellata*, *N. signata*, *M. granulate*, *H. biconical*, *L. melanostoma*, *L. carinifera*, *M. callifera*, *P. fasciata*, *N. polita*, *C. punctatum*, *S. nodosa*, *N. olivaria*, *E. margariticola*, and *C. vespaceum* with mangrove species *R. stylosa* trees, and *S. alba* trees. In middle zone of Lembongan were found gastropods species *C. sulculosa*, *C. capunicus*, and *M. fasciatus* with mangrove species *R. lamarckii* tree, *R. lamarckii* sapling, *A. rumphiana* tree, *A. marina* tree, *B. gymnorrhiza* tree, *R. stylosa* sapling, and *R. stylosa* seedling. In the Lembongan land zone were found gastropods *T. telescpium*, and *T. sulcata* with mangrove *A. marina* tree, *A. marina* sapling, *R. lamarckii* tree, *R. lamarckii* sapling, *X. granatum* tree, *R. stylosa* sapling, *R. stylosa* seedling, and *C. tagal* sapling.

In sea zone of Perancak were found gastropod species *S. miniata*, and *T. palustris* with mangrove *A. alba* tree, *A. alba* sapling, *A. marina* sapling, *S. alba* sapling, and *R. apiculata* seedling. In middle zone of Perancak were found gastropod species *N. planospira*, *C. nucleus*, *C. alata*, *C. quardrata*, and *M. castaneus* with mangrove species *R. mucronata* tree, *R. mucronata* sapling, *R. mucronata* seedling, *R. apiculata* tree, *R. apiculata* sapling, *A. officinalis* tree, *A. officinalis* sapling, *A. alba* tree, and *A. marina* seedling. In land zone of Perancak were found gastropod species *S. miniata*, *C. nucleus*, *C. aurisfelis*, and *V. turrita* with mangrove species *R. mucronata* tree, *R. mucronata* sapling, *R. mucronata* seedling, *B. gymnorrhiza* tree, *B. gymnorrhiza* sapling, *X. granatum* sapling, *R. apiculata* tree, and *R. apiculata* sapling.

Correspondence Analysis (CA) results show the relationship between gastropod spatial distribution based on gastropod species density and mangroves in each zone in Nusa Lembongan and Perancak (Figure 4).

The highest number of gastropods in Nusa Lembongan was found in sea zone with dense mangrove density (Ki>15 ind/100 m²). The Lembongan sea zone has a high abundance of gastropods where environmental characteristics such as habitat (substrate) in this zone support gastropods and mangroves to grow and develop. This proves that the gastropod species *Pyrene ocellata* and *Littoraria scabra* in Lembongan sea zone favor sandy substrate textures. The zone with the lowest number of gastropod species, the land zone with dense mangrove density (Ki>15 ind/100 m²), has environmental characteristics characterized by high salinity (Figure 4). The low number of gastropod species in this zone is thought to be due to predation by chickens, proximity to residential areas, natural pressure, and competition. Based on the traces found, the number of chickens in mangrove areas close to residential areas affects the abundance of gastropods (Figure 5). This could be due to the movement of gastropods from areas with many predators. Human settlements that provide food for predators result in increased predator abundance (Kabir et al. 2014), which influences the final distribution and abundance of gastropods (Peng et al. 2017).

In addition to predation in land zone, natural pressures such as dry substrate conditions influence the presence of gastropods. Data collection was conducted in the eastern season, where environmental conditions experience additional natural pressures such as high water temperatures and intense sun exposure (Prayudi et al. 2024), even causing the soil to dry out. These conditions affect the distribution of gastropods in the environment. The adaptation ability of adult gastropods to cope with

drought is different from the response of juvenile gastropods. Adult gastropods are able to cope with drought by closing the operculum and making a flat body posture or elevating the shell (Chapperon et al. 2017), but juvenile gastropods do not yet have the adaptation ability like adult gastropods, so juvenile gastropods must stay close to water to avoid drought (Ries et al. 2020).

Perancak is most commonly found in sea zone with sparse mangrove density (Ki<10 ind/100²) having environmental characteristics characterized by dust and clay substrate textures with high temperatures. This indicates that the gastropod species *S. miniata* likes the texture of dust and clay substrates. According to Febrita et al. (2015), *S. miniata* really likes areas with mud or sandy mud substrates that contain lots of detritus and algae. This is in accordance with the statement of Efriyeldi et al. (2021) that gastropods prefer mud substrates because of their fine texture with higher nutrient content than coarse textured substrates.

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