

# The influence of physicochemical environment on the distribution and abundance of mangrove gastropods in Ngurah Rai Forest Park Bali, Indonesia

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**Abstract.** Imamsyah A, Arthana IW, Astarini IA. 2020. The influence of physicochemical environment on the distribution and abundance of mangrove gastropods in Ngurah Rai Forest Park Bali, Indonesia. *Biodiversitas* 21: 3178-3188. Ngurah Rai Forest Park is the widest mangrove ecosystem in Bali that close to the business center and tourism area. The strategic location of the Ngurah Rai Forest Park is estimated to produce anthropogenic waste that can disrupt the gastropod population and stability of the mangrove ecosystems. This study aims to analyze the mangrove density, distribution, and abundance of gastropods based on the quality of the biophysical environment. Mangrove data collection was carried out using a plot transect of 10 m x 10 m, 5 m x 5 m, and 1 m x 1 m. Meanwhile, samples gastropods were collected on a plot transect of 0.5 m x 0.5 m in plot transect of 5 m x 5 m. A total of 11 gastropods species and 6 mangrove species were recorded in this study. The dominant gastropods species found were *Assiminea brevicula* (28 ind/m<sup>2</sup>). Species mangrove of *Sonneratia alba* and *Rhizophora apiculata* found were in all study sites with tree density values of 1000 ind/ha. Subsequently, the ecological index calculation results show that the diversity index ( $H'$ ) (2.89-3.2), evenness index ( $E$ ) (0.87-0.93), and dominance index ( $C$ ) (0.12-0.17). Based on the Principal Component Analysis (PCA) found was *Assiminea brevicula* spread on sand and silt substrates and adaptive to the temperature condition, salinity, pH, and dissolved oxygen. Furthermore, other analysis results showed that *Cerithidea cingulata*, *Cerithidea quadrata*, *Littoraria articulata*, and *Littoraria scabra* were found on clay substrate with high C-organic content. In conclusion, gastropods are evenly distributed and no species dominate the ecosystems.

**Keywords:** Coastal environment, ecological index, ecosystem, gastropods, mangrove

## INTRODUCTION

Mangrove ecosystem has unique vegetation where their growth depends on tidal conditions, salinity, and generally grows well on mud substrates that are rich in organic matter. As a form of adaptation, mangrove species have a specific root system that is adaptive to existing environmental conditions (Norris et al. 2019). The mangrove aerial rooting system, salinity, and substrates determined the zone of mangrove species. (Wijayasinghe et al. 2018; Muhammad-Nor et al. 2019; Virgulino-Junior et al. 2019). Mangrove ecosystem is arranged into three zones. Mangrove species closest to sea are found *Avicennia* sp., and *Sonneratia* sp. More toward the land commonly found *Rhizophora* sp. associated with *Bruguiera* sp., and *Xylocarpus* sp. Next up is the transition zone which is dominated by *Nypa fruticans* and several other species such as *Achantus* sp., *Aegiceras* sp., *Excoecaria* sp., *Lumnitzera* sp., and *Scyphiphora* sp. (Sreelekshmi et al. 2018; Basyuni et al. 2019; Priosambodo et al. 2019). Mangrove ecosystem in the coastal region makes the ecosystem has high productivity and biodiversity. Mangrove ecosystem has all the potential to be developed both in terms of economic, physical, and ecological (Koch et al. 2009; Buncag et al.

2019; Hilaluddin et al. 2020). Mangrove ecosystems are used by the community as charcoal, firewood, medicine, and others. Physically, the mangrove ecosystem serves to protect the coast from tidal waves, prevent abrasion, and erosion. After that, the ecological utilization of mangrove ecosystems namely as a place for spawning ground, nursery ground, and feeding ground for various marine organisms (Sheaves et al. 2016; Marley et al. 2020), one of which is gastropods.

The distribution of gastropods is strongly influenced by biotic and abiotic factors. Biotic factors consist of predators, life cycles, and food sources (Peng et al. 2017; Abdelhady et al. 2018). In this case, mangrove trees as producers play an important role in gastropods survival. Leaves that fall from mangrove trees become food sources for gastropods. Subsequently, abiotic factors consist of environmental biophysical such as temperature, salinity, pH, dissolved oxygen, and substrate types. Temperature is one of the important parameters for supporting gastropods because of the temperature changes can affect the gastropods metabolism (Latupeirissa et al. 2020). Furthermore, salinity can affect gastropods horizontally and vertically. Generally, gastropods are found in coastal areas because changes in salinity are more stable when to

compared close to estuaries. Estuaries are very susceptible to environmental pressures because estuaries are the first areas to be contaminated waste disposal from the mainland (Villate et al. 2017), so that gastropods are more suitable for breeding in coastal areas. In addition, substrate types also affect the distribution of gastropods in mangrove ecosystems. Commonly, gastropods are found on mud and clay substrates contain more organic matter than sand substrate. Organic matter content is used by gastropods as a food source derived from mangrove litter through the decomposition process by microorganisms (Ariyanto 2019; Pazira et al. 2019). Therefore, the presence of gastropods in mangrove ecosystems can describe a good environmental condition and be able to maintain mangrove ecosystem stability. According to Savic et al. (2016); Litaay et al. (2017); Reguera et al. (2018); Baroudi et al. (2020), gastropods have high economic values and can be used as bioindicators of environmental quality.

Ngurah Rai Forest Park is the widest mangrove ecosystems in Bali, Indonesia. Administratively, this area is located in Badung Regency with an area of 627 ha and Denpasar City covering of 746.5 ha. Ngurah Rai Forest Park Bali located in a very strategic area, close to the tourism area and business center in Bali. This area is divided into 14 utilization blocks where 5.8 ha is used as the arrangement of springs, landfills covering an area of 36.7 ha, pond rehabilitation covering an area of 70.7 ha, and utilization as a business center, trade, and home residents covering an area of 1098.6 ha. The utilization is estimated to produce anthropogenic waste which disrupts mangrove ecosystems so that it can decrease gastropods habitat. Considering the importance of gastropods function, it is necessary to study the influence of physicochemical

environment on the distribution and abundance of mangrove gastropods in Ngurah Rai Forest Park Bali.

## MATERIALS AND METHODS

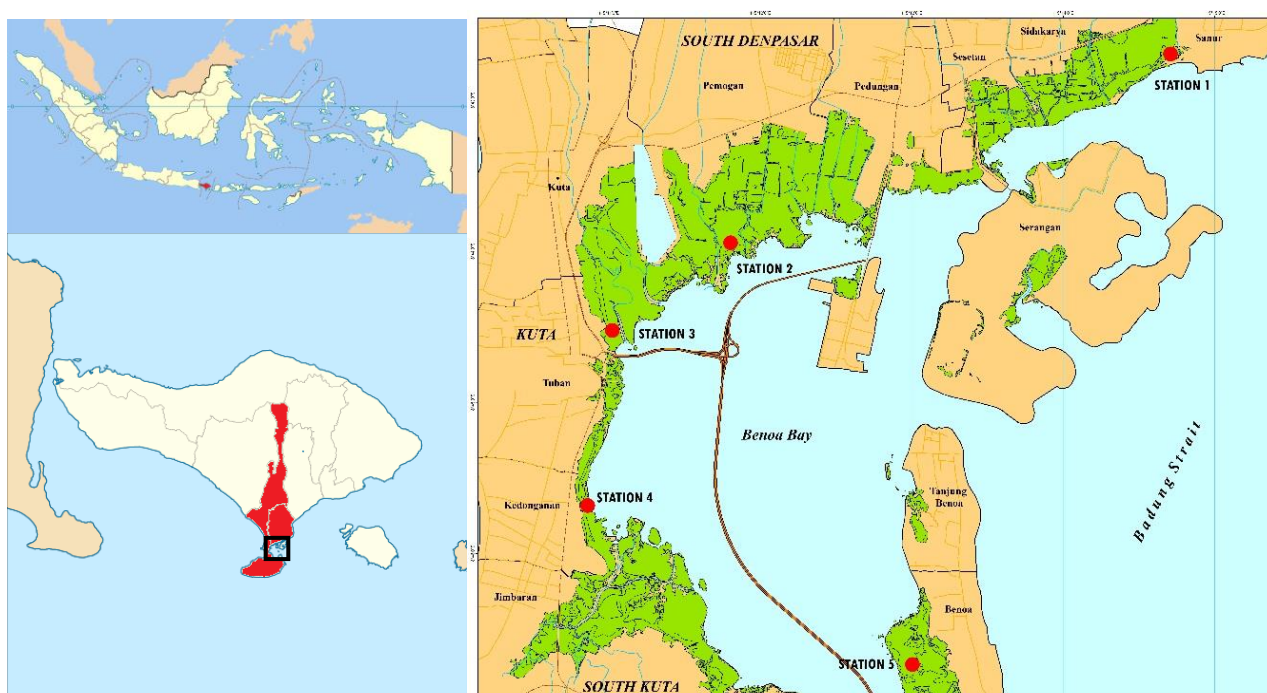
### Study area

This research was conducted in September until December 2019 in Ngurah Rai Forest Park, Bali, Indonesia. The study sites were divided into 5 stations namely Mertasari Beach ( $8^{\circ}42'41.64''\text{S}$ ,  $115^{\circ}14'42.54''\text{E}$ ) (Station 1), MIC Office (*Mangrove Information Center*) ( $8^{\circ}43'56.66''\text{S}$ ,  $115^{\circ}11'48.24''\text{E}$ ) (Station 2), Mati River ( $8^{\circ}44'31.47''\text{S}$ ,  $115^{\circ}11'1.38''\text{E}$ ) (Station 3), Kedonganan Village ( $8^{\circ}45'41.01''\text{S}$ ,  $115^{\circ}10'51.62''\text{E}$ ) (Station 4), and Tanjung Benoa ( $8^{\circ}46'44.12''\text{S}$ ,  $115^{\circ}13'0.29''\text{E}$ ) (Station 5) (Figure 1). Samples were collected using purposive sampling where the process must pay attention to environmental variability that is easily understood and sampling points that are easily accessible.

### Procedures

#### *Mangrove data collection*

A sampling of mangrove vegetation was carried out using line-transect that stretches from the land boundary to the sea level where mangroves grow. For sampling, each line transect was subdivided into 3 substations and each substation was further divided into 2 square plots. Transect  $10 \times 10 \text{ m}^2$  was used to observe mangrove trees, transect  $5 \times 5 \text{ m}^2$  for observing mangrove saplings, and transect  $1 \times 1 \text{ m}^2$  for observing mangrove seedlings (Bengen 2004). Subsequently, the mangrove trees, saplings, and seedling were identified using Kitamura et al. (1997).



**Figure 1.** Research location in Ngurah Rai Forest Park Bali, Indonesia

### Gastropods data collection

Gastropods data collection was sampled vertically in the plot. Sampling was carried out at low tide to facilitate sample collection. Gastropods observed were only species that were in 0.5 x 0.5 m<sup>2</sup> transect plots in 5 x 5 m<sup>2</sup> mangrove transect plots in mangrove roots, stems, and leaves. Samples were washed using aquadest and preserved using alcohol 70%. Subsequently, the sample was identified using Dharma (2005).

### Biophysical environment data collection

Biophysical environment samples (temperature, salinity, pH, dissolved oxygen, and substrate) were collected using an in-situ sampling technique. Thereafter, water temperature measurements were carried out using a water thermometer. The water thermometer was inserted into the water for approximately 15 seconds and the thermometer scale shows the results. Water salinity measurements were performed with a refractometer. The next step is to open the glass and put two drops of water, then close the glass. Point the refractometer at sunlight and the measurement results can be seen. The pH of the water was measured using a pH meter. Insert the tip of the pH meter sensor for approximately 15 seconds and then the pH value was obtained. Dissolved oxygen was measured using the DO meter. Dip the DO meter sensor into the water for approximately 15 seconds and the measurement results were recorded. Subsequently, substrate analysis was carried out in Aquaculture Environmental Laboratory, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University. Substrate samples were further analyzed to determine the substrate granules and organic matter content. Measurement of the substrate was carried out using sieving method where the substrate granules refer to the Wentworth Scale namely Clay (< 4 µm), silt (4 µm-63 µm), sand (63 µm-2 mm), and gravel (> 2 mm) (Blout and Pye 2001).

### Data analysis

#### Gastropods density

Density is the number of individuals per unit area (Krebs 1989):

$$D = \frac{Ni}{A}$$

Where: D: Individual density (ind/m<sup>2</sup>); Ni: Sum of individuals; A: Sample plot area (m<sup>2</sup>).

#### Diversity index (H')

The formula for calculating diversity index is as follows (Magurran 2004):

$$H' = - \sum_{i=1}^s (P_i \log_2 P_i)$$

Where: H': Diversity index of Shannon-Wiener; Pi: Sum of individual species per total number of individuals (ni/N); ni: Sum of the individual in type i; N: Total numbers of individuals; s: Sum of species.

The relationship between diversity index with the stability of the gastropod community is as follows: 0 < H'

≤ 1: Low species diversity (unstable); 1 < H' ≤ 3: Moderate species diversity; H' > 3: High species diversity (stable).

#### Evenness index (E)

The formula for calculating evenness index is as follows (Magurran 2004):

$$E = \frac{H'}{H_{\max}}$$

Where: E: Evenness index; H': Diversity index of Shannon-Wiener; H<sub>max</sub>: Maximum species diversity (log<sub>2</sub> s); s: Sum of species.

Criteria for evenness index results are as follows: E ≤ 0,5: Low evenness; 0,5 < E ≤ 0,75 : Moderate evenness; E > 0,75: High evenness.

#### Dominance index (C)

The formula for calculating the dominance index is as follows (Magurran 2004):

$$C = \sum_{i=1}^s (P_i)^2$$

Where: C: Dominance index; Pi: Sum of individual species per total number of individuals (ni/N).

Criteria for dominance index results are as follows: 0 < C < 0,5: Low dominance (No species dominate); 0,5 < C < 1: High dominance (There are species that dominate).

#### Mangrove density

Mangrove species density is the number of stands a species of mangrove compared to the area of observation (Bengen 2004):

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

Where: Di: Species density (ind/m<sup>2</sup>); ni: Total number of stands; A: Sample plot area (m<sup>2</sup>).

#### Association of gastropods based on environmental characteristics

The relationship between the distribution of gastropods based on environmental parameters was determined using Principal Component Analysis (PCA) with XLStat 2016 software. PCA is a factorial analysis method that can reduce large amounts of data so that interpretation is easier by pulling essential information (Kherif and Latypova 2020). The data matrix consists of research station as individual (rows), while gastropods and mangrove species as quantitative variables (columns). The main purposes of PCA analysis are: (i) extract essential information contained in large data or table matrix; (ii) produce graphical representation to be easily understood; and (iii) study a data or table matrix from similarities between individuals or relationship between variables (Bachelet 1996; Bengen 2000).

#### Association of gastropods and mangrove species

The distribution gastropods on mangrove species were determined using Correspondence Analysis (CA). CA is a multivariate technique that converts a data matrix into graphical displays in which the table or data matrix is represented as points (Greenacre and Hastie 1987). The CA

method is descriptive in which no variable has a more important role than the other variables. The primary purposes of CA analysis are: (i) looking for a close relationship between the modalities of two characters or variables in a contingency data or table matrix; and (ii) looking for close relationship between all modalities and similarities between individuals based on the configuration of answers in tables or complete disjunctive data matrix (Bengen 2000).

## RESULTS AND DISCUSSION

### Physicochemical parameters of water

The results of the physicochemical parameters (temperature, salinity, pH, and dissolved oxygen) measurements at five research observation in Ngurah Rai Forest Park Bali shows the fluctuation in each physicochemical environment (Table 1). The water temperature is one factor that can affect the condition of mangrove vegetation and gastropods that life surrounding. The water temperature at each research observation approximately 28.3-29.1°C, in which the lowest temperature was found in Mati River (Station 3) of 28.3°C and the highest temperature was observed in MIC Office (Station 2) of 29.1°C. The difference in temperature due to the high and low density of mangroves. The temperature will increase if the mangrove density is low because of the high intensity of sunlight received by waters, otherwise, the temperature will decrease if the density of mangroves is high. Peng et al. (2016) state that lack of light penetration is the main limiting factor in growth for mangroves. According to Ministry of Environment Decree Number 51 (2004), the optimum temperature for the life of marine organisms ranged between 28-32°C. Efrilyeldi et al. (2020) reported that water temperatures above 40°C not too significantly influence the life of mangrove ecosystems. Based on the measurement results, water temperature in the present study is within the normal range and suitable for mangroves and gastropods existence.

Salinity is the salt concentration in water. Water salinity at each research station approximately 21.3-29.6‰. Several studies reported the salinity content in mangrove ecosystems has different values. One of the studies from Mitra (2018), the distribution of salinity during monsoon and pre-monsoon was approximately 14.45-18.97‰. Meanwhile, Xu et al. (2019) collected data from dry season and wet season indicated that average salinity for the dry season was 4.1-23.2‰. Meanwhile, during the wet season, average salinity decreases to 18.2 ‰. High and low salinity is influenced by evaporation, runoff, and rainfall (Uncles and Stephens 2011; Asri et al. 2015; Geng et al. 2016). The greater intensity of sunlight entering the water column, the higher process of evaporation which causes high salinity, conversely the higher rainfall causes low salinity. According to Ministry of Environment Decree Number 51 (2004), the optimum salinity for marine organisms is not more than 34‰ so it can be said that salinity normal for gastropods life in the mangrove ecosystems of Ngurah Rai Forest Park Bali.

**Table 1.** Physico-chemical parameters in each station

Environmental parameters	Research stations				
	1	2	3	4	5
Temperature (°C)	28.9	29.1	28.3	28.4	28.9
Salinity (‰)	27.3	27.2	21.3	26.5	29.6
pH	7.18	7.28	7.09	7.25	7.2
DO (mg/l)	3.18	4.19	2.74	4.13	4.16

The pH is the amount of activity of hydrogen ion in water (Boyd et al. 2011). Koch (2001) argued that pH is related to decomposer activity. Decomposer activity will not be optimal if the acidic pH disrupts mangrove ecosystem growth due to a lack of nutrients and minerals. The results showed pH values ranged between 7.09-7.25. As a comparison, there are several studies that measurement of pH water in mangrove ecosystems. According to research conducted at Zuari estuary India by Jayachandran et al. (2018), pH values range from 7.3-7.6. Meanwhile, Sreelekshmi et al. (2020) reported at Sundurban Delta India in which the pH water values were obtained to 8.14. The difference in pH was thought to be a litter of leaves, stems, and roots that fall to the ground causing the pH to become acidic due to the decomposition process. The decomposition process will produce organic acids which can reduce the pH concentration (Adeleke et al. 2017). Ministry of Environment Decree Number 51 (2004) states that the pH values between 7-8.5 are considered appropriate for mangrove and marine organisms.

Dissolved Oxygen (DO) is an oxygen concentration in water. DO concentration is one of the most important indicators of the waters biological and chemical (Rajwa-Kuligiewicz et al. 2015). Measurements of DO were carried out to analyze changes in biological and chemical processes in the waters. DO concentration will be high if there is a process of photosynthesis and otherwise DO will below if there is an oxidation process of organic matter and respiration by organisms (Dubuc et al. 2019; Mitra 2019). DO concentration in waters plays a role in the oxidation and reduction of organic and inorganic materials. In aerobic conditions, DO concentration oxidizes organic matter and inorganic materials which can fertilize the waters. Meanwhile, in anaerobic conditions DO concentration reduces chemical compounds in the form of nutrients and gases (Barreto et al. 2018; Shantelle et al. 2018; Lin et al. 2020). This oxidation and reduction process is very important in the effort to reduce the debit of pollution from anthropogenic waste. Subsequently, the results were obtained that DO concentration in waters ranged between 2.74-4.19 mg/l. According to Ministry of Environment Decree Number 51 (2004), DO optimum for marine organisms is > 5 mg/l. The difference in DO concentration was due to the location of the observations that were close to residential areas, tourism, and businesses center to produce anthropogenic waste. Gobler and Baumann (2016); Gedan et al. (2017); Farooq and Siddiqui (2020), states that DO concentration will decrease if the waters are polluted by waste without any prior processing.

Based on the present finding, DO concentration recorded is not natural and can disrupt overall ecosystem stability.

### Characteristics of substrates

The substrate is a solid material derived from the weathering of rocks process, sedimentation, and transport by water and wind. The substrate is composed of several biogenic materials derived from organisms, autogenic materials from the marine chemical process, residual material, detritus material, and depositional residual material (Barnard et al. 2013; Prarikeslan 2016). Sand, silt, and clay substrates are common soil formation that can be found in many types of forest e.g.: inland forest, island forest, and mangrove forest (Kawaida et al. 2017; Lo et al. 2019). The results of the substrate characteristic measurements at five research observations in Ngurah Rai Forest Park Bali showed that there were differences in the substrates texture (Table 2). The dominant sand substrate was found at station 1 (90.25%), station 4 (85.9%), and station 5 (79.04%). Conversely, the sand substrate has a low value at station 2 (33.18%) and station 3 (25.85%). Thereafter, the silt substrate was observed at station 5 (19.3%), station 4 (12.91%), station 1 (7.64%), station 2 (6.3%), and station 3 (3.35%), respectively. Moreover, the dominant clay substrate was obtained at station 3 (70.8%) and station 2 (60.52%), while the clay substrate has a low value at station 1 (2.11%), station 5 (1.66%), and station 4 (1.19%), respectively. The difference in the texture of the substrate occurs due to the characteristics of the research station which were close to the river and beach. The sand substrate was found in coastal areas due to the influence of currents and waves that can change the composition, size, and shape of the substrate. According to Abdulkarim et al. (2011); Wang et al. (2016); Sane et al. (2020), the waters with strong currents will find coarse granules while the waters with weak currents will settle more fine granules.

Organic matter (C-organic) is all organic materials derived from plant tissues and animals that are alive or dead (Strosser 2010; Reyes and Crisosto 2016; Gmach et al. 2020). C-organic content is a source of productivity and germplasm used by gastropods. The main source of C-organic content derived from mangrove litter. The high production of mangrove litter makes the higher of C-organic content. Mangrove litter that falls then has a decomposition process that can affect the abundance of gastropods and can play as an indicator of water fertility. Furthermore, the role of the mangrove ecosystems as a producer of C-organic is very important. Damaged mangroves conditions cause low litter production and cause gastropods to be difficult to adapt to environmental conditions.

**Tabel 2.** Substrates texture on five research stations

Station	Substrate Texture (%)			C-organic (%)
	Sand	Silt	Clay	
1	90.25	7.64	2.11	2.31
2	33.18	6.3	60.52	5.47
3	25.85	3.35	70.8	4.27
4	85.9	12.91	1.19	2.6
5	79.04	19.3	1.66	4.6

The results showed that the C-organic at station 2 (5.47%), station 5 (4.6%), station 3 (4.27%), station 4 (2.6%), and station 1 (2.31%), respectively. The difference in C-organic was suspected due to the use of mangrove ecosystems that are not following environmental sustainability so that the condition of mangroves is damaged. According to Lugina et al. (2017), misuse the mangrove ecosystems in Ngurah Rai Forest Park Bali is caused by (i) Infrastructure development. Strategically, Ngurah Rai Forest Park is located as a business center and tourism area which cause water pollution can affect coastal ecosystems life. This utilization was further exacerbated by the reclamation that can cause abrasion, sedimentation, and change the structure of mangrove vegetation; and (ii) Land conversion. Ngurah Rai Forest Park is the widest mangrove ecosystem in Bali so that forest managers find it difficult to protect their area. Under this condition, the community utilizes mangroves but not protect the environment e.g.: illegal logging, misuse the mangrove ecosystems as ponds, and others.

### Mangrove density

There were six species were found in the mangrove ecosystems of Ngurah Rai Forest Park Bali. Overall, *S. alba* was recorded the highest density (878 ind/ha) (Table 3). According to previous studies, such as Mulla and Chavan (2017) in the Coast of Ratnagiri India, Widyastuti et al. (2018) in Segara Anakan Mangrove Forest Cilacap, Costa et al. (2019) in the Coast of Metinaro Timor Leste reported that *S. alba* had a high density. *S. alba* is one of the true mangrove species that is adaptive to environmental changes. Polidoro et al. (2010) argued that true mangrove has the ability to the salt exclusion or salt excretion by utilizing pneumatophores or aerial roots, exclusively restricted to tropical intertidal habitats, and adaptive to existing environmental conditions.

Conversely, the lowest density was found *X. granatum* (44 ind/ha) (Table 3). Shah et al. (2016); Dimalen and Rojo (2018) revealed that *X. granatum* had a low density. The low density is due to highly exploited. In Bali, *X. granatum* seeds are used as cosmetic ingredients and subsequently sold as Balinese products. In Togean Central Sulawesi, *X. granatum* seeds have activity inhibition of tyrosinase and antioxidants which has the potential to brighten the skin (Zamani et al. 2015). Das et al. (2019) reported that leaves, fruits, and barks of *X. granatum* can be processed into medicine for various diseases e.g.: fever, malaria, cholera, dysentery, thrush, and diarrhea. Overall, *S. alba* density is classified as a good condition with a total density value of 3144 ind/ha. Meanwhile, *X. granatum* density is classified as damage condition with a total density value of 66 ind/ha (Table 4).

### Gastropods density

Gastropods observations obtained 5 (five) families and 11 (eleven) species that are in 5 (five) research locations in the area of Ngurah Rai Forest Park Bali. The observations consist of 1 species of Assimineidae family (*A. brevicula*),

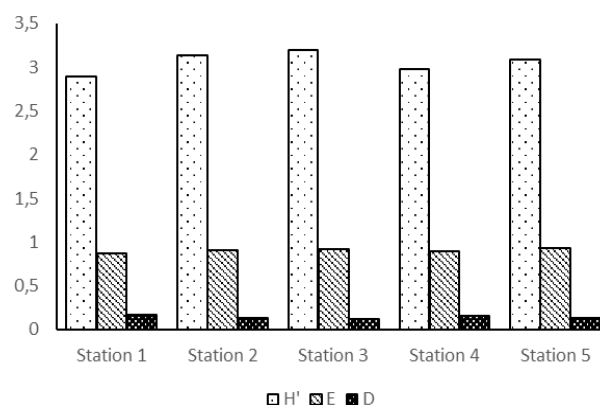
1 species of Fascioliidae family (*Latirus polygonus*), 2 species of Littorinidae (*L. scabra* and *L. articulata*), 3 species of Neritidae family (*Nerita balteata*, *Vittoida turrita*, and *Vittoida variegata*), and 4 species of Potamididae (*C. cingulata*, *C. quadrata*, *Terebralia palustris*, and *Telescopium telescopium*). Gastropods density found at the study sites is presented in Figure 2.

Gastropods density calculation results showed that the total density was 153 ind/m<sup>2</sup>. The highest gastropods density was found in station 2 (36 ind/m<sup>2</sup>), followed by station 3 (30 ind/m<sup>2</sup>), station 5 (31 ind/m<sup>2</sup>), station 1 and station 4 (28 ind/m<sup>2</sup>). Species *A. brevicula* were the most common species (28 ind/m<sup>2</sup>), followed by *C. quadrata* (24 ind/m<sup>2</sup>), and *C. Cingulata* (23 ind/m<sup>2</sup>). On the other hand, two rare species recorded which were *L. polygonus* and *V. variegata* with 4 ind/m<sup>2</sup> each, respectively. Our finding showed that *A. brevicula* has the highest density which is confirmed by Suartini et al. (2013), in which were found 17 species in Ngurah Rai Forest Park. *A. brevicula*, *C. cingulata*, and *T. palustris* are the dominant species were found in the research. Nurprasaja (2018) also reported that were found 15 species in Ngurah Rai Forest Park, in which *A. brevicula* dominated with a total density value of 40 ind/m<sup>2</sup>, followed by *L. articulata* (15 ind/m<sup>2</sup>), *C. cingulata* and *C. quadrata* with 2 ind/m<sup>2</sup> each, respectively.

**Table 4.** Standard criteria for mangrove damage

Density (ind/ha) *	Criteria	
≥1500	Great	Good
≥1000 - <1500	Medium	
<1000	Rarely	Damage

Note: \*Ministry of Environment Decree Number 201 (2004) about guidelines criteria determination of mangroves damage

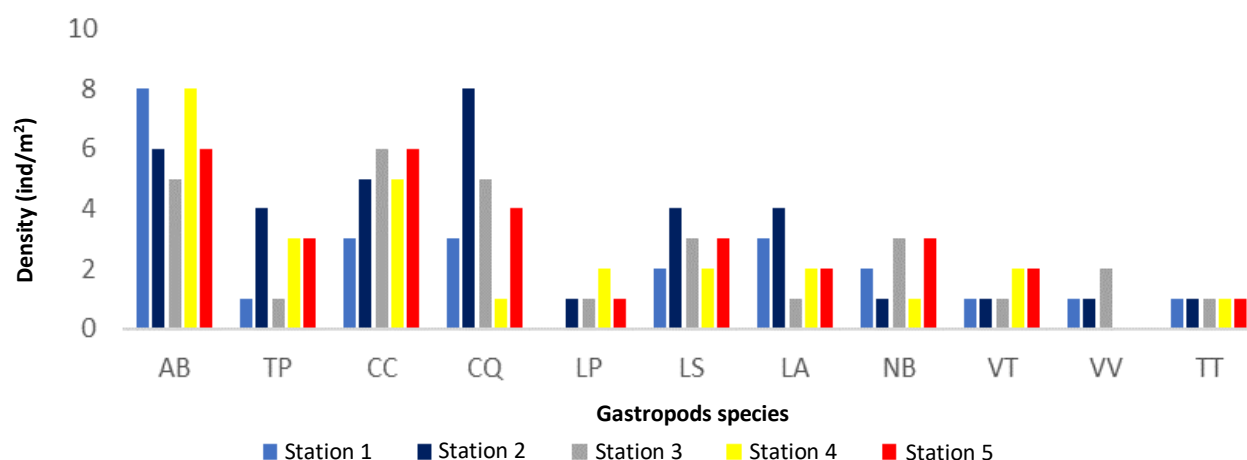


**Figure 3.** Results of the ecological index of gastropods community. H' (diversity index), E (evenness index), and C (dominance index)

**Table 3.** Mangrove density (ind/ha) in Ngurah Rai Forest Park, Bali, Indonesia

Species	Research location					Total
	S1	S2	S3	S4	S5	
<i>Sonneratia alba</i>	733	611	89	833	878	3144
<i>Rhizophora apiculata</i>	544	122	311	211	322	1510
<i>Rhizophora mucronata</i>	0	400	878	0	0	1278
<i>Bruguiera gymnorrhiza</i>	211	0	67	0	44	322
<i>Avicennia marina</i>	0	0	67	0	78	145
<i>Xylocarpus granatum</i>	0	0	22	44	0	66
Total	1488	1133	1434	1088	1322	6465

Note: S1: Mertasari Beach; S2: MIC Office; S3: Mati River; S4: Kedonganan Village; S5: Tanjung Bena



**Figure 2.** The density of gastropods species in Ngurah Rai Forest Park Bali, Indonesia. Note: AB: *Assiminea brevicula*; LA: *Littoraria articulata*; TP: *Terebralia palustris*; NB: *Nerita balteata*; CC: *Cerithidea cingulata*; VT: *Vittoida turrita*; CQ: *Cerithidea quadrata*; VV: *Vittoida variegata*; LP: *Latirus polygonus*; TT: *Telescopium telescopium*; LS: *Littoraria scabra*

### Ecological index of gastropods community

Ecological index values consist of diversity index ( $H'$ ), evenness index ( $E$ ), and dominance index ( $C$ ) can be used as a description of the gastropods community in Ngurah Rai Forest Park Bali. The results of the ecological index gastropods community can be seen in Figure 3.

Gastropods diversity was determined using the Shannon-Wiener diversity index. The diversity index value ranged between 2.89 to 3.2 indicating moderate to high diversity species richness (Figure 3) (Magurran 2004). According to Gu et al. (2016); Prasetya et al. (2017); Huang et al. (2020), diversity of gastropods can describe the stability of the ecosystems. The high diversity index value makes ecosystem existence said well, conversely, the low diversity index causes unbalanced gastropods habitat.

Evenness index values can indicate the presence or absence of dominance of species at research location (Ricotta et al. 2014; Kvalseth 2015). The results of the evenness index were in the range of 0.87 to 0.93 (Figure 3). The evenness index ranged from 0 to 1. A site with a high evenness index indicates that no species dominate the site. Conversely, if a community has a low evenness index, the spread of the number of individuals within each species not the same and there is a tendency for one species to dominate (Shaheen et al. 2011; Zhang et al. 2012; Strong 2016). Based on the results of the research, the evenness index value was close to 1 so that the distribution of gastropods is good because the distribution of each individual is evenly distributed.

The results of the dominance value show the richness of species communities and the balance of a total of individuals of each species (Levin et al. 2015; Gilardoni et al. 2019). The results of the dominance index were in the range of 0.12-0.17 (Figure 3). Dominance index value between  $0 < C < 0.5$  indicating no tendency of gastropods species dominate in study area. A low dominance index in the present study (0.12-0.17) is in line with evenness index (0.87-0.93) recorded. The greater of evenness index value indicates the density of each species is relatively the same and there tends to be no domination by specific species. The absence of dominant species causes gastropod life not stressed. Therefore, it can be said that the gastropod habitat condition is stable because there are no species dominate the site.

### Association of gastropods and environmental characteristics

Principal Component Analysis (PCA) results showed that gastropods spread to all research stations. Species *A. brevicula* scatters on the sand and silt substrates and adaptive to conditions of temperature, salinity, pH, and dissolved oxygen. Meanwhile, *A. brevicula* has a negative correlation on clay substrate (Figure 4). This is supported by the various study by Liao et al. (2018) and Idrus et al. (2019). *A. brevicula* was widely distributed along the coast of China (Liao et al. 2018) and was also found adapted well on *Rhizophora stylosa* tress with characteristics of sand and mud substrates (Idrus et al. 2019). The wide distribution of *A. brevicula* indicates that these species very adaptive to

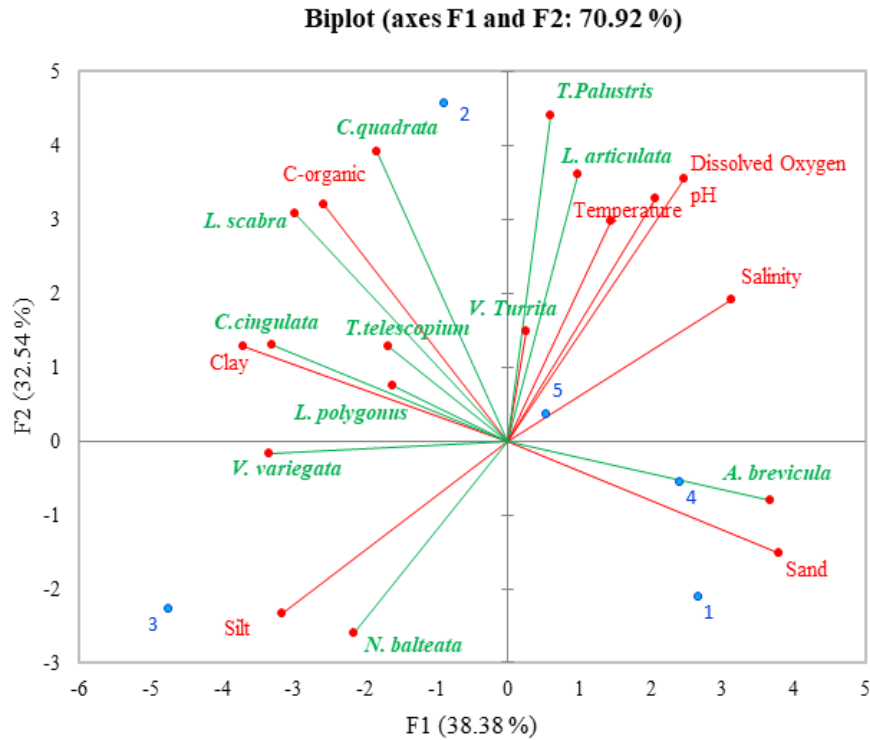
the existing environmental conditions on the mangrove ecosystem. According to Premcharoen et al. (2016), the presence of *A. brevicula* can be used as an indicator of mangrove ecosystem health because of their tolerance to environmental variability.

Meanwhile, *C. cingulata*, *C. quadrata*, *L. articulata*, and *L. scabra* spread on clay substrate conditions with high C-organic content and had a negative relationship with sand substrate. According to several previous studies, *C. cingulata*, *L. articulata*, and *L. scabra* exist optimally on clay substrates Premcharoen et al. (2016); Wanthongchai and Pongruktham (2019). On the other hand, there was a negative relationship with the sand substrate because it had a rough size. The presence of a coarse substrate indicates that the substrate was deposited in an open area that is directly related to the high seas. The study site at station 1 and station 4 which were on the coastal area so that the influence of sea current can affect the substrate fraction composition. According to Eddy and Roman (2016); Gao et al. (2018); Soler et al. (2020), which the stronger current will be found coarse granules. Conversely, in waters with the weak current will be found smooth granules will be deposited. Smooth granules are closely related to the availability of C-organic content in the substrate. Generally, the higher smooth granules (clay), the higher C-organic content will be found in the mangroves area. This is consistent with study conducted by Serrano et al. (2016) and Chen et al. (2020) that clay has a good ability to storage C-organic because it has dense pores while sand has large pores so that organic matter is easily carried by currents. The C-organic content in the substrate is very important as a source of nutrients for gastropods in the mangrove ecosystems. However, if the C-organic content exceeds the threshold then it can be considered as a pollutant (Zhang et al. 2015; Laut et al. 2017; McAlister and Rott 2019).

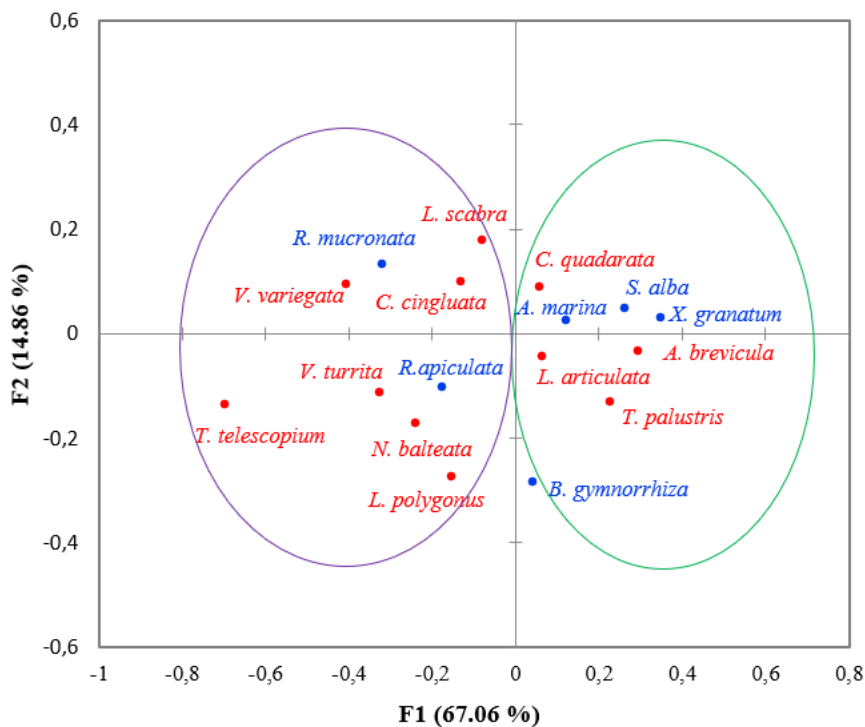
### Association of gastropods and mangrove species

Correspondence Analysis (CA) results show that gastropods species have different associations with mangrove species. Associations of gastropods and mangroves form two groups (Figure 5). The first group (purple circle) explained that the species *C. cingulata*, *T. telescopium*, *N. balteata*, *V. turrita*, *V. variegata*, *L. polygonus*, and *L. scabra* has a close relationship with *R. apiculata* and *R. mucronata*. Researchers in various studies have demonstrated a strong association of *L. scabra* (Littorinidae), *N. balteata* (Neritidae), *C. cingulata* and *T. Telescopium* (Potamididae) with clay substrate at middle zone towards intertidal areas (Haumahu and Uneputty 2018; Padovan et al. 2019; Laraswati et al. 2020). Clay substrate is suitable for the growth of *R. apiculata* and *R. mucronata*. According to several studies, *R. mucronata* was dominated in the research observation with a root system that can trap smooth granules to form a clay substrate (Setyawan and Ulummudin 2012; Robertson and Alongi 2016; Prabu and Gokul 2017). The roots system of *R. apiculata* and *R. mucronata* from branches and sticks to the soil which is commonly called the stilt roots. According to

Strauch et al. (2012); Srikanth et al. (2015), stilt roots clay substrate and litter which will become food for functions as a buffer for coastal ecosystems by trapping gastropods.



**Figure 4.** Principal component analysis gastropods distribution with environmental characteristics



**Figure 5.** Correspondence analysis gastropods species with mangrove ecosystem

The second group (green circle) shows the species of *A. brevicula*, *C. quadrata*, *L. articulata*, and *T. palustris* in close association with *S. alba*, *A. marina*, *B. gymnorrhiza*, and *X. granatum*. According to research conducted by Patria and Putri (2017) in Panjang Island Banten, *T. palustris* also was associated with *S. alba* mangroves that grow very well on sand and mud substrates. In addition, Idrus et al. (2019) also reported several gastropods species from Potamididae family (*C. cingulata*, *C. quadrata*, *T. telescopium*, and *T. palustris*) which associated with mangrove species of *S. alba* and *A. marina* in the southern coast of East Lombok. Meanwhile, Li et al. (2017) recorded distribution of *A. brevicula* in the intertidal zone along the Gulf of Xiamen, China. The intertidal zone is located on the coast which borders the terrestrial ecosystems (Nordlund et al. 2013; Wang et al. 2018). The intertidal zone is the narrowest because that zone is strongly influenced by tides. The existence of tides can cause water environmental parameters such as temperature, pH, salinity, and dissolved oxygen to change at any time. Gastropods that live and can survive in the intertidal zone are commonly able to adapt to existing environmental conditions by moving to the terrestrial areas and immersing themselves in the sand or clay substrate to keep getting water supply. Roy and Nandi (2012); Namchote et al. (2015); Solanki et al. (2016); and Itsukushima et al. (2019) also reported distribution of *A. brevicula* species were able to live well in zone conditions that approached the coastline. This indicates that the species of *A. brevicula* in mangrove zonation near the sea which generally grows mangrove species of *Avicennia* sp. and *Sonneratia* sp.

Ecological index results of the gastropods community indicated that the gastropods are in good condition and evenly distributed with no species dominate the study area. Species of *A. brevicula* were found on the sand substrate associated with *S. alba*, *A. marina*, *B. gymnorrhiza*, and *X. granatum*. Meanwhile, species of *C. cingulata*, *C. quadrata*, *L. articulata*, and *L. scabra* were found on clay substrate with high C-organic content and associated with *R. apiculata* and *R. mucronata*. As an outlook, the negative effect of the anthropogenic waste in these areas can disrupt the mangrove ecosystem. It would be interesting to investigate the influence of heavy metal content considering mangrove ecosystem has an important role in organisms.

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