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Shell size distributions, land use, and water quality relationships of a freshwater apple snail *Pomacea canaliculata* (Lamarck, 1822) in Maninjau Lake, West Sumatra, Indonesia

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Abstract. *Takarina ND, Soeprobowati TR, Komala PS, Subehi L, Wojewódka-Przybył M, Nurdin D. 2023. Shell size distributions, land use, and water quality relationships of a freshwater apple snail* Pomacea canaliculata *(Lamarck, 1822) in Maninjau Lake, West Sumatra, Indonesia. Biodiversitas 24: 5478-5484.* The freshwater apple snail, *Pomacea canaliculata* (Lamarck, 1822), is a common mollusk in lake ecosystems, including Maninjau Lake, West Sumatra. Despite its presence in Maninjau Lake, the information about its shell size, land use, and water quality variable relationships is very limited. This paper aims to study how the land use surrounding the lake and water quality variables can affect the shell size distributions of *P. canaliculata*. The samples were collected from several locations representing the varieties of land uses, including settlements, paddy fields, forest covers, and river mouths, along with water quality variables. Statistical analysis was done using ANOVA and validated by Tukey's post hoc test to analyze differences among locations. Pearson's correlation test was used to analyze the relationship between shell size and water quality variables. The results show that the differences in land use and water quality variables affected the variations of shell length ($P < 0.05$, $F = 4.925$) and width ($P< 0.05$, $F = 12.369$) of *P. canaliculata*. The average shell length was 2.709 cm and 2.022 cm for the width. The large shell size was observed in settlement land uses ($P< 0.05$), and the small shell was observed in forest and paddy field land uses ($P< 0.05$). The water near settlement land uses was characterized by high temperatures, while colder water was observed in forest and paddy field land uses. Pearson's test confirms that increases in shell length and width were correlated with increases in temperature and dissolved oxygen.

Keywords: Aquatic condition, dissolved oxygen, land exploitation, mollusk, wetland

INTRODUCTION

The apple snail genus Pomacea is a freshwater snail belonging to the family Ampullariidae. The *Pomacea canaliculata* (Lamarck, 1822) species is an invasive freshwater snail species (Manara et al. 2022; Marwoto et al. 2020) that inhabits natural wetlands (Horgan et al. 2014) or river waters, rice field irrigation canals and ponds (Yang et al. 2018) with high calcium (Jesús-Navarrete et al. 2023). In more detail, Seuffert and Martin (2013) explained that *P. canaliculata* can be found in coastal areas which have low current speeds, fine sediment and are rich in organic material, as well as macrophytes, which are their food and support their growth (Larasati et al. 2023). *Pomacea canaliculata* is a species that is not selective in food, causing its growth rate to be faster than that of other species in the same habitat (Chaichana and Sumpan 2014).

Low temperature is one of the limiting factors for population and geographic expansion of *P. canaliculata* (Qin et al. 2020). However, differences in water temperature can affect the growth and survival of *P. canaliculata* (Latip and Clement 2021). However, this species can adapt well to environmental conditions in new areas, whether the environmental conditions are colder, hotter, drier, or wetter. *Pomacea canaliculata* had a wider niche breadth than other mollusks and the ability to occupy different niche positions. This ability is supported by well adaptation of this snail to novel environmental conditions. Regarding temperature and climatic variables, Yang et al. (2023) estimated that *P. canaliculata* can shift their niche into environments characterized by both drier and colder climatic conditions. This finding was partially supported by the current records of this snail expanding to both warmer and wetter regions covering South Asia, from the southern slope of the Himalayas to the Indo-China Peninsula, including snails's presence in Malaysia, Indonesia, and also in tropical regions in South America. In Asian regions, in particular Hong Kong, *P. canaliculata* consumes semi-aquatic vegetables, including watercress (*Nasturtium officinale*) and water spinach (*Ipomoea acquatica*). In recent years, in the aquatic ecosystem, *P. canaliculata* is grazing on macrophytes and having predation on benthic invertebrates, and altering wetland function by releasing nutrients into the water.

The presence of P. canaliculata has been recently reported in aquatic ecosystems in Indonesia. In the wetlands of Rawa Pening, Central Java, Marwoto et al. (2020) reported the presence of *P. canaliculata* in 15 locations. The presence of *P. canaliculata* has also been reported on Sumatra Island. In the rice-fish farming system, Fitriadi et al. (2023) confirmed the densities of *P. canaliculata* from several locations were 23.0 individuals/m^2, 12.7 individuals/m^2, 3.3 individuals/m^2, and 10.0 individuals/m^2. In inland waters of South Konawe District, Southeast Sulawesi Province, Oetama and Purnama (2022) recorded a density of under 5 individuals/m^2.

Recently, shell length-width-water quality relationships in mollusks have been studied. By studying *Nerita lineata* species, Samsi and Karim (2019) confirmed the correlations of *N. lineata's* length and salinity, length and acidity (pH), and length with total organic matter. In contrast, there were no correlations between *N. lineata's* length and water temperature.

West Sumatra Province in Indonesia has five big lakes, including Singkarak Lake (10,908 ha), Maninjau Lake (9,737.5 ha), Diateh Lake (3,500 ha), Dibawah Lake (1,400 ha), and Talang Lake (500 ha). Those lakes are the primary producer of freshwater fish in West Sumatra, besides being a tourist destination. Maninjau Lake located in Tanjung Raya Subdistrict, Agam District, has received attention recently. Maninjau Lake was known for its mollusk diversity supported by water quality. Kropotin et al. (2022) confirmed the presence of endemic mollusks, locally known as Pensi (*Corbicula moltkiana*) in Maninjau Lake. At the same time, records on the *P. canaliculata* in Maninjau are still limited. Moreover, *P. canaliculata* is a mollusk that has nutritional content, especially as a source of high protein for consumption (Ghosh et al. 2017; Pertiwi and Saputri 2020).

Currently, most studies on *P. canaliculata* only emphasize the presence of this species. As a result, records on the shell length and width of this particular species and its relationship with water quality are still limited. This relationship information is needed to provide insight and guidelines to manage this species in aquatic ecosystems. Having information about the shell length and width of this particular species and its relationship with water quality will inform how to control the water quality required for conserving this species. Then, this study aimed to elaborate on how the land use surrounding the lake and water quality variables can affect the shell size of *P. canaliculata* distributions, in particular at Maninjau Lake in West Sumatra.

MATERIALS AND METHODS

Study area

The study was conducted in August 2023 in four locations located in Maninjau Lake, West Sumatra, Indonesia (Figure 1). Those four locations were selected using purposive methods aimed to purposively select locations that represented land uses. Maninjau Lake is a techno-volcanic lake formed by volcanic activity around 52,000 years ago and its eruption created a crater filled with water with volume of 10.26 billion m^3 (Widyani et al. 2020).

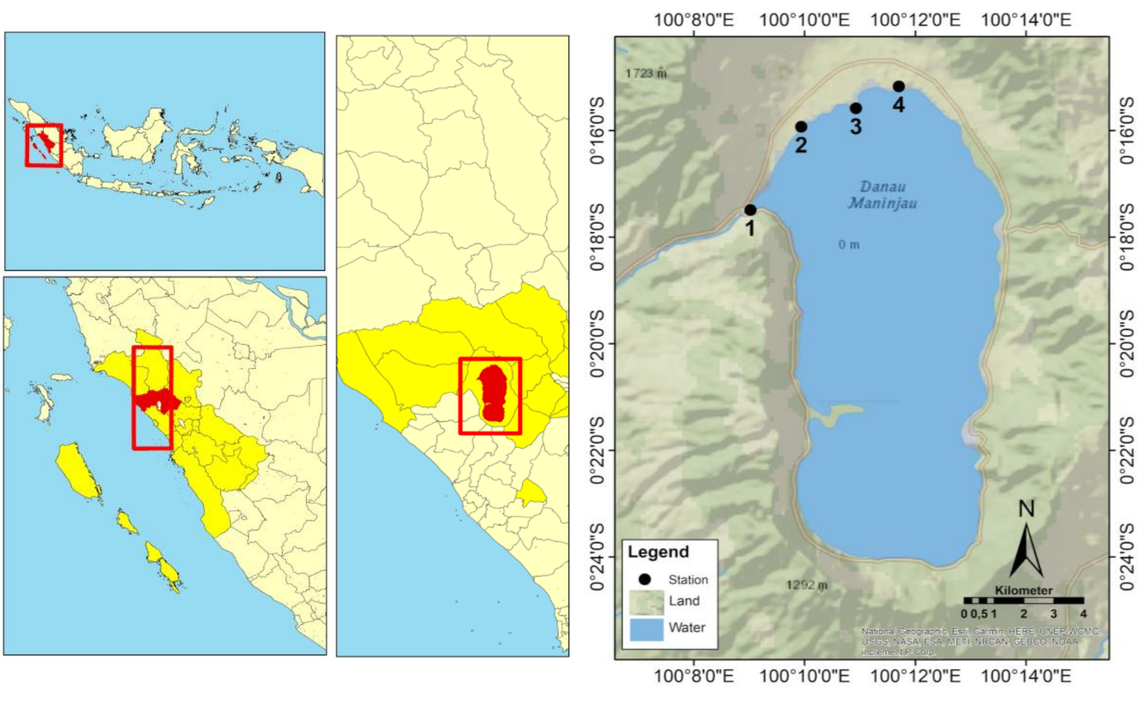

Figure 1. Map of Maninjau Lake, West Sumatra, Indonesia, with the four sampling locations and land uses in Muko muko (Forest), Talao (Settlement/river mouth), Muara Tanjuang (Paddy field), and Linggai (Settlement)

This lake is located at an altitude of 461.50 m above sea level, making it one of the highest-altitude lakes. The surface area of the lake is 99.5 km^2, with an average depth of around 105 m and can reach 495 m as a maximum depth. Due to its fertile lands, Maninjau Lake is currently populated despite its remoteness. The consequence of settlement encroachment in Maninjau Lake is the degraded water quality. According to Salsabil et al. (2018), Maninjau Lake is slightly polluted, caused by organic and inorganic contaminants from many activities surrounding, especially household and fish breeding activities. It shows that Maninjau Lake is in an oligotrophic state or nutrient-deficient waters.

In Maninjau Lake, four sampling locations were purposively selected to represent settlements, paddy fields, forest covers, and river mouth land uses. Each sampling station geocoordinate was recorded using Global Positioning System (GPS) handheld Etrex Garmin. The detailed description of each sampling location can be seen in Table 1.

Table 1. Sampling location characteristics

Locations	Coordinates	Land uses nearby lake
Muko muko	0.299601°S, 100.150436°E	Forest
Talao	0.291048°S, 100.168931°E	Settlement/rivermouth
Muara Tanjuang	0.259722°S, 100.182166°E	Paddy field
Linggai	0.25289°S, 100.19508°E	Settlement

Table 2. Snail and water quality measurement methods

Variables	Unit	Measurement methods
Snail	individuals	Eijkman grab
Length-width	cm	Caliper
pH	na	Lutron PH 208
Temperature	°C	Lutron DO 5510 multi parameter
Dissolved oxygen	mg/L	Lutron DO 5510 multi parameter
Geocoordinate	Decimal degree	Garmin Etrex GPS handheld

Procedures

Pomacea canaliculata *sampling*

Pomacea canaliculata were sampled directly from the field following designated locations. The method used to collect the *P. canaliculata* was following Fitriadi et al. (2023) using a quadrat of 1x1 m^2 replicated three times. Then, in total, there were 12 sampling sites representing four locations. Eijkman grab was used to collect the snail from sediments. While snail observed in shallow water at a depth of 50 cm (Darby et al. 2002) were collected by hand picking following Purnama and Salwiyah (2022). All samples were put in a plastic bag for further identification and measurements in the Universitas Andalas Animal Ecology Laboratory. Here, the collected samples were measured for their shell length and width with cm unit using a caliper. Samples were identified using Benthem-Jutting (1977).

Water quality measurement

Water quality variables were measured in situ in each sampling station with 3 replications for each station (Table 2). The measured variables included water Dissolved Oxygen (DO), pH, and temperature. DO and temperature were measured using multi parameter (Lutron DO 5510), and pH with a pH meter (Lutron PH 208).

Data analysis

ANOVA statistical test was used to analyze the significant differences in shell length and size and water quality variables among locations. A prior parametric test was performed to test the distribution of the data, whether normally distributed or not. This test was continued with Tukey's post-hoc test to analyze the effects of paired locations on shell length and size. Correlation analysis using Pearson's R was used to test the correlation significance between shell length and size and water quality variables among locations. The Pearson's R values ranged from 1 as very correlated to -1 as not correlated.

RESULTS AND DISCUSSION

Shell length and width

The shell length and width of snails collected from various locations in Maninjau are presented in Table 3. The order of shell length from the longest to the shortest was Talao (settlement/river mouth) > Linggai (settlement) > Muko muko (forest) > Muara Tanjuang (paddy field), as can be seen in Figure 2. The average length was 2.709 cm. The shell length among those locations was significantly different ($P < 0.04$, $F = 4.925$). This indicated that the snails found in the parts of the lake dominated by settlement land uses were observed to be significantly longer in terms of shell length when compared to the snails sampled from the paddy fields, regardless of the locations. It can also be observed using post-hoc analysis that Talao (settlement/river mouth) and Linggia (settlement) locations are significantly different from Muara Tanjuang (paddy field) locations in terms of shell length, as can be seen in Table 4. The length size classes of 1.6-3 cm were dominating the snail populations in Muara Tanjuang and Linggai. Muko muko was the only location where small-sized snails could be found (Figure 3). Based on the result, the average width was 2.022 cm. The shell width among those locations was significantly different ($P < 0.03$, $F = 12.369$). According to Table 3, the order of shell width from the longest to the shortest was Linggai (settlement) > Talao (settlement/river mouth) > Muko muko (forest) > Muara Tanjuang (paddy field), as can be seen in Figure 4. This also indicated that the snails found in the parts of the lake dominated by settlement land uses were observed to be significantly larger in terms of shell width when compared to the snails sampled from the paddy fields, regardless of the locations (Figure 5). It can also be observed using post-hoc analysis that Talao (settlement/river mouth) and Linggai (settlement) locations are significantly different from Muara Tanjuang (paddy field) locations in terms of shell length, as can be seen in Table 4.

Water quality variables

The results of the water quality variable measurement are presented in Table 2. The order according to the water pH was Muara Tanjuang (paddy field) > Muko muko (forest) > Talao (settlement/river mouth) > Linggai (settlement) (Figure 6). This indicated that the water in Linggai was more acidic in comparison to the pH in other locations. According to the statistical test, there were no significant differences in terms of pH. For water temperature, the order was Talao (settlement/river mouth) > Muko muko (forest) > Linggai (settlement) > Muara Tanjuang (paddy field) (Figure 7). This indicated that the water in Talao and Muko muko was significantly warmer ($P< 0.05$, $F = 74.714$) other than the water temperature in other locations. For dissolved oxygen, the order was Linggai (settlement) > Muara Tanjuang (paddy field) > Talao (settlement/river mouth) > Muko muko (forest) (Figure 8). This indicated that the water in Talao and Muko muko was significantly experiencing hypoxia ($P< 0.05$, $F = 728.75$), other than water dissolved oxygen in other locations.

Shell length and width and water quality variable correlations

The correlations of shell length and width and water quality variables are available in Figure 9. The parametric test resulted in normal distribution, then Pearson's Test was used. The positive correlation trends were observed for shell length and width with temperature and dissolved oxygen water quality variables. In contrast, negative correlations were observed for shell length and width with pH water quality variables. An increase in temperature and dissolved oxygen water quality variables will cause an increase in shell length and width. At the same time, an increase in pH water quality variables will cause a decrease in shell length and width. These findings indicate that snails favor locations and ecosystems with high temperatures and dissolved oxygen. This snail avoids ecosystems with high pH in water.

Table 4. Post-hoc analysis of shell length and width distributions in Maninjau Lake, West Sumatra, Indonesia (significance at P <0.05)

Location pairs	Length	Width
Muko muko - Talao	0.390	0.053
Muko muko - Muara Tanjuang	0.195	0.776
Muko muko - Linggai	0.779	0.000*
Talao - Muara Tanjuang	0.003*	0.003*
Talao - Linggai	0.917	0.235
Muara Tanjuang - Linggai	0.021*	0.000*

Note: * statistically significant at P <0.05

Table 3. Shell length and width averages and water quality variables in various locations in Maninjau Lake, West Sumatra, Indonesia were tested with one-way ANOVA (significance at P< 0.05)

Variables	Locations				P	F
	Muko muko (Forest)	Talao (Settlement/rivermouth)	Muara Tanjuang (Paddy field)	Linggai (Settlement)		
Length (cm)	2.686 (1.8-4.5)	2.966 (2.5-4.6)	2.333 (2-3.2)	2.853 (2.5-3.5)	0.003*	4.925
Width (cm)	1.773 (1.2-2.8)	2.193 (1.5-3)	1.62 (1.2-2.6)	2.504 (2-3)	0.000*	12.369
pH	6.8 (6.7-7.2)	6.7 (6.6-7.2)	7.033 (6.6-7.2)	6.666 (6-6.8)	1.045	0.394
Temperature (°C)	26.833 (26.7-26.9)	27.2 (27.1-27.3)	25.033 (24.7-25.3)	26.366 (26.1-26.9)	0.000*	74.714
Dissolved oxygen (mg/L)	6.1 (6-6.2)	6.9 (6.8-7)	8.333 (8.1-8.6)	10.5 (10.3-10.8)	0.000*	728.75

Note: * statistically significant at P<0.05

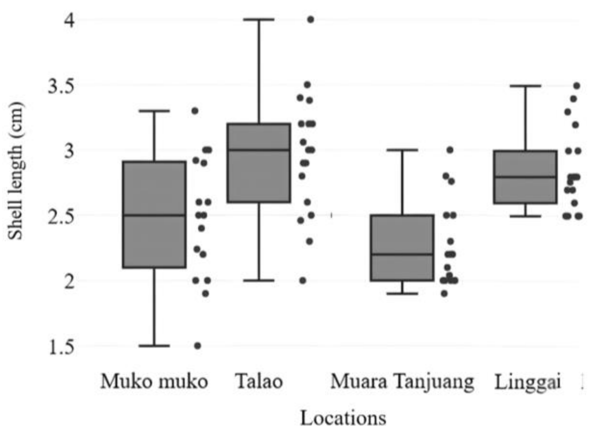

Figure 2. Boxplots of shell length (cm) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

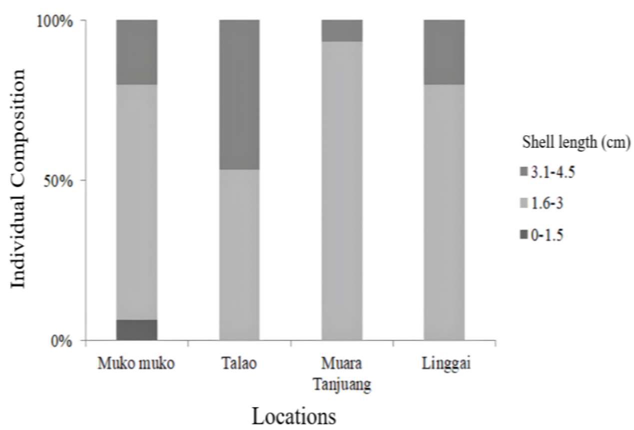

Figure 3. Individual compositions based on shell length classes (0-1.5, 1.6-3, 3.1-4.5 cm) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

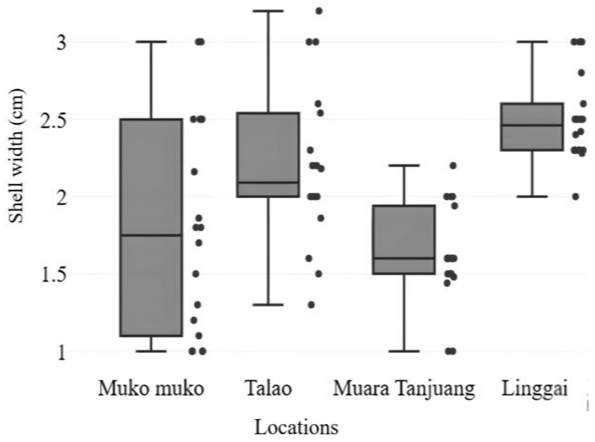

Figure 4. Boxplots of shell width (cm) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

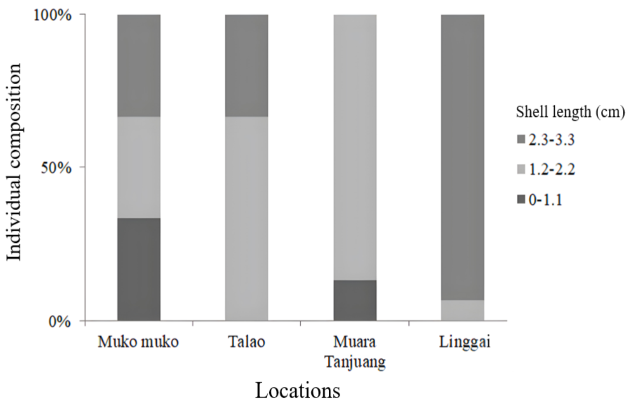

Figure 5. Individual compositions based on shell width classes (0-1.1, 1.2-2.2, 2.3-3.3 cm) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

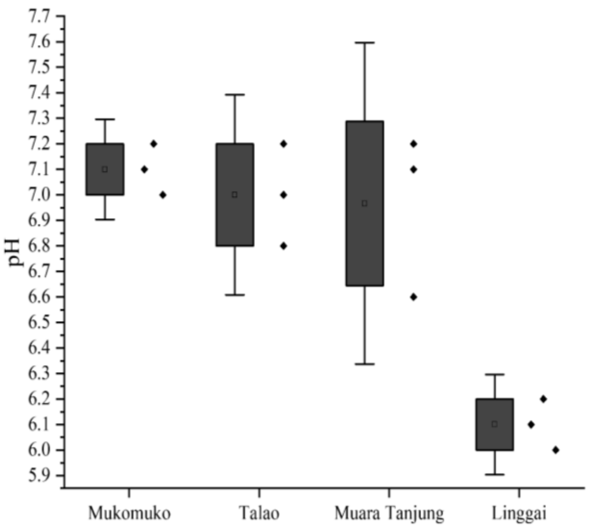

Figure 6. Boxplots of water pH distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

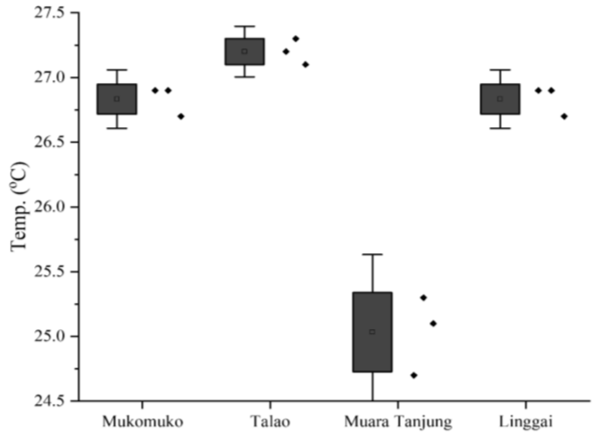

Figure 7. Boxplots of water temperature (°C) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

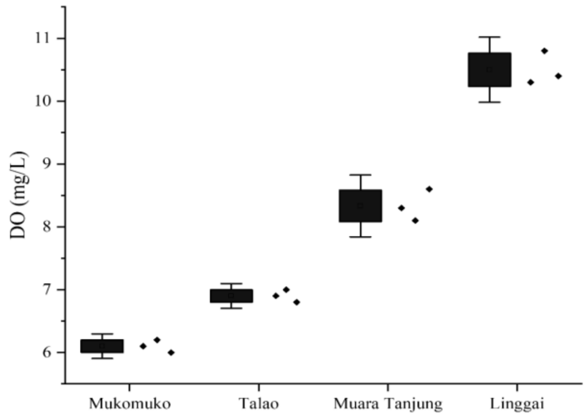

Figure 8. Boxplots of water-dissolved oxygen (mg/L) distributions in various locations in Maninjau Lake, West Sumatra, Indonesia

Discussion

Species morphological variation, in this case, represented by variation in shell length and width, can be used to assess population differences in aquatic organisms and is recognized as one of the basic characteristics. Having information about the shell length and width characteristic of this particular species and its relationship with water quality will inform how to control the water quality required for conserving this species. For mollusks, the shell is vitally important, providing protection and additional required support to the internal metabolism and body in the form of a calcareous exoskeleton (Colvin et al. 2022). Measurement, description, and analysis of the morphological variations are the basic steps to answering biological questions. The shell length-width-water quality relationships can be used to calculate the condition index of selected snail species as well as to compare the life history and morphological differences between populations from different regions (Nie et al. 2013). In this study, we assess the length-width-water quality relationship affected by land use variations of *P. canaliculata*. Obtained data informed the length-width correlation of *P. canaliculata*, which can then be used to assess this particular snail's growth and resource assessment (Yang et al. 2020).

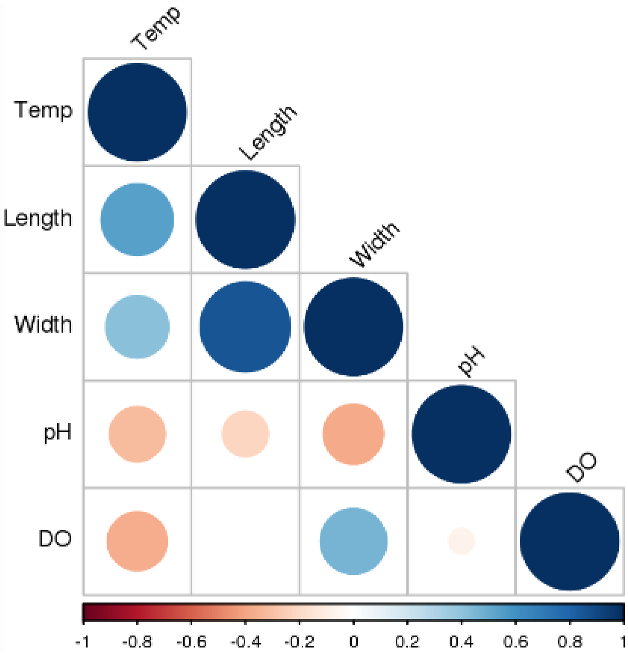

Figure 9. Pearson's correlogram of shell length, width, and water quality in Maninjau Lake, West Sumatra, Indonesia. Red dots indicate negative correlations, blue dots indicate positive correlations, and the size of the dots representing the R^2 values with increases in dot size representing increases in R^2 values

Among land use types, Talao and Linggai have the highest shell length values. Talao was located near the river mouth. In this location, there will be deposits and discharges of sediment transported from upstream to downstream. Those deposits will contain a nutrient that can be utilized by snails. In Talao, it was estimated that the presence of large snails was related to the nutrients deposited in sediment and accumulated in the river mouthparts. This condition is in agreement with Fitriadi et al. (2023). Sediment-deposited substrate tends to produce high nutrient values (Wang and Li 2022) if supported by a sufficiently strong water input (Aguilera and Melack 2018). This is a good influence on the growth of gastropods because some gastropods tend to like living in mud substrates, including *P. canaliculata* (Ng et al. 2020). Besides that, settlement locations tend to have large size snails due to the availability of substrates. Settlement often discharges used wood that can be utilized by the snail to attach as a substrate.

The presence of large individuals in the settlement land uses characterized by a lack of canopy closures is related to the reflectivity of the shell (Franklin et al. 2022). Mollusks resided in water with limited protection from the sun and exposure to thermal extremes. Only individuals with large shells can tolerate these conditions since the size of the shell can add more protection. In contrast, small to medium-sized individuals were common in forest and paddy field lands that still had trees to protect from the sun. In this study, the results and size classes obtained were related to the sampling efforts. Here in Maninjau, the species were sampled near the coasts at limited depth. As a consequence, this study only collects a limited sample size and a certain size class.

In Maninjau Lake, water temperature was known to have a positive correlation with snail shell length and width. This condition is related to the fact that the water temperature in Maninjau Lake was suitable to support the presence and growth of snails. Fitriadi et al. (2023) stated that a suitable temperature range will support mollusks. Okumura and Rocha (2020) stated that the optimal temperature suitable for the growth of gastropods in rice fields is around 24-32°C. In Maninjau Lake, the recorded water temperatures were within the optimum ranges. Chatzinikolaou et al. (2021) noted that the increases in temperature will cause shells to become thicker and denser, and this means that shell length and width are increasing.

Besides temperature, a positive correlation was observed between dissolved oxygen and an increase in shell width. Dissolved oxygen recorded in Maninjau Lake was considered suitable to support the snails. Gastropod biota can live where the minimum oxygen level is above 4 mg/L (Harahap et al. 2018). In Maninjau Lake, the recorded minimum water dissolved oxygen levels were above the minimum requirements of snails. The only limiting factor was the pH, since pH has a negative correlation with shell length and width. In Maninjau Lake, increases in pH reduced the shell length and width and the presence of large-sized snails. Low and high water pH can both affect mollusks. A pH that is too low will be acidic and become corrosive, and a pH that is too high will be toxic and cause mortality of gastropods (Wang et al. 2020). According to Fatmawati et al. (2020), the optimal pH for freshwater biota, including gastropods, is around 7.0-8.0. Negative correlations of pH and shell sizes observed in Maninjau Lake are in agreement with previous results. Ferlyn and Rosanilio (2022) noted that the higher pH could limit the length and width of snails. An increase in pH will reduce shell length and lead to shell erosion.

This study confirms the presence of *P. canaliculata* in Maninjau Lake in various environmental backgrounds. Environmental temperature and dissolved oxygen water quality variables had a positive correlation with shell length and width. Environmental pH had negative correlations with shell length and width. To conclude, large size individuals were common in settlement land uses. This indicates that the alteration of land uses from intact form to developed form, in this case, settlement, will favor the presence of snails and support their growth.

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