Production, biomass, and turnover of exploited mangrove clams (*Geloina expansa*, Mousson 1849) in Kendari Bay mangrove forest, Southeast Sulawesi Indonesia

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Abstract. *Geloina expansa* is a front-runner commodity of the mangrove ecosystem. This species is notably experiencing ecological pressures in Kendari Bay. Accordingly, this study aims to determine their production, biomass, and turnover in the mangrove ecosystem. This research is hoped to provide empirical information that will aid in the formulation of the management strategy of mangrove clam resources in Southeast Sulawesi. Clam samples were collected at random in three selected sampling areas using a 1x1 m^2 quadrat-transect sampling approach. The clams were measured for their shell length, total weight and weight of fresh meat. The clam meat was dried to obtain a shell-free dry mass. The production, biomass, and turnover of the clams were calculated using standard formulas. The population density of the clams ranged from 23.78 ind/m^2 (October) to 77.44 ind/m^2 (February), where the remaining months of observations showed similar values throughout. The clams biomass population in each size class ranged from 0.04 to 4.95 g/m^2. The somatic production, as per the dry weight showed the highest value at 6.9 cm shell length (2.01g/m^2/year). The lowest individual somatic production was found in the shell width of 9.7 cm (0.55 g/m^2/year). The turnover rate (P/B) of the mangrove clam was 1.73/year. The density of the mangrove clams in the mangrove forest in Kendari Bay was found to be high. This was accompanied by high productions in the young or small-sized groups, peaking at a size smaller than the size where peak biomass was found.

1 Introduction

Kendari Bay mangrove ecosystem to the extent that they are massively exploited by fishermen and the like[1][2]. Locally, this species of clam is known as "kalandue" and is a very popular seafood delight. The large market demand for mangrove clams in Kendari City brings about the high fishing pressure for mangrove clams[1]. Addedly, Kendari Bay is also experiencing prolonged environmental degradation due to the rapid city developments in the coastal areas[3]. The conversion of mangrove forests into aquaculture areas and buildings

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(real estate & settlements) as well as environmental pollution (heavy metals & plastics: macroplastics/microplastics)[4][5] as a result of household and factory-scale anthropogenic activities[3], cause Kendari Bay coast to be loaded with matters that physiologically threaten the sustainability of the mangrove ecosystem and its associated organisms, including that clams[6]. Lower density and smaller existing size of clams as caused by the previous can affect population dynamics (production, biomass & recoverability) of pelecypods in nature[7][8].

Research related to the population dynamics of clams, specifically in terms of production, biomass, and turnover, in Indonesia, especially in Southeast Sulawesi, is rarely carried out, contrary to other countries with recognizable research development of the same concern. Reports on production, biomass, and turnover have been previously been made on *Glauconome virens*[9], *Batissa violacea*[10], *Eurhomalea exalbida*[11], *Corbicula fluminea*[12], *Keletistes rhizoecus*[13], *Batissa violacea* var. *celebensis*[8], and *Anodonta* sp[14]. However, the same research on *Geloina expansa* has yet to be carried out. Such research will hold significant importance in providing information to devise an optimal and sustainable management strategy of mangrove clam resources. Given that mangrove clams have a high market price, i.e., economically valuable, and that they are under threat of anthropogenic activities and rapid urban development, the lack of scientific information on biomass, production, and turnover of these clams needs to be immediately resolved. Thus, this study aims to determine the production, biomass, and turnover of mangrove clams in the mangrove forest of Kendari Bay, Southeast Sulawesi. It is hoped that the results obtained will provide empirical information crucial to the formulation of management strategies for mangrove clams in Southeast Sulawesi.

2 Method

2.1 Location and period

Samples of mangrove clams were collected periodically every month for 1 year from January-December 2014 from the mangrove forest of Kendari Bay around the ordinate point of S = 03°30'20,3" and E = 122°09'05,9" to S = 03°31'55,1" and E = 122°13'14,6") (Figure 1).

2.2 Sample and data collection

The material sampled in this study was mangrove clams. Moreover, the data gathered were the population density of mangrove clams, shell width, the total weight of mussels, fresh meat weight, and dry meat weight.

2.3 Data collection and processing

2.3.1 Sample collection and examination

Clam samples were collected randomly (purposive random sampling) at three points of collection using a 1x1 m^2 quadratic-transect approach on 20 different sampling occasions per month. Subsequently, the total number of mangrove clam samples was count and population density (ind/m^2) was calculated. The clam samples were then measured for shell length (SL), total shell and meat mass (TW), and shell-free fresh mass (FM). The meat was then dried in an oven for 48 hours at 70°C to obtain shell-free dry mass (SFDM) (Abraho et al., 2010). The

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sampling of water quality and substrate was carried out simultaneously with the sampling of clams.

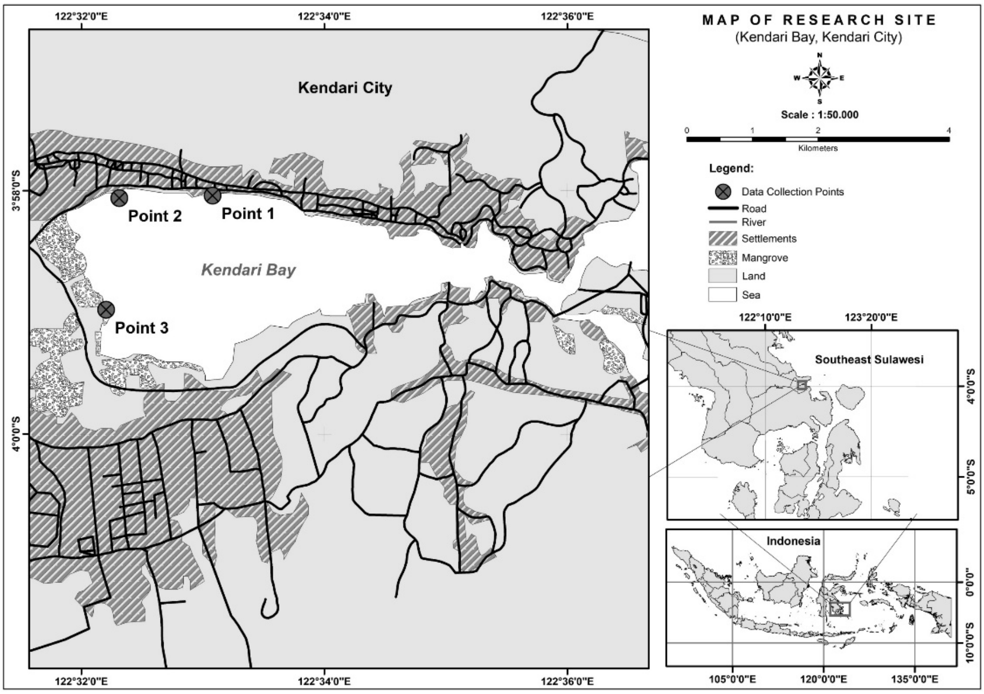

Fig. 1. Map of mangrove forest research location in Kendari Bay

2.3.2 Data analysis

Population density

The average density of the mangrove clams is a function of the sample area (ind/m^2) analyzed by the Mann-Whitney test (U-test)[15] as follows:

$$K = ni/A \quad (1)$$

Where:
K = population density (ind/m^2)
ni = number of individuals (ind)
A = area (m^2)

Biomass

The average annual biomass (gDM/m^2) was calculated using the equation[16]:

$$B = \sum Ni.Mi \quad (2)$$

Production

Total annual production was calculated using the mass-specific growth rate method[17][18] as follows:

$$P = \sum Ni.Mi.Gi \quad (3)$$

Where:
P = annual production (g DM.m^2/year)
Ni = average population density (ind/m^2) in the i-th length class
Mi = average dry mass (DM) of individuals in i-th length class
Gi = mass-specific growth rate

The specific mass growth rate (Gi) was calculated using the following equation[16]:

$$Gi = b.K.\left[\left(\frac{L\infty}{Li}\right) - 1/(year)\right] \quad (4)$$

The value of the coefficient b was obtained from the relationship between shell length (L) and dry mass (DM) which was determined using the following simple regression analysis:

$$MK = aL^b \quad (5)$$

Where:
a and b = coefficients
L = shell length
DM = dry mass (g)

The growth coefficient (K) and asymptotic length (L∞) were computed using ELEFAN I (Electronic Length Frequency Analysis) integrated with the FiSAT II version 3.0 program package. K and L∞ were adapted from another research[18].

Turnover rate

The turnover rate was calculated from the total annual production (P) divided by the average annual biomass (B).

$$T = P/B \quad (6)$$

The shell-free dry mass (SFDM) was converted into ash-free dry mass (AFDM) with a conversion factor of 82.7%[19].

3 Results

3.1 Population density

The population density of *G. expansa* clams in Kendari Bay waters varied during the study period. The highest density occurred in February at 77.44 ind/m^2 and the lowest was in October at 23.78 ind/m^2 (Figure 2). The Mann Whitney test for inter-month density (P-value 0.1) showed that the densities of the mangrove clams in the remaining months did not differ significantly.

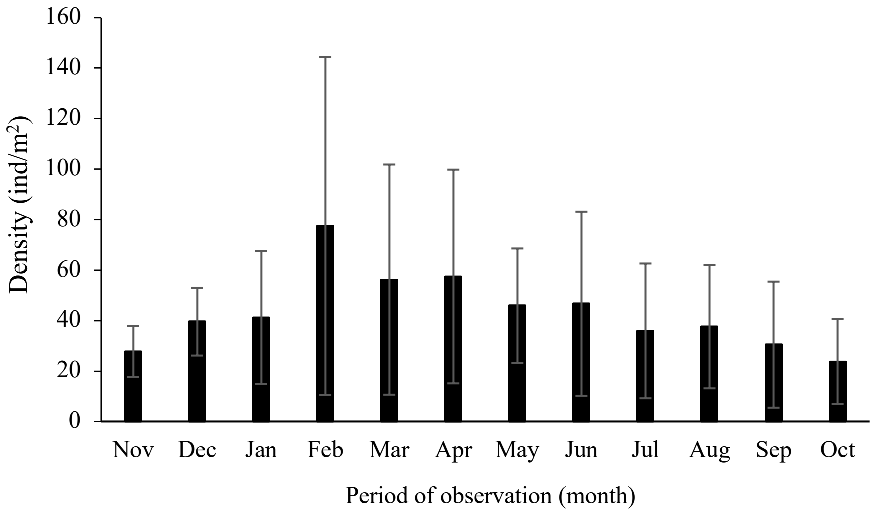

Fig. 2. Monthly average density estimation of *G. expansa* clams in Kendari Bay waters

3.2 Biomass and production

3.2.1 Biomass

The population biomass analysis results of *G. expansa* demonstrated varied values ranging from 0.04 to 4.95 g/m². The pattern surrounding the peak population density value of *G. expansa* clams was not concurrent with that of the peak biomass value. Although, the increase and decrease in the population density value tended to have the same relative pattern. The highest density was found at 4.1 cm (8.51 ind/m²), while the highest biomass was found at a larger size, namely 5.2 cm (4.95 g/m²). At the size of 5.2 cm, the density of *G. expansa* clams was smaller than the peak density of 6.43 (ind/m²) (Figure 3).

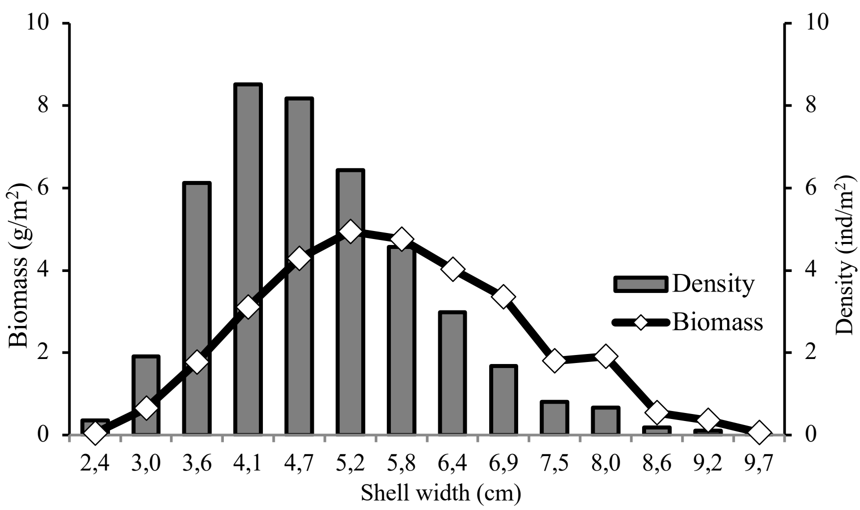

Fig. 3. Graphs of average density and dry biomass of *G. expansa* clams in each size class

3.2.2 Production

The (dry mass) somatic production analysis results of *G. expansa* indicated the highest value at 6.9 cm shell length (2.01 g/m²/year). The lowest individual somatic production was found in the shell length of 9.7 cm (0.55 g/m²/year) (Figure 4).

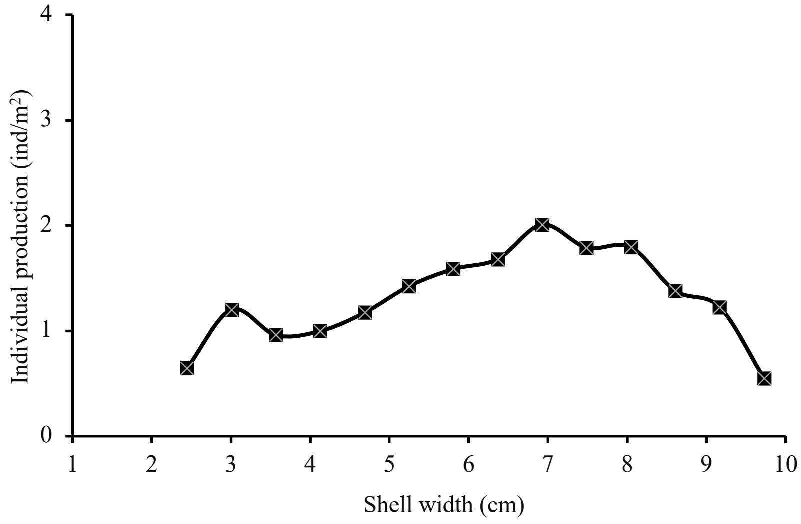

Fig. 4. *G. expansa* clam somatic production in each size class

Annual population production of *G. expansa* ranged from 0.009-9.57g/m²/year with a total production of 54.44 g/m²/year. Population density demonstrated a relatively similar size class pattern to the production of *G. expansa* clams. The highest production and density occurred from the size class of 4.1 cm to 5.8 cm (Figure 5).

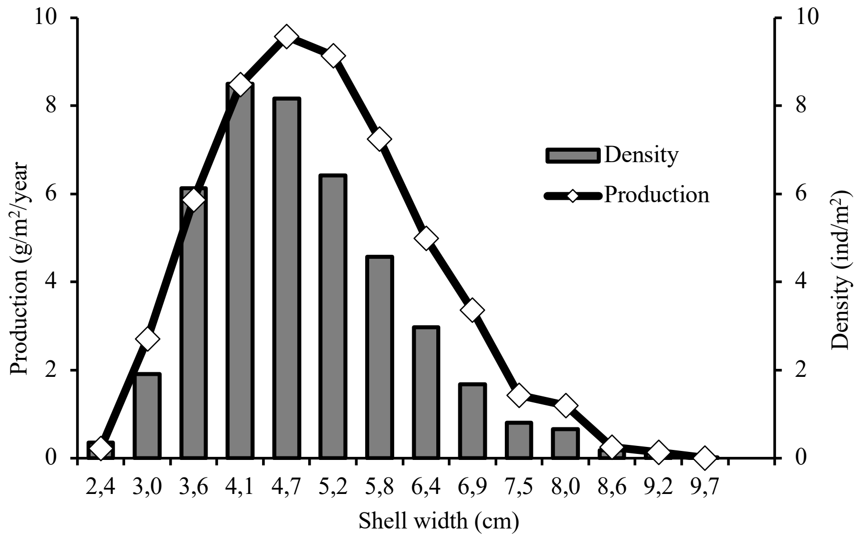

Fig. 5. Graphs of average density and estimated secondary production of *G. expansa* clams in each size class

3.2.3 Relationship between biomass and production

The increasing and decreasing production rate pattern in each size class of *G. expansa* clams in Kendari Bay waters generally coincided with the increasing and decreasing pattern of biomass values. The highest production and biomass of *G. expansa* clams occurred from the size class of 4.1 cm to 5.8 with a P/B ratio of 1.73/year (Figure 6).

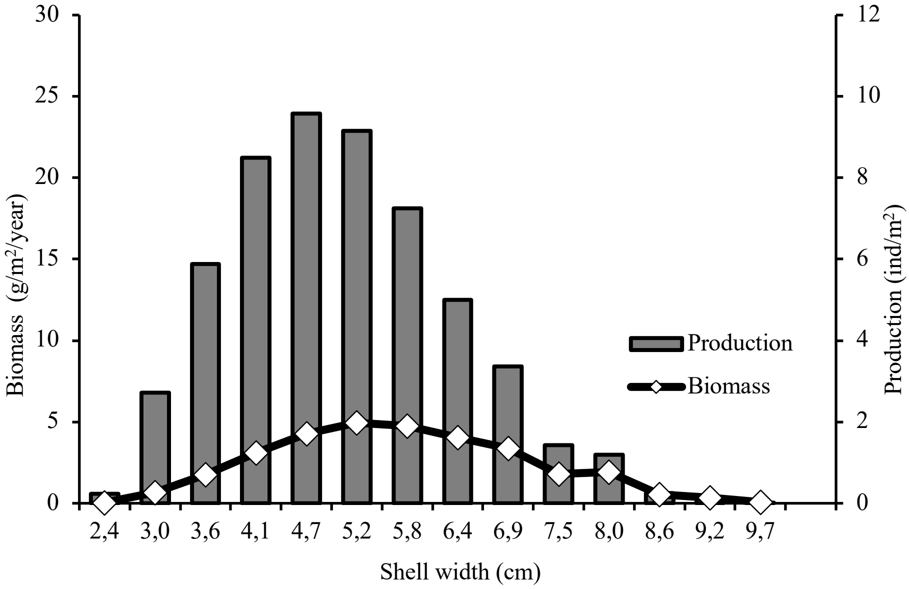

Fig. 6. Graphs of secondary production and biomass of *G. expansa* clams in each size class

4 Discussion

The population density of mangrove clams (*G. expansa*) in the mangrove forest of Kendari Bay, despite fluctuations, was quite steady over the observation time. That is, temporal variations in density values were not significantly different. This implies that mangrove clams were evenly distributed in the mangrove ecosystem, which is a hotspot area for harvesting mangrove clams. This also indicated the success of the reproductive process, i.e., the population recruitment in the mangrove forest of Kendari Bay. Mangrove clams can spawn all year round on Chorao Island, particularly when there is an increase in temperature and salinity concentrations[20]. Likewise, such conditions might have factored the spawning of the mangrove clams in Kendari Bay. This condition afforded fishing activities in the coastal waters of Kendari Bay to not significantly affect the population density of the mangrove clams. Moreover, limited fishing gear and difficulties in accessing harvesting locations also posed a challenge for the fishermen to fully exploit the mangrove population. The mangrove clam population in Kendari Bay could thus be maintained within the balanced or under-fished category[11].

The density of mangrove clams in Kendari Bay was relatively higher than other similar clams in other places. The population density of mangrove clams (*Polymesoda bengalensis*) in Muaro Pasia Kapa Padang Tae was 2.37 ind/m^2 [21]. For this case, the highest density was found on sandy mud substrates with a dense nipa palm population, which was 1.0 ind/m^2. The lowest density was found in mud substrates with a sparse presence of nipa palm at 0.63 ind/m^2. Furthermore, from another research reported that the population density of mangrove clams (*P. bengalensis* Lamarck) in the Kenagarian Mangguang mangrove area, Pariaman

City was 1.8 ind/m^2 and fell under the very low category[22]. Accordingly, the population density of mangrove clams depends on the presence of mangrove trees that form dense canopies, supply large quantities of nutrients from plant residues, and stimulate water fertility as they attract phytoplankton[23][24][21][22].

The density of the mangrove clams in Kendari Bay was relatively lower when compared to the density of *Cerastoderma edule* of 32-704 ind/m^2[25], *Mesodesma mactroides* of 110-543 ind/m^2[26], *Donax trunculus* of 36-272 ind/m^2[27], *Anomalocardia brasiliana* of 22-1592 ind/m^2[28], and *Darina solenoides* of 56.4-779.4 ind/m^2[29] in other beaches and estuaries. Differences in the density of clams both of differing and the same species are closely related to geographic location and climate[30][31], habitat type and conditions[32][33], fluctuations in environmental parameters including food and nutrient availability[23][34] as well as predator and prey density[35]. Certain ecological characteristics of habitat and niches that provide safe and optimal living space are also preferred by mangrove clams. This is in line with the statement of several researches in which substrate and morphological structure of mangrove plants such as *Rhizophora*, *Sonneratia*, *Nypa fruticans*, and others, provide collection sites for plant residues that are utilized by macrozoobenthos or bottom feeders as food, particularly clams associate with mangroves including *G. expansa*[24][36][37][38].

The annual production of the mangrove clam showed an increasing trend in the smaller or younger clam and reached a peak at a shell length of 5.2 cm shell. Beyond this size, the mangrove clams experienced a very significant decrease and then a stagnation at sizes close to the maximum (L∞), i.e., when the clams were mature/old. The decrease in population production when approaching the maximum size (L∞) is related to productive age, decreased reproductive potential, low density, as well as the preferred exploitation of clams of larger size[39]. The results indicated that, empirically, clams with a shell length of 5.2 cm contributed to the high production value of the mangrove clam population of 54.44g/m^2/year. This also implies that variation in densities of the size groups determined the annual production value of mangrove clams. This is despite the fact that peak density and production occurred at different shell length sizes, unlike other clams which typically show a corresponding relationship between production and density[15][40][19]. This occurrence is thought to be caused by the harvesting pressures of mangrove clams in Kendari Bay, in particular, due to fishermen's preference towards certain clam sizes (large/old). Consequently, the peak density and production of mangrove clams in Kendari Bay occurred at smaller sizes of 4.1 cm and 5.2 cm, respectively. The high population density of the young or smaller-sized clams contributed greatly to the annual production.

The availability of food was also a key factor that generated the high annual production of mangrove clams in the waters of Kendari Bay. Moreover, the mangrove forest provides habitats and living niches that are very rich in nutrients. That is, biota associated with mangrove forests will have access to abundant food sources[23][24]. One of the factors that can produce a high total annual production of a clam population is the high availability of food as well as its effective or optimal use[40].

The living tissue generation, in mass per m^2 area, of mangrove clams was very high and peaked at 5.2 cm in shell length. Typically, a pelecypod will have a distinct population group (based on size/age) in which the annual production peaks. Pokea clams (*Batissa violacea*), for instance, will have increased annual production along with the increase in size until it reaches a peak of 94.76 AFDM/m^2/year, whereby from then on will decline until it reaches its maximum size[10]. Additionally, *M. mactroides* reaches an annual production peak at 4.7 cm at 0.12 AFDM/m^2/year, which will then decrease along with growth to its maximum length (L∞ = 8.5 cm)[26], *E. exalbida* clams with L∞ = 7.4 cm reaches a peak at 5 cm at 22.2 AFDM/m^2/year[11], and *Donax striatus* clams with L∞ = 36.1 mm reaches maximum production at 24 mm with a value of 6.11 AFDM/m^2/year[15].

The size of the mangrove clams at the peak biomass was found to be slightly different from the peak density. The highest density was found at 4.1 cm (8.51 ind/m^2), while the highest biomass was found at a larger size of 5.2 cm. This demonstrated that a high density of mangrove clams at a certain size is not always accompanied by high biomass. In other words, the highest biomass of a clam population can occur in size groups of lower density. This difference can be caused by a decrease in the population of mangrove clams due to harvesting pressure of sizes larger than 5.2 cm with larger biomass. This harvesting, in turn, affects the formation of biomass at these larger sizes.

In general, the annual biomass of mangrove clams was relatively the same as that of other bivalve species such as *Tivela mactroides* at 2.67 grAFDM/m^2/year[40], *Donax striatus* at 1.76 grAFDM/m^2/year[15], *Donax trunculus* of 1.64-3.05 grAFDM/m^2/year, and *Anomalocardia brasiliana* of 3.56-3.60 grAFDM/m^2/year[28]. However, the annual biomass production of the mangrove clams was significantly different from *Corbicula fluminea* of 160.48 grAFDM/m^2/year[12], *Donax trunculus* was 92.94 SFFMg/m^2/year[39], *E. exalbida* of 185 AFDMg/m^2/year[11], and *Anomalocardia brasiliana* of 9.14 grAFDM/m^2/year[41]. The differences in biomass in each type of clams are influenced by factors such as: 1) space competition[42], 2) food supply[43][26], and 3) clam life history. Coastal areas that experience up welling are found to have higher annual biomass than non-up welling areas[16]. Furthermore, clams that have a short lifespan, are opportunistic, and invasive tend to have larger biomass, such as *Corbicula fluminea*[12].

The increasing and decreasing patterns of biomass in terms of size groups of the mangrove clams in Kendari Bay waters generally coincided with the reproduction rate. Clams with smaller shell sizes (young clams) experienced a very rapid increase in production value and reached its peak at 5.2 cm in size, after which it decreased until a maximum size was reached. The production and biomass of mangrove clams tended to occur in a coinciding manner, i.e., they decreased at larger sizes, close to or up to the maximum size. This implies that the growth of clams towards maturity or larger size drastically reduces production and biomass.

The turnover rate of mangrove clams in the waters of Kendari Bay (1.73/year) was not much different from pokea clams (*Batissa violacea*) at 1.8/year[44], *Trochulus plebeius* at 1.37/year[45], *Donax serra* at 2.86/year[13], *Donax striatus* at 3.47/year[15], *P. solida* at 0.23/year[46], *Donax trunculus* at 1.14/year[47], *Mesodesma mactroides* 1.84-2.93/year[26], *Anomalocardia brasiliana* 0.79/year[28] and 1.27/year[41], and *Darina solenoides* at 0.96/year[29].

The turnover of the mangrove clam population in the waters of Kendari Bay was relatively fast because the population was dominated by young clams which, as previously discussed, promote annual production and biomass. This further emphasized the harvesting pressure toward larger sizes. A difference in turnover rate is related to the growth rate of a species. Rapid growth and short life spans indicate the ability to recover (turnover) quickly. Conversely, the turnover rate is low if the individual size is large, the growth rate is low, and the life span is long[48]. In addition, within the same species, the turnover rate changes following the shift in latitude, whereby clams located toward the tropics will have a higher P/B ratio[45]. Whereas among different species, turnover is dominantly influenced by food availability[48].

High P/B values are also found in some waters where bivalves resources are exploited, particularly when the harvesting pressure is high. In such conditions, clams physiologically adapt to carry out reproduction earlier in their life stage and for a longer period (of up to 6 months). This adaptation strategy can increase clam production at small sizes which are not preferred to be harvested. The high density of the small-sized clams was not balanced by the equal presence of mature/old productive clams of higher biomass[49]. Meaning that too high of a turnover rate can be used as an indicator of high harvesting pressure.

5 Conclusion

The density of the mangrove clams in the mangrove forest in Kendari Bay was found to be high. This was accompanied by high productions in the young or small-sized groups, peaking at a size smaller than the size where peak biomass was found. The decrease in the production and biomass in larger size or old/mature groups as a result of pressures from harvesting activities of the *Geloina expansa* clams prompted faster turnover of the mangrove clams.

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