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Population dynamics of mud clam *Geloina expansa* (Mousson, 1849) in degraded mangrove area at Kendari Bay, Indonesia

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Abstract. *Bahtiar B, Kasim M, Hati YIP, Ishak E. 2024. Population dynamics of mud clam* Geloina expansa *(Mousson, 1849) in degraded mangrove area at Kendari Bay, Indonesia. Biodiversitas 25: 616-623.* Mud clams, *Geloina expansa* (Mousson, 1849), locally known as *kalandue*, are bivalves living in mangrove forests. These mud clams are currently experiencing ecological pressure, and are susceptible to the degradation of mangrove areas and the exploitation of the clams. This research was conducted in the mangrove forests of Kendari Bay for a year, from November 2016 to October 2017. *Geloina expansa* samples were collected throughout the mangrove forest area, and the water temperature was measured simultaneously with *G. expansa* sampling. The width of *G. expansa* shell was measured using a caliper. Population structure, growth, mortality, and exploitation rate data were analyzed using the Bhattacharya method, the von Bertalanffy inverse function, the width converted catch curve, and Pauly's empirical formula, all accommodated in the FiSAT II program version 3.0. The results showed that the *G. expansa* population was spread out from two and three-size groups, i.e., juvenile, adult, and old-size groups, dominated by the older group. *Geloina expansa* growth model follows the L_t = 10.08-(10.08-0.025) $e^{-0.6t,}$ which generally consists of 1.5-2.5 years of maturity. The total mortality (Z) of *G. expansa* was 2.26, in which the highest contributing factor was natural mortality (M) as opposed to fishing mortality (F), with values of M = 1.72 and F = 0.56. Thus, the exploitation rate (E) was within the low category, with a value of 0.24.

Keywords: Exploitation rate, growth, mortality, population structure

INTRODUCTION

Mangrove forests are a source of nutrients that provide a comfortable place for the growth and development of various macrobenthos/invertebrate species that live within (Janestia et al. 2017; Sihombing et al. 2017), including mud clam *Geloina expansa* Mousson, 1849 (Yahya et al. 2018; Bahtiar et al. 2022a), locally known in Southeast Sulawesi, Indonesia as *kalandue*. *Geloina expansa* is an accepted name (WORMS 2023) previously known by several other names including: *Geloina erosa* auct. non Lightfoot, 1786) (as in Peralta and Serrano 2014; Sarong et al. 2015), *Polymesoda expansa* Mousson, 1849 (as in Idris et al. 2017; Ong et al. 2017) and *Polymesoda erosa* Lightfoot, 1786 (as in Argente et al. 2014; Dolorosa and Dangan-Galon 2014; Yap et al. 2014; Duisan et al. 2021). These clams bury themselves in the substrate in the mangrove forest (Argente et al. 2014). Geographically, this clam has a wide distribution from all regions of the Indo-West Pacific (Poutiers 1998), including Indonesia (Sarong et al. 2015; Bahtiar et al. 2022b). Like other bivalves, *G. expansa* is a filter-feeder animal whose role in the ecosystem is essential, large (ecosystem architect in the aquatic environment) (Bódis et al. 2014a,b; Basyuni et al. 2018), including (i) improving the substrate and purifying the waters through the deposition of organic matters into dissolved and precipitated inorganic matters at the bottom of the water (Vaughn 2018; Li et al. 2020), restoring water contaminated with organic materials (Ercan 2013; Li et al. 2015), (ii) the function of energy transfer between primary producers and consumers (fish) (Boltovsky and Correa 2015) and (iii) the ability as bio-indicator in waters contaminated with heavy metals (Zhang et al. 2014; Yancheva et al. 2016). *Geloina expansa*, as an organism that can decompose organic matter and is strongly tied to the mangrove ecosystem (Muhammad et al. 2017; Hasibuan et al. 2021), along with the degradation of the *G. expansa* habitat (mangrove forest) will experience changes in population structure and growth as well as population decline in nature (Bahtiar et al. 2022b). In general, the changes in the population of bivalves can be caused by habitat degradation and direct exploitation (Bahtiar et al. 2022a,b). Kendari Bay is one of the sites in Southeast Sulawesi, Indonesia, which has been seriously degraded, with high turbidity levels and rapid conversion of mangrove forests. The degradation rate in this location is fast enough that by 2020, it has lost more than half of the mangrove trees. It is reported that the mangrove forests in the waters of Kendari Bay in the 1990s were estimated at 300 ha and reduced to 10 ha in 2012 (Marwah and Alwi 2014). The high conversions and functional shifts of mangrove forest areas for the needs of the community and the government have also accelerated the loss of suitable living places for this bivalve (Susetya et al. 2021).

On the other hand, the high activity in the upland section of Kendari Bay, as the center of all community activities around Kendari City and South Konawe areas, exacerbates the decline of *G. expansa*, whose life depends on the quality of the environment and the substrate in the mangrove ecosystem (Idris et al. 2017; Bahtiar et al. 2023), marked by the high natural mortality of *G. expansa* populations in mangrove waters. Several species of *Polymesoda* or *Geloina* clams, such as: *Polymesoda solida* R.A.Philippi, 1846, *Polymesoda arctata* Deshayes, 1855 (Argente and Ilano 2013; Dolorosa and Dangan-Galon 2014), have been exploited on large scales because of their high economic values (Yahya et al. 2018; Ransangan et al. 2019). These clams have been served as grilled/satay dishes at roadside and restaurants in Marudu Bay (Duisan et al. 2021) or as additional feed to induce gonad maturation of raw crabs in hatcheries (Thien and Yong 2017). High demand causes intensive fishing activities (F = 1.44 $year^{-1}$) carried out by fishers which trigger over-exploitation (E = 0.65) (Ransangan et al. 2019). Likewise, *G. expansa* are delectable, predisposing to the high consumption of *G. expansa* meat by the people of Kendari City (Putra et al. 2017). The increasing demand from the people of Kendari City has decreased the population of *G. expansa* from year to year (Bahtiar et al. 2023). A decrease in clams' harvested size indicates overfishing (Tamsar et al. 2013). So far, no strong data indicates that *G. expansa* in Kendari Bay has been overfished.

Research on population dynamics of *G. expansa* has been carried out in several places (Argente and Ilano 2013; Dolorosa and Dangan-Galon 2014; Yahya et al. 2018; Ransangan et al. 2019), while in the same area, it has been carried out for a limited time (3 months) (Tamsar et al. 2013). Therefore, it is important to conduct research on population structure, growth, mortality and exploitation rates of *G. expansa* in the mangrove forests of Kendari Bay, Southeast Sulawesi, Indonesia so that the appropriate actions can be undertaken to maintain the continuity of life of *G. expansa* (Akbar and Ishak 2014). Thus, this study aims to determine the population structure, growth, mortality and exploitation rate of *G. expansa* in the mangrove forests of Kendari Bay, Southeast Sulawesi. The results of this study are expected to provide basic information for managing *G. expansa* resources.

MATERIALS AND METHODS

Study area

This research was conducted from November 2016-October 2017 in the mangrove forest area of Kendari Bay, Southeast Sulawesi, coordinates 03˚30'20.3"S, 122˚09'05.9" E to 03˚31'55.1"S, 122˚13'14.6" E. Sampling was carried out at 3 different points, namely: point 1 is located near the hotel area, point 2 is located near the mangrove tracking area (city forest), and point 3 is located near the Wua-Wua River and office and hospital areas (Figure 1).

Procedures

The sample collection was carried out by considering purposive random sampling. For each location (in 3 stations), *G. expansa* samples found on the surface and substrate were collected in 5×5 m^2 transect quadrats with 12 replications throughout the mangrove forest. *Geloina expansa* in the substrate were taken by digging 20 cm deep using a spade. Furthermore, clam samples were combined from all stations. Data were compiled assuming that *G. expansa* found in all mangrove forests come from one herd with the same population parameters. Water quality samples (water temperature) were taken at the same time as *G. expansa* sampling. The shell width of *G. expansa* was measured using a caliper with an accuracy of 0.05 cm (Figure 2) (Bahtiar et al. 2023).

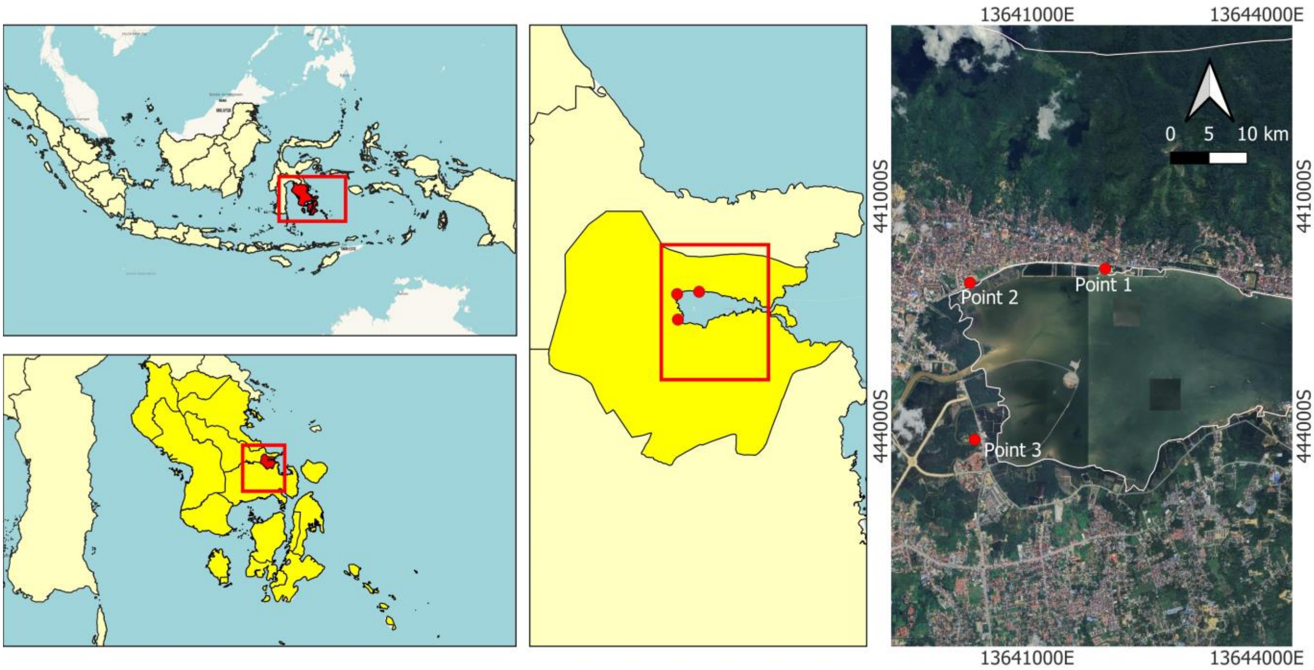

Figure 1. *Geloina expansa* research sampling map in the mangrove forest area of Kendari Bay, Southeast Sulawesi, Indonesia

Figure 2. Measurement of the shell length of mud or *Geloina expansa nsa* in the mangrove forest of Kendari Bay, Southeast Sulawesi, Indonesia

Data analysis

Population structure

The population structure of *G. expansa* can be determined through the separation analysis of the *G. expansa* age groups based on the size of the shell using the Bhattacharya method. This method was used to separate the shell width frequency distribution data into several normal distributions developed by Gayanilo et al. (2002) and Bahtiar et al. (2022b).

Growth

Growth parameters were calculated using the von Bertalanffy inverse function as suggested by Anthony et al. (2001) and Bahtiar et al. (2022b) as follows:

$$L_t = L_\infty - (L_\infty - L_o)e^{-Kt}$$

Where:

Lt : length of shells at time t (mm)

L_∞ : asymptotic/maximum shell length (mm)

K : growth coefficient ($year^{-1}$)

Lo : size of *G. expansa* as larvae or glochidia (Anthony et al. 2001).

T : age of *G. expansa* at Lt (years)

Mortality

The natural mortality coefficient (M) was calculated using Pauly's empirical equation (Bahtiar et al. 2022b):

$$\text{Log}(M) = -0{,}0066 - 0{,}279 \text{ Log } L_\infty + 0{,}6543 \text{ Log } K + 0{,}463 \text{ Log } T$$

Where:

L_∞ : asymptotic length of *G. expansa* (mm)

K : growth coefficient of *G. expansa* (yr^{-1})

T : water temperature (°C)

The total mortality rate (Z) was calculated using the width-converted catch curve, developed by Pauly (1980) (Sparre and Venema 1999) as follows:

$$Ln\frac{C(L1,L2)}{\Delta t(L1,L2)} = C - Z * t\frac{(L1+L2)}{2}$$

The above equation is simplified to become:

$$\ln(N_i/\Delta t_i) = a + b \cdot t_i$$

Where:

N_i : number of *G. expansa* in the i-th width class (ind)

Δt_i : period length of *G. expansa* within the i-th width class (yr^{-1})

Z : total *G. expansa* mortality (yr^{-1})

a and b : regression coefficient (b = -Z)

t : age calculated from t0 = 0

Exploitation rate (E)

The exploitation rate estimation of the *G. expansa* population can be estimated by the following formula (Sparre and Venema 1999):

$$E = F/(F + M)$$

Where:

E : exploitation rate

F : fishing mortality coefficient (yr^{-1})

M : natural mortality coefficient (yr^{-1})

Where: E>0.5 indicates a high level of exploitation (overfishing), E = 0.5 indicates optimal utilization (E opt), and E <0.5 indicates a low exploitation rate (underfishing) (Gulland 1977).

RESULTS AND DISCUSSION

Population structure

Geloina expansa in the waters of Kendari Bay spread from the smallest to the largest size range, namely 2.17-2.72 cm and 8.89-9.44 cm, respectively. The number of clams found from each size class in each month ranged from 2-9 and 1-5 individuals and consisted of several size groups, from small, medium and large to enormous sizes. The small group was within the size range of 3.71-4.72 cm, the medium group was 5.5-7.45 cm, the large group was 7.12-8.1 cm, and the massive group had an average value of 8.78 cm. The two groups of size (small-medium) within the *G. expansa* populations were found at the beginning of the study (November-April 2016), while one small-size group distribution was only found in January. *Geloina expansa* population consisting of three groups of size from small to large were found in May-October, while very large-sized clams were found only in November. The shift in the size of the *G. expansa* population to the right of the graph occurred in December-April, whilst a shift in the size group to the left occurred in May-November (Figure 3).

The results of the population structure analysis showed that *G. expansa* that live in the mangrove forests of Kendari Bay consist of 1-4 age groups with a mean size of 3.71-9.32 cm. The size groups found indicated that *G. expansa* were scattered from small, medium, large, and massive size groups representing their respective age groups, namely juvenile (early maturing gonads), adult, old and very old. Juvenile, adult, and old-size groups dominate the *G. expansa* population found in the mangrove forests of Kendari Bay. The findings in this study are similar to Mendoza et al. (2018), who found that the size of *P. erosa* in the estuary of the Pasak River in the Philippines ranged from 3.23 to 8.45 cm and was dominated by the juvenile or young size. According to Clemente and Ingole (2011), a shell width of more than 3 cm is categorized as an adult or mature stage shell. The *G. expansa* age classifications depict a relatively stable population structure of *G. expansa* indicated by: (i) the presence of representation in several age groups in the population, meaning that *G. expansa* regeneration ensues in the mangrove forests of Kendari Bay when population pressure that causes the loss of specific age groups occurs; (ii) the *G. expansa* population which was dominated by the juvenile, adult, and old clams which are the productive age groups that will produce the next generation of *G. expansa*; (iii) the dynamic population of *G. expansa* characterized by the shift to the left side size group, relative to the population, that occurred in the months of May-November and the small size group that was found throughout the study period originating from the constant reproduction that occurred over time. The stable population structure of *G. expansa* is similar to the *Batissa* clams in the Pohara River estuary and Lasolo River, which are spread over three groups: young, adult, and old (Bahtiar et al. 2022b).

Growth

The growth parameters of the *G. expansa* population followed the equations of $Lt = 10.08\text{-}(10.08\text{-}0.025)e^{-0.6t}$ with growth parameters, namely: asymptotic length (L_∞), growth coefficient (K) and t_o, amounting to 10.08 cm, 0.6, and 0.025, respectively. The growth performance index was 1.79 (3.78 mm) and the maximum age of the clam was estimated to be one year (Figure 4).

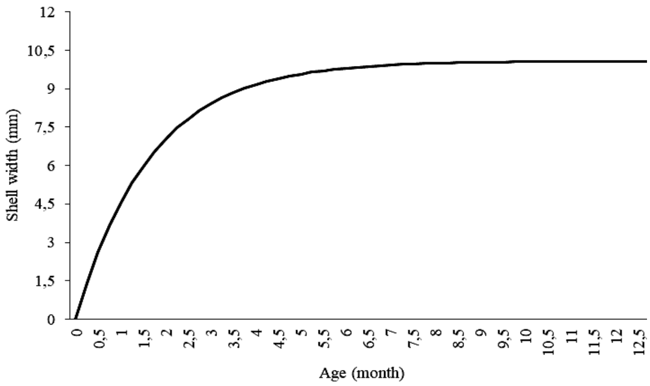

Figure 4. *Geloina expansa* growth in the mangrove forests of Kendari Bay, Southeast Sulawesi

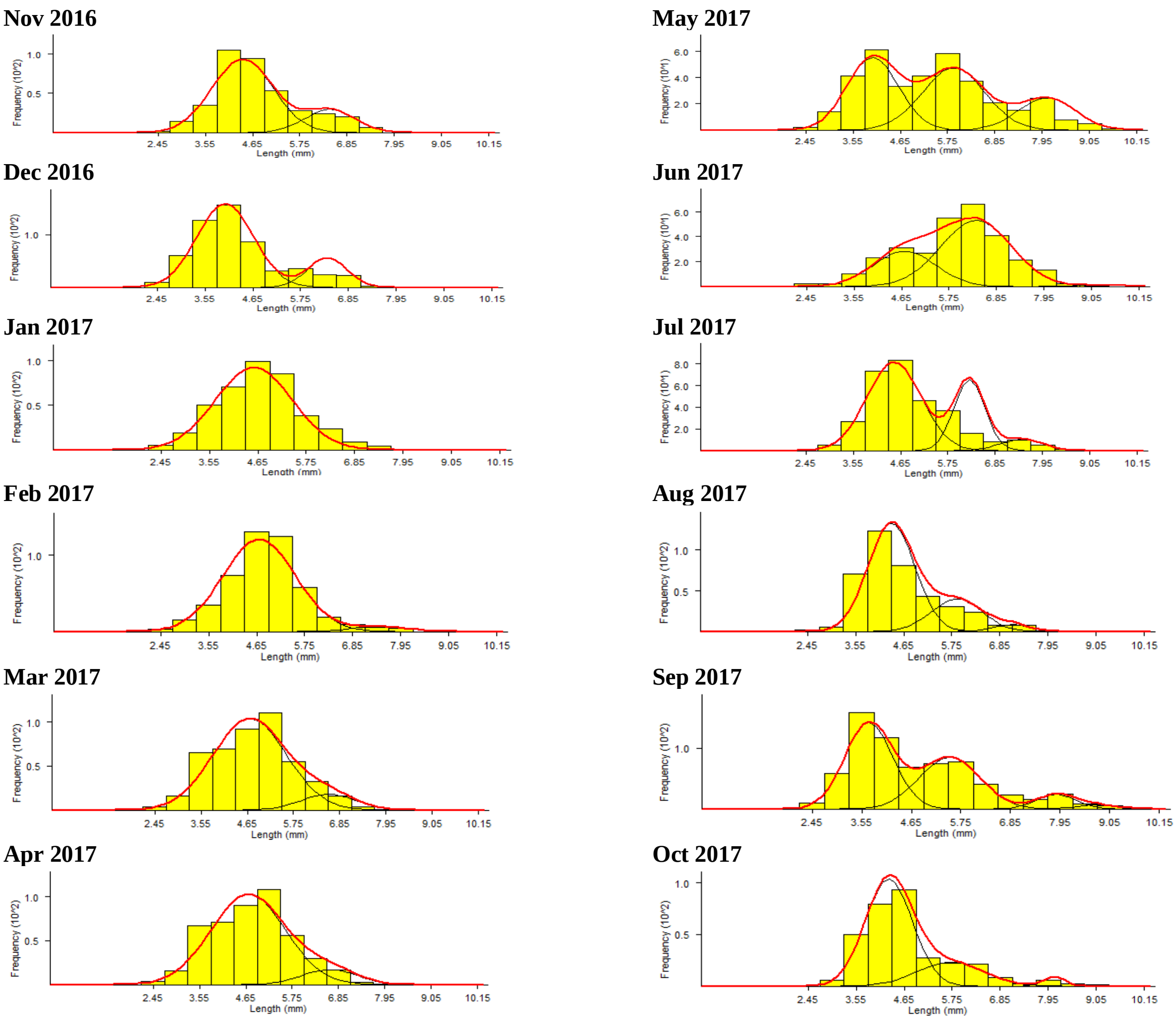

Figure 3. The population structure of *Geloina expansa* in the mangrove forests of Kendari Bay, Southeast Sulawesi, Indonesia

Geloina expansa has a relatively fast growth with a growth coefficient (K) above 0.6. In general, *Polymesoda* clams in several areas have the same pattern, namely fast growth as shown by *Polymesoda* in Marudu Bay (Ransangan et al. 2019), Iwahig and Bohol Philippines (Argente and Ilano 2013; Dolorosa and Dangan-Galon 2014). Likewise, several other shellfish showing the growth coefficient demonstrate a moderate-fast value (Table 1). In general, the types of shellfish that live in the waters of river estuaries and mangrove forests have relatively fast growth. This is due to several things, including (i) the productive ecosystem provided by the mangroves, which produces a high food source in the form of detritus; (ii) the high ability of shellfish or clam to filter and sweep food on the ground floor of waters (Schartum et al. 2017; Zanzerl et al. 2019).

Mortality and exploitation rate

Geloina expansa mortality can be classified into three parts, namely natural mortality (M), fishing mortality (F) and total mortality (Z), with values of 1.72 yr^{-1}, 0.54 yr^{-1}, and 0.24 yr^{-1}, respectively. Natural mortality was found to be higher than fishing mortality. The analysis of the exploitation rate of *G. expansa* achieved a value below 0.5 at 0.24 (Figure 5).

The decline in the *G. expansa* population in the mangrove forests of Kendari Bay is predominantly caused by natural mortality, with a value of 1.72 yr^{-1}, as opposed to fishing mortality, at a value of only 0.54 yr^{-1}. A similar situation was demonstrated by natural mortality in the shells *Batissa violacea* Lamarck, 1818 (Bahtiar et al. 2022b) and *Tegillarca granosa* Linnaeus, 1758 in Kendari Bay (Bahtiar et al. 2022a) (Table 2). This indicates that the environmental factor in these waters is the limiting factor of stock in nature. Environmental factors that cause natural mortality in shellfish are the high TSS of the waters that enter the semi-closed waters of Kendari Bay, especially during the rainy season. In addition, the dredging of sediment in the bay increases the turbidity of the waters (Marwah and Alwi 2014). Although shellfish are relatively more adaptive in stressed aquatic conditions, massively poor environmental quality can cause physiological disturbances because of the integrated feeding and respiration mechanisms that permit the accumulation of TSS, causing them to be repressed and die (Bahtiar et al. 2016; Mayor et al. 2016; Bahtiar et al. 2022b). Another factor that plays a role in the natural mortality of *G. expansa* is the reclamation in Kendari Bay, which causes the degradation of the *G. expansa* habitat. The decline in the population of *P. expansa* in Segara Anakan was similarly caused by the high land conversion, logging of mangrove forests, and high sedimentation rates (Widianingsih et al. 2020). Moreover, mortality can also occur due to the dredging of the substrate around the bivalve habitat. Mass death of *Batissa violacea var. celebensis* along 2 km in the Pohara River often occurs during sand mining activities, especially for small shellfish (Bahtiar et al. 2022b).

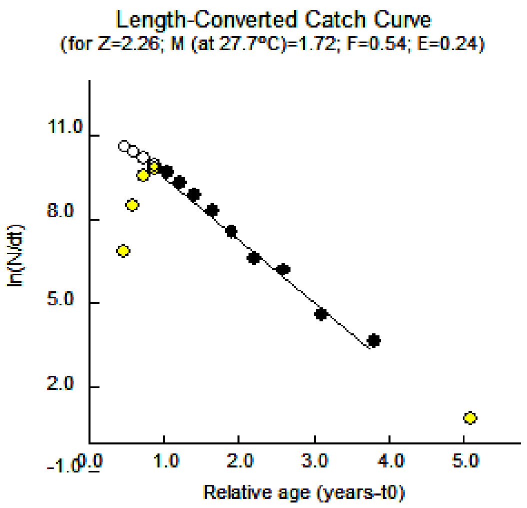

Figure 5. Mortality and exploitation rate of *Geloina expansa* in the mangrove forests of Kendari Bay, Southeast Sulawesi

Table 1. Comparison of growth parameters of various types of clam in different waters

Location	Species	Sex	K (yr^{-1})	L inf (cm)	Reference
Kendari Gulf, Southeast Sulawesi	*Tegillarca granosa*	♂♀	0.72	6.67	Bahtiar et al. (2022b)
Qarun Lake, Egypt	*Cerastoderma glaucum*	♂♀	0.45	2.84	Kandeel et al. (2017)
Laeya, Southeast Sulawesi, Indonesia	*Batissa violacea*	♂	0.54	8.39	Bahtiar et al. (2022b)
		♀	0.52	7.74	
India	*Meretrix casta*	♂♀	2.12	2.42	Laxmilatha (2013)
Cidade Beach, Southeast Brazil	*Anomalocardia brasiliana*	♂♀	0.53	4.25	Corte et al. (2015)
Ebrie Lagoon, Assinie	*Crassostrea gasar*	♂♀	0.58	13.54	Yapia et al. (2017)
Riio Gallegos Estuary, Argentina	*Darina solenoides*	♂♀	0.5	4.94	Lizarralde et al. (2018)
Iwahig, Palawan, Filipina	*Polymesoda erosa*	♂♀	1.0	10.71	Dolorosa and Dangan-Galon (2014)
Bohol Filipina	*Polymesoda expansa*	♂♀	0.51	9.15	Argente and Ilano (2013)
North China Sea Mangroves	*Geloina expansa*	♂♀	0.7	7.61	Yahya et al. (2018)
Marudu Bay, Malaysia	*Polymesoda erosa*	♂♀	0.76	9.24	Ransangan et al. (2019)
	Polymesoda expansa	♂♀	0.82	9.24	
Kendari Bay, Southeast Sulawesi	*Geloina expansa*	♂♀	0.6	10.08	*Present research*

Note: K: growth coefficient (yr^{-1}); L inf: asymptotic width (cm)

Table 2. Mortality and exploitation rates of several types of clams in various waters

Location	Species	Sex	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E	Reference
Kendari Bay, Southeast Sulawesi	*Tegillarca granosa*	♂♀	3.09	2.18	0.29	0.29	Bahtiar et al. (2022a)
North Kerala Estuary, India	*Meretrix casta*	♂♀	3.92	1.80	2.12	0.54	Laxmilatha (2013)
Ebrie Lagoon, Assinie	*Crassostrea gasar*	♂♀	2.0	0.83	1.18	0.59	Yapia et. (2017)
Lasolo River, Southeast Sulawesi	*Batissa violacea*	♂♀	11.84	3.69	8.15	0.69	Bahtiar et al. (2016)
Laeya River, Southeast Sulawesi, Indonesia	*Batissa violacea*	♂	2.94	2.04	0.91	0.69	Bahtiar et al. (2022b)
		♀	2.41	1.51	0.90	0.63	
Qarun Lake, Egypt	*Cerastoderma glaucum*	♂♀	1.02	1.06	-0.04	0.04	Kandeel et al. (2017)
Bohol, Phillipines	*Polymesoda expansa*	♂♀		0.19		0.20	Argente and Ilano (2013)
Iwahig, Palawan, Philippines	*Polymesoda erosa*	♂♀	3.74	1.41	2.33	0.62	Dolorosa and Dangan-Galon (2014)
North China Sea Mangroves	*Geloina expansa*	♂♀	2.1	1.1	1.0	0.5	Yahya et al. (2018)
Marudu Bay, Malaysia	*Polymesoda erosa*	♂♀	2.20	0.76	1.44	0.65	Ransangan et al. (2019)
	Polymesoda expansa	♂♀	2.77	0.82	1.95	0.70	
Kendari Bay, Southeast Sulawesi	*Polymesoda erosa*	♂♀	2.26	1.72	0.54	0.24	*Present research*

Note: Z: total mortality coefficient (yr^{-1}); M: natural mortality coefficient (yr^{-1}); F: fishing mortality coefficient (yr^{-1}); E: exploitation rate

The exploitation rate of *G. expansa* in Kendari Bay is relatively low, i.e. 0.24 (E<0.5). This means that *G. expansa* are exploited below the sustainable potential, or in other terms, the clams are under exploitation (Sparre and Venema 1999). The utilization rate of *G. expansa* in Kendari Bay is relatively the same as *P. expansa* in Bohol, Philippines (Argente and Ilano 2013) and other shellfish such as *T. granosa* (Bahtiar et al. 2022a) and *Cerastoderma glaucum* Bruguière, 1789 (Kandeel et al. 2017) (Table 2). The low exploitation rate indicates that *G. expansa* harvesting activity is lower than the regeneration ability of the clam. This is reflected in the population structure, the juvenile size group found throughout the month of *G. expansa* sampling, and the dominance of the juvenile to adult size groups can regenerate *G. expansa* population in Kendari Bay. These findings are consistent with Thangavelu et al. (2011), which stated that the high population size of mature shellfish indicates that the exploited species are recovering. In general, the mortality and exploitation rates of *G. expansa* are low when compared to *P. erosa* and *P. expansa* in Marudu Bay, Malaysia (Ransangan et al. 2019), Iwahig, Palawan (Dolorosa and Dangan-Galon 2014), and Noth China Sea (Yahya et al. 2018), and several other types of shellfish in other locations (Table 2). Ultimately, *G. expansa* harvesting activity in Kendari Bay can still be carried out until a peak condition is reached (E = 0.5). *Geloina expansa* in Kendari Bay has a relatively stable population and fast growth. The natural mortality of *G. expansa* plays more significant role in the total mortality of the clams, while the exploitation rate is within the under-exploitation category. Still, management efforts are needed to avoid excessive harvesting in the future, as fishermen are continuously harvesting these clams. Subsequent research (time series data) needs to be done on managing *G. expansa* resources in Kendari Bay.

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