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Original Article

Population dynamics of horse mussels *Modiolus modulaides* (Röding, 1798) in Kendari Bay, Southeast Sulawesi, Indonesia

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Abstract: Horse mussels are bivalves found in Kendari Bay and are frequently consumed by the people in the surrounding coastal communities. The population dynamic of this mussel species in Kendari Bay is not yet fully understood. This study aims to determine the size structure, growth, mortality, and exploitation rate of horse mussels in Kendari Bay. This research was carried out in Kendari Bay on the outskirts of Southeast Sulawesi, Indonesia, from January to December 2019. Horse mussel samples of all different sizes were randomly collected from different points of the area of the mussel habitat. The collected samples were counted in total, and their shell length was measured using a caliper with an accuracy of 0.05 mm. The size, growth, mortality, and exploitation rate data were analyzed using the Bhattacharya method, inverse von Bertalanffy, Pauly empirical, and length-converted catch curve accommodated in the FiSAT II. The results showed that the horse mussels comprised two dominant size groups, with one dominating most of the months. The asymptotic length (L_∞) of the mussels was 9.7 cm, with a growth coefficient (K) of 1.1 yr^{-1}. Moreover, the growth performance index of the mussels was (Ø)'=2.01 yr^{-1}, and the maximum age (T_{max}) was 2.73 years. The generated inverse von Bertalanffy equation for the horse mussels was $Lt = 9.7\text{-}(9.7\text{-}0.025)e^{-1.1t}$. The natural mortality (M), fishing mortality (F), and total mortality (Z) of the horse mussels were 2.73 yr^{-1}, 1.17 yr^{-1}, and 3.90 yr^{-1}, respectively. The horse mussels in Kendari Bay were well within the underexploited category, with an exploitation rate of 0.30.

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Introduction

Modiolus modulaides (Röding, 1798) is a beach mussel species in the Mytilidae family that lives in intertidal and subtidal areas (Hutchison et al., 2016). This species is globally known as horse mussels; however, the local people of Southeast Sulawesi are more attuned to calling it nail mussels (Nasrawati et al., 2017). These mussels are commonly found sticking together and occupying rigid substrates such as rock crevices (Davenport and Kjøsvik, 1982; Jasim and Brand, 1989) or can also be found, alive or dead, attached to mangrove roots in their juvenile stage (Tenjing et al., 2013). Mussels of the genus *Modiolus* are widely distributed worldwide, particularly in tropical and subtropical regions (Abu-Zaid et al., 2014; Brown, 1984; Rosa-Vélez et al., 2000). These mussels are found in the coastal waters of Indonesia's eastern regions, including Southeast Sulawesi (Musni et al., 2017; Bahtiar et al., 2023a).

Horse mussels live in large colonies, whereby this manner of living plays a recognizable role in coastal ecosystems. In general, bivalves, including those of the genus Modiolus, can stabilize aquatic ecosystems through biological mechanisms (food chain and metabolic products) (Vaughn et al., 2008) and mold the physical structures of their surrounding marine environment (changes in sediment grain size) (Bódis et al., 2014a, b). This mussel species has been modestly consumed by fishermen and communities around the Kendari Bay coast. People consume the mussels as a side dish instead of fish (during a famine) (Nasrawati et al., 2017). Due to their relatively sedentary nature, they are easy targets for small-scale fishermen (Napata and Andalecio, 2011). Concerning

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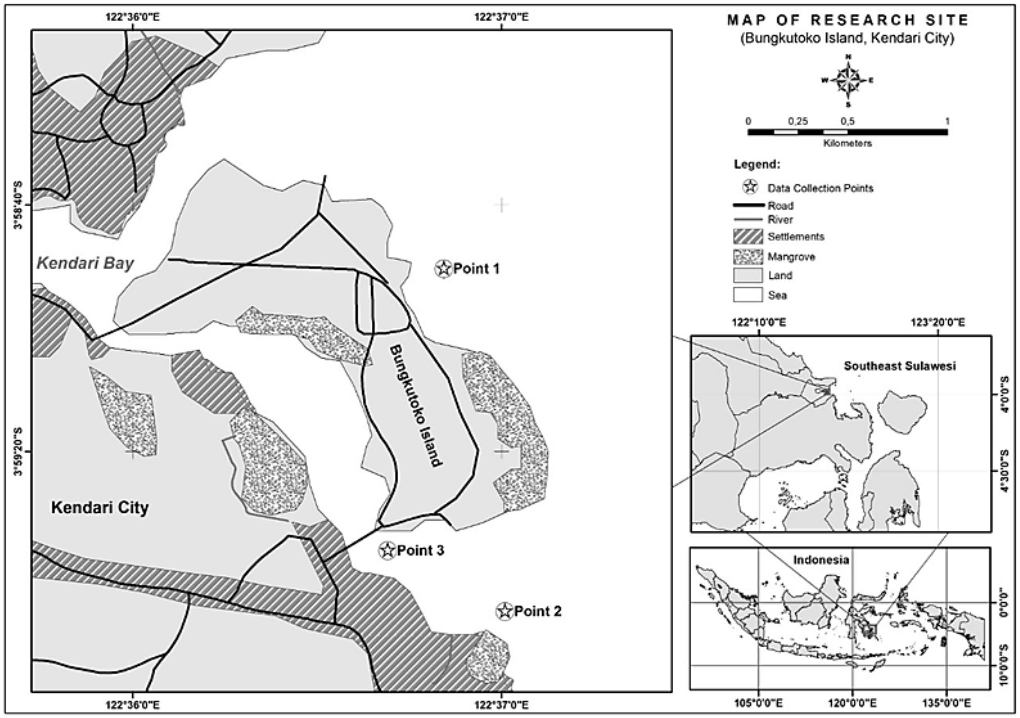

Figure 1. Map of the horse mussel research location in Kendari Bay.

this, the extent of the impact that horse mussel harvesting from the waters of Kendari Bay has on their population has not yet been investigated. In other locations, such as the Philippines, this mussel species is exploited on a large scale as food. Accordingly, proper management based on relevant and accurate information is required to prevent overfishing (harvesting) (Napata and Andalecio, 2011). In addition to mortality caused by fishing activities, the decline in mussel population from natural death can also occur due to the degradation of aquatic environmental conditions (Thippeswamy and Joseph, 1991) and changes in community composition (Napata and Andalecio, 2011; Rajagopal et al., 2005).

Kendari Bay collects polluted loads and materials from the upland and exhibits high turbidity, particularly when it rains (Bahtiar et al., 2023b). This can eventuate the death of mussels, especially those in the early stages of the life cycle. In contrast, the entry of organic materials/materials into the waters can promote the growth of the horse mussels. Growth is a function of environmental conditions and the physiology of bivalves (Dame, 2016). Sufficient food availability promotes the growth of somatic tissue and population growth in nature (Das et al., 2014; Saleky et al., 2016). Principally, mussels' size, structure, growth, and mortality vary significantly by location (Seed, 1976).

Research on population structure, growth, and mortality of horse mussels has been conducted in several regions. The regions where such information on horse mussels has been recorded include California Coast, Mexico (Garza-Aguirre and Bückle-Ramírez, 1989), Panguil Beach, Philippines (Tumanda et al., 1997), Karnataka Beach, India (Tenjing et al., 2013), and Iloilo Beach, Philippines (Napata and Andalecio, 2011). By comparison, very few similar studies have been recorded in Kendari Bay waters, among which was Nasrawati et al. (2017). It would be unpropitious if left as such, as data/information can contribute to devising the right management approach of horse mussel resources in Kendari Bay waters. As such, this study aimed to determine and assess the size structure, growth, mortality, and exploitation rate of horse or nail mussels in Kendari Bay, Southeast Sulawesi.

Materials and Methods

This research was conducted in Kendari Bay, on the outskirts of Southeast Sulawesi, Indonesia, in January-December 2019 (Fig. 1). Horse mussel samples were collected perpendicular to the coast from the mainland from the initial points where the horse mussels could be found, and up to 700 meters into the sea. The mussels were collected randomly (to represent all size classes of the mussels) using a shovel at different points, encompassing all areas of the mussel habitat in the research location. The collected samples were then counted, and the shell length was measured using a caliper with an accuracy of 0.05 mm. Water temperature was measured monthly using a thermometer during the research period that coincided with the sample collection.

Data analysis

Age structure: Size or age classification (cohorts) was exercised based on the length of the horse mussels using the Bhattacharya method (Gayanilo et al., 2005; Bahtiar et al., 2008, 2022).

Growth: Growth parameters of L_∞ and K were determined using FiSAT II version 3.0, while the mussel growth was described using the inverse von Bertalanffy formula as suggested (Bretos, 1980; Hughes and Roberts, 1980; Narasimham, 1981; Anthony et al., 2001; Bahtiar et al., 2016) as follows: $L_t = L_\infty - (L_\infty - L_0)e^{-K}{}_t$, where Lt = length of mussel at t (mm), L_∞ = asymptotic/maximum length of mussel (mm), K = growth rate coefficient (yr^{-1}), L_0 = size of mussel as larva or glochidium (Anthony et al., 2001), and T = age of mussel at L_t (year).

Growth performance index: The growth performance index was calculated from L_∞ and K (Pauly and Munro, 1984) as follows: Ø' = 2log10 L_∞+log10K.

Longevity: The maximum age of the horse mussels was calculated using the formula (Pauly, 1980): T_{max} = 3/K

Mortality: The natural mortality coefficient (M) was determined using Pauly's empirical equation (Pauly, 1983), namely: Log (M) = -0.0066 – 0.279 Log L_∞ + 0.6543 Log K + 0.463 Log T. The total mortality rate (Z) was calculated using the length-converted catch curve (Sparre and Venema, 1992) using the formula developed by Pauly (1983):

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

The above equation can be simplified to: $\ln(N_i/\Delta t_i) = a + b \cdot t_i$, where N_i = number of mussels in the i-th length class, Δt_i = length of dwelling time of the horse mussels at the i-th length class, Z = total mortality of horse mussels (yr^{-1}), a and b = regression coefficient (b = -Z), and t = age with respect to $t_0 = 0$.

Exploitation rate (E): The exploitation rate was determined using the equation proposed by Sparre and Venema (1992): E = F/(F + M), where E = exploitation rate, F = fishing mortality rate (yr^{-1}), and M = natural mortality rate (yr^{-1}). 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 level of exploitation (underfishing) (Gulland, 1988; Bahtiar et al., 2022). Determination of natural mortality, fishing mortality, total mortality, and exploitation rate values was done using FiSAT II version 3.0 software.

Results

Age/Size group: One smaller size group of the horse mussels was found to be dominant in all the months except for March, in which a larger size group was dominant. The first size group, found to be dominant in nearly all the months, had a value of 2.95-3.28 cm, while the second dominant size group in March had a median value of 6.23 cm (Fig. 2).

Growth Parameters: The horse mussels had a maximum length (L∞) of 9.7 cm, a growth coefficient (K) of 1.1yr^{-1}, and a growth performance index (Ø)' of 2.01. The mussel population's growth followed the inverse von Bertalanffy equation: Lt = 9.7 - (9.7 - 0.025)$e^{-1.1t}$ (Fig. 3).

Mortality and exploitation rate: Mortality of the horse mussels can be described as natural mortality (M), fishing mortality (F), and total mortality (Z). The respective values of these mortality aspects were 2.73, 1.17, and 3.90. Whereas the exploitation rate of the mussels was 0.30 (Fig. 4).

Discussions

Age/Size structure: The horse mussel population was dominated by the early-mature gonad size group. Lack of the mature size/age group can bring about high susceptibility of the regeneration of the mussels due to

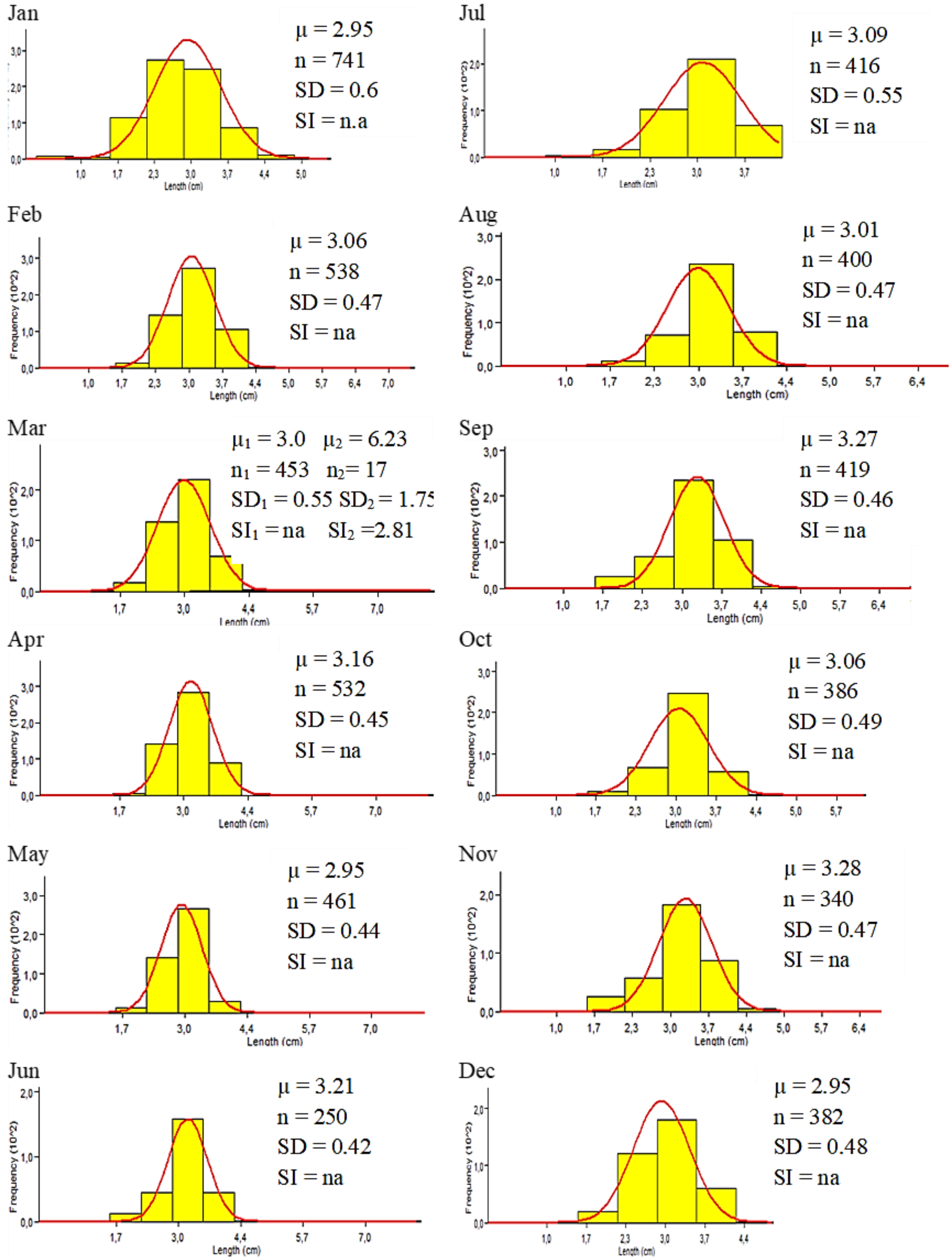

Figure 2. Horse mussels size groups in Kendari Bay.

(1) a low population of the size group that appropriately supports regeneration and (2) low reproductive ability of the adult stage at their early gonad maturity. Moreover, the small number of juvenile mussels suggested high natural mortality. Opposingly, the rapid regeneration of the mussels was indicated by the continuous presence of the adult age group during nearly all of the months, i.e., recruitment into the adult stage (Lopez and Gomez, 1987; Garza-Aguirre and Bückle-Ramírez, 1989). The

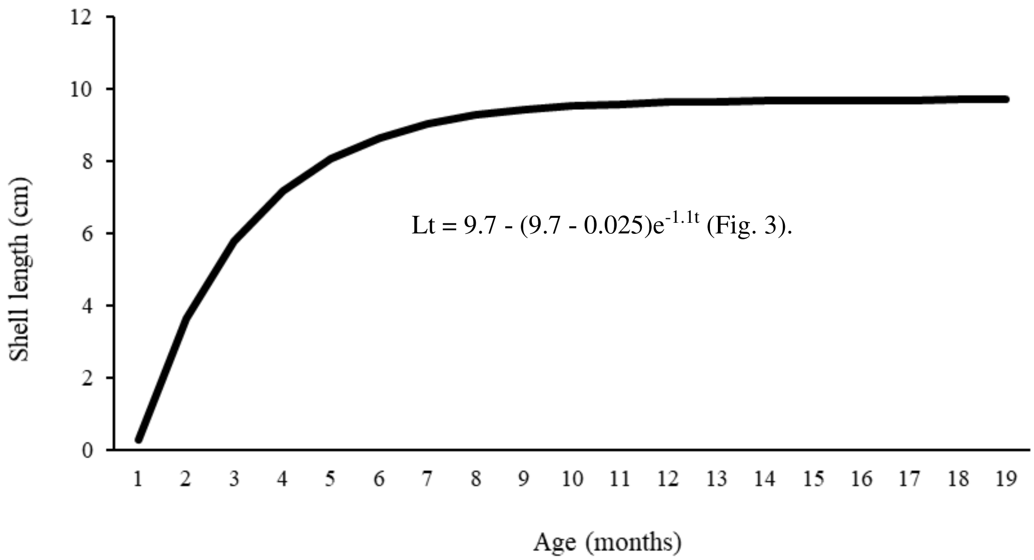

Figure 3. Growth of horse mussels in Kendari Bay, Southeast Sulawesi.

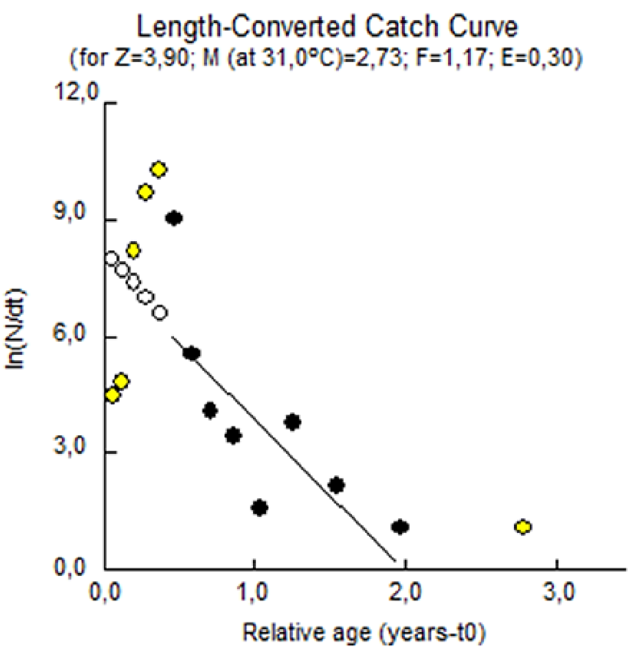

Figure 4. Mortality and exploitation rate of horse mussels in Kendari Bay.

approximately year-long domination of just one size/age group in Kendari Bay is rare. Typically, temporal population domination alternates among 2 to 3 size groups, whereby the juvenile and adult size groups are predominant, such as in *Batissa violacea* with 2-3 alternating dominant size groups (Bahtiar et al., 2008, 2018), as well as *Circenita callipyga* (Bagher et al., 2007), *Cerastoderma edule* (Callaway et al., 2013), *Darina solenoides* (Lizarralde et al., 2018) and *Donax trunculus* (Hafsaoui et al., 2016) with 3-4 size groups.

Growth: Horse mussels in Kendari Bay were predominantly 1-2 years of age and were at their height of growth. These mussels reach their initial gonad maturity at the age of 2 years, whereas the old or mature phase is reached at the age of 8 years. Congruously, the growth rate of a mussel species can be marked by the growth coefficient, growth performance index, and the life span of the mussels (Bahtiar et al., 2016). The growth rate of horse mussels in Kendari Bay was lower than that of *M. metcalfei* in Panguil Beach, Philippines, which had K and L inf values of 2.04 and 6.25 cm (Tumanda et al., 1997), mussels of the *Meretrix casta* species had a K-value of 1.87 (Laxmilatha, 2013), and *Anadara gubernaculum* (Fauzan et al., 2018), *Eumarcia paupercula* with K of 1.65 (Mugabe et al., 2019), and *Tageus plebeuis* with a K-value of 1.73 (Abrahão et al., 2010). The horse mussel growth could be relatively fast, which pointed to the effort to offset the high natural mortality due to environmental pressures. In comparison, the growth rate of the horse mussels was more rapid than *Anadara tuberculosa* which had a K-value of 0.33 (Lucero et al., 2012), *Tageus plebeuis* with a K of 0.52 (Silva-Benavides and Bonilla, 2015), *Lithophaga patagonica* with K of 0.22 (Bagur et al., 2013), *Gafrarium tumidum* of 0.2 (Kurihara, 2003), *Megapitaria squalida* of 0.44

(López-Rocha et al., 2018), *Geloina expansa* of 0.7 (Yahya et al., 2018), *Polymesoda erosa* of 0.76 (Ransangan et al., 2019), and *D. solenoides* of 0.5 (Lizarralde et al., 2018). These dissimilarities between bivalves of different locations demonstrate that growth rates can vary depending on species and habitat location.

Mortality and exploitation rates: The total mortality of the horse mussels was very high, most of which was attributed to natural deaths, i.e., mortality caused by factors other than fishing. Horse mussels of all age groups that reside in Kendari Bay are very vulnerable to natural deaths due to the high turbidity of the waters. Open and fleshless/empty samples were found in colonies of small and adult mussels on rocks and mangrove roots, especially during the rainy season. Mortality, predominantly caused by the high turbidity of the water, was also shown in *Batissa* mussels in the Pohara River estuary, whereby loads from sand mining activities enter their habitat (Bahtiar et al., 2012). Natural mortality of horse mussels in coastal waters can also be caused by heat waves (McDowell et al., 2017), i.e., temperature increases (Ilarri et al., 2011), and inadequate submersion in water for a certain period due to drought (Atkinson et al., 2014).

In addition to natural deaths, the mussels experience death due to capture. However, this particular cause of mortality could still be very low. Fishermen in this area harvested the horse mussels on a small scale for household and recreational purposes. As such, the exploitation rate of the horse mussels was very low and fell under the under-exploited category. Cultivations of certain species of coastal mussels, including the horse mussels, are done modestly by and large because these species are not of top priority to be harvested and consumed, and thus their exploitation is low. Among the species referred to are *Anadara granosa,* with an exploitation rate of 0.20 (Mirzaei et al., 2015), *A. gubernaculum* of 0.1 (Fauzan et al., 2018), *Meretrix casta* of 0.33 (Laxmilatha, 2013), and *Potaocorbula faba* of 0.12 (Hariyadi et al., 2017). Moreover, the total mortality of the horse mussels in Kendari Bay was lower than that of heavily exploited economically important bivalves such as *M. metcalfei* with an exploitation rate of 7.64 yr^{-1} (Tumanda et al., 1997), as well as *Batissa violacea* in the Pohara River with E of 6.46 yr^{-1} (Bahtiar, 2012) and the Lasolo River with E of 11.84 yr^{-1} (Bahtiar et al., 2018). Still, the exploitation of this mussel species was higher than *A. tuberculosa* with E of 1.79 yr^{-1} (Lucero et al., 2012), *Donax striatus* with E of 3.07 yr^{-1} (Ocaña, 2015), *Tageus plebeuis* of 2.58 yr^{-1} (da Silva et al., 2015), *G. expansa* of 2.1 yr^{-1} (Yahya et al., 2018), and *Batissa violacea* of 2.93 yr^{-1} (Basri et al., 2019).

Conclusion

The study on horse mussels in Kendari Bay revealed that the population was dominated by a smaller size group (median 2.95-3.28 cm) throughout the year, except in March, which was dominated by a larger size group (6.23 cm). Growth parameters indicated a maximum length (L_∞) of 9.7 cm, a growth coefficient (K) of 1.1 yr^{-1}, and a growth performance index (Ø') of 2.01, suggesting relatively fast growth as an adaptation to high natural mortality caused by environmental pressures such as turbidity. Mortality was predominantly natural (M = 2.73 yr^{-1}), while fishing mortality was low (F = 1.17 yr^{-1}), resulting in a total mortality (Z) of 3.90 yr^{-1} and an exploitation rate (E) of 0.30, classifying the species as under-exploited. Despite high natural mortality, continuously recruiting individuals into the adult stage highlights the population's regenerative potential, emphasizing the need for sustainable management to ensure the species' long-term viability.

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