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RESEARCH ARTICLE

Growth patterns and condition factor of the mudskipper (*Periophthalmus gracilis*) in mangrove ecosystem rehabilitation areas in Banda Aceh and Aceh Besar, Indonesia

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Abstract. The mudskipper is one of the fishes that inhabit mangrove ecosystems. Its growth and distribution is influenced by food sources, tidal action, and environmental factors. The aims of the research were to analyze the growth patterns and condition factors of the mudskipper, *Periophthalmus gracilis* Eggert, inhabiting mangrove ecosystem rehabilitation areas in Banda Aceh and Aceh Besar, Aceh Province, Indonesia. The research period in these mangrove ecosystems was from August to October 2020. The research was conducted at three sampling stations using the purposive sampling method to determine their location. The mudskippers caught at each station were identified and body length and weight were measured. Physicochemical water parameters were measured directly at the sampling stations to determine the suitability of them for mudskipper growth and occurrence. The mean total lengths (TL) and weights (W) of the mudskipper specimens caught at stations 1, 2, and 3 were 52.0 mm and 6.2 g; 53.5 mm and 6.4 g, and 56.0 mm 6.7 g, respectively. The growth patterns of the mudskippers from the three sampling stations were negative ($b < 3$), and Fulton's condition factor (K) exceeded 1. The K value at stations 1, 2, and 3 ranged from 1.28 to 3.62, 1.15 to 3.56, and 1.05 to 3.89, respectively. The relative weights (Wr) at the three stations were 103.8 ± 26.5, 104.3 ± 29.3, and 104.1 ± 28.2, respectively. Wr >100 indicated that there was sufficient food availability, low predator density, and the environment was in equilibrium. Furthermore, physicochemical water parameters at the study stations were suitable and within optimal ranges for the mudskipper. Significant differences in total length were noted among specimens from the three stations ($P < 0.05$); however, no significant differences in body weight were noted at them ($P > 0.05$).

Keywords: Length-weight relationship, negative allometric growth, condition factors, mangrove, mudskipper

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Introduction

The mudskipper, *Periophthalmus gracilis* Eggert, is a unique fish because it can move using its fins, which is a form of morphological adaptation to its habitat, and it is adapted into two different habitats-terrestrial and aquatic. Mudskipper habitats are commonly estuaries, parts of seas, and tidal areas (Jaafar et al. 2009, Mahadevan and Ravi 2015, Santoso et al. 2020). Moreover, they inhabit muddy substrates that are linked to mangrove vegetation (Takita et al. 2011, Bidawi et al. 2017). The mudskipper is one of fishes that occupy mangrove ecosystems as feeding grounds and is also included in the food chain; thus, it is not only a primary consumer but also as secondary consumer (Polgar and Lim 2011). Additionally, its behavior and distribution is closely linked to tidal rhythms (Maturbongs et al. 2018, Ravi 2011, Sunarni et al. 2019).

Taxonomically, the mudskipper belongs to the family Gobiidae. Common names for the mudskipper include timpakul, tembakul, belodog, gelodok, belacak, and lunjat in various parts of Indonesia. The mudskipper has the potential to be exploited, and it is utilized as raw material for the fisheries in the study areas. The mudskipper is widely consumed as a traditional medicine in India, and it is used as a drug to strengthen fetuses in China and Japan (Ravi and Rajagopal 2009). Furthermore, the mudskipper is a bioindicator in estuarine water thanks to its high resistance to polluted conditions, and it has the ability to accumulate heavy metals in its tissues (Santoso et al. 2020). Bu-Olayan and Thomas (2008) showed that, as bio-accumulators, *Periophthalmus waltoni* Koumans can absorb heavy metals and degrade them into environmentally friendly materials. Several species are consumed or used as ornamental fish, while it is cultivated in countries such as Bangladesh, Thailand, the Philippines, China, Taiwan, and Japan (Polgar and Lim 2011).

Various numbers of mudskipper species are reported, i.e., four species in the Maluku waters of Indonesia namely, *Periophthalmus argentilineatus* Val., *P. gracilis*, *Periophthalmus malaccensis* Eggert, and *Periophthalmus kalolo* Lesson (Taniwel et al. 2020), four species in the waters of Brunai Darusalam, namely *P. malaccensis*, *P. gracilis*, *Periophthalmus vulgaris,* and *Periophthalmodon schlosseri* (Pallas) (Polgar 2016), *Periophthalmus pusing* Jaafar, Polgar & Zamroni, and *P. gracilis* were reported from the Lesser Sunda Islands (Jaafar et al. 2016). However, there is no information about the mudskipper from the mangroves of Aceh Province, Indonesia. Furthermore, research that has been conducted on the mudskipper has focused on the morphology, identification, and habitat type of the species (Rumahlatu et al. 2020, Nugroho et al. 2016) and biodiversity and abundance (Mahadevan and Ravi 2015, Elviana and Sunarni 2018, Maturbongs et al. 2018). Specifically, a study on the length-weight relationship of the mudskipper showed that *P. argentilineatus* and *P. gracilis* collected from the mangrove of Kairatu Beach, Maluku, Indonesia had a negative allometric length-weight relationship ($b < 3$) (Taniwel et al. 2020), the allometric length-weight relationship of *Boleophthalmus pectinirostris* (L.) was negative for males ($b < 3$) and positive for females ($b > 3$) (Sunarni et al. 2019), while *Periophthalmus chrysospilos* Bleeker exhibited positive allometric growth patterns in Bayan Bay, Penang-Malaysia (Abdullah and Zain 2019), and three species of mudskipper – *P. chrysospilos*, *P. gracilis*, and *Boleophthalmus boddarti* (Pallas) – observed in the mangrove ecosystem of Sembilan, North Sumatera exhibited negative allometric growth patterns (Bidawi et al. 2017).

Research on the growth patterns or condition factors of the mudskipper has yet to be reported for Aceh Province. These parameters can be identified by measuring the length-weight relationship (LWRs) of fish in order to estimate the biomass of certain fish stocks and to manage fisheries resources (Karna et al. 2018, Shalloof and El-Far 2017) and as an indicator of fish condition (Froese 2006, Koutrakis and Tsikliras 2003). Moreover, Muchlisin et al. (2010) mentioned that growth patterns are critical parameters in fish farming because they can determine the results of cultivation. The LWR parameter can predict fish condition by estimating weight (Wr) and Fulton's condition (K) and comparing fish growth among areas (Froese 2006). Therefore, it was necessary to research the growth patterns and condition of the mudskipper in mangrove ecosystem rehabilitation areas. The purpose of the present study was to analyse mudskipper growth patterns through length-weight relationships and condition factors of specimens inhabiting the mangrove ecosystem rehabilitation areas of Banda Aceh and Aceh Besar.

Materials and Methods

Sampling time and location

The research was conducted from August to October 2020 in the mangrove ecosystems in Banda Aceh and Aceh Besar, Aceh Province (Fig. 1). The locations studied were determined with the purposive sampling method, which is commonly applied to determine locations based on the purposes of research, i.e., by considering the amount of mangrove vegetation and human activities in this case of this study. Fish sampling was carried out at three stations that were identified as representative of mangrove areas where the mudskipper occurs. Station 1 was in Ujong Pancu Village, it had a small amount of mangrove vegetation (3–6 specimens 100 m^{-2}) with community fish ponds and boat berths. Station 2 near the village of Jawa had a large amount of mangrove vegetation (11–14 specimens 100 m^{-2}) but there was no human activity, and station 3 near the village of Alue Naga had a moderate amount of vegetation (7–10 specimens 100 m^{-2}) and some fish ponds.

Fish measurements

Mudskipper specimens were sampled at low tide with one of two catch methods. The first method used

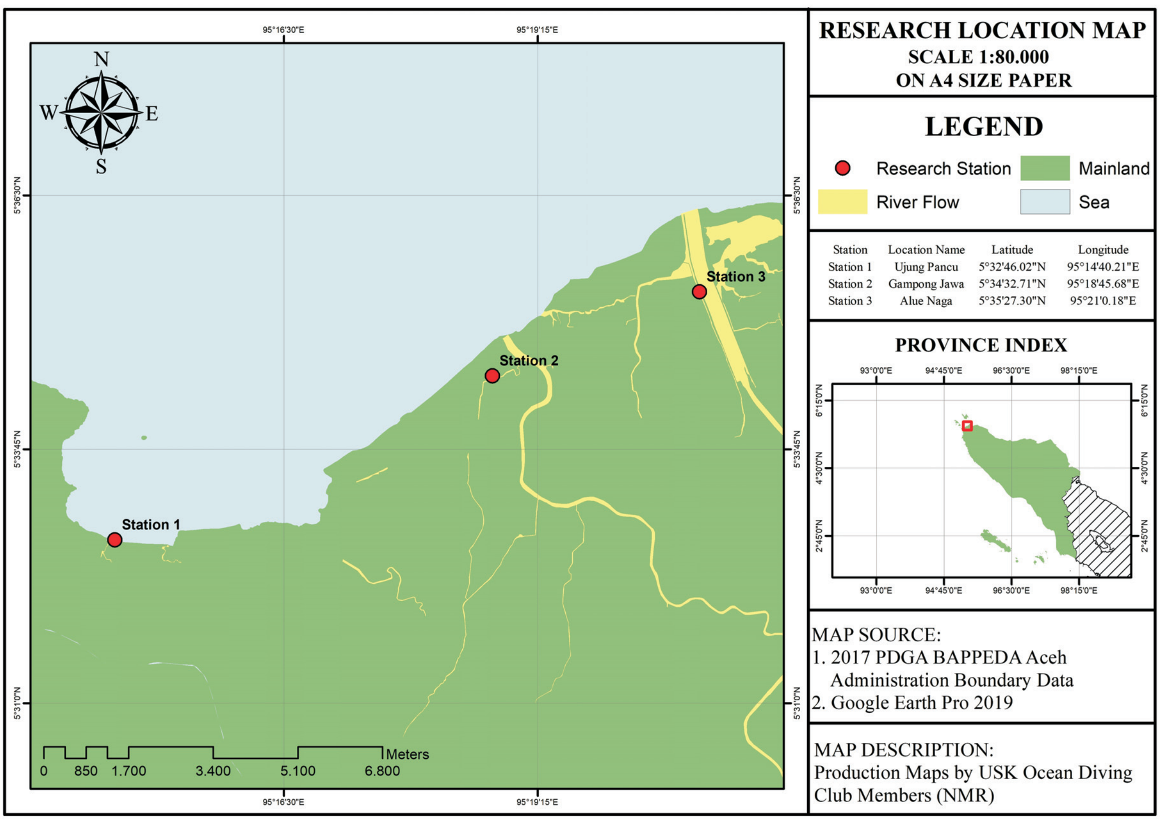

Figure 1. Map of study area showing sampling sites.

fishing gear made of net, wood, and wire, and the fish occurring in the sampling area were trapped. In the second method, fishing was done manually with the assistance of locals who were expert at catching mudskippers. Fish were sampled at the three stations every week, and all specimens caught were measured for length and weight. In total, 223 mudskipper specimens were collected during the study. The fish caught were measured in the field, but the species were identified in the laboratory. The fishes were stored in sample bottles and identified at the Laboratory of Marine Biology, Marine and Fishery Faculty, Universitas Syiah Kuala according to Fishbase and Kottelat (2013). Some biological parameters of the fish were measured including total length (TL) and body weight (W). TL was measured from edge of the head to the tip of the tail fin with a digital caliper to the nearest 0.1 mm. Fish body weight was measured with a digital balance to the nearest 0.1 g. The physicochemical parameters of water, including temperature, dissolved oxygen (DO), salinity, and pH were measured at each sampling station in three repetitions.

The length-weight relationship (LWR) was estimated using the Linear Allometric Model (LAM) according to De Robertis and Williams (2008) and Muchlisin et al. (2010) as follows:

$$W = e^{0.56} \times aL^b$$

where W is fish body weight (g), L is fish total length (mm), a is the linear regression intercept, b is the regression coefficient, e is the residual variance, and 0.56 is the correction factor. The value of b can reflect fish growth patterns. The value of b = 3 and b ≠ 3 indicates that the growth pattern is isometric or allometric. The latter growth pattern is divided into positive and negative allometric growth. Values of b > 3 indicate positive allometric growth, while values of b < 3 indicate negative allometric growth. A simple linear regression equation was calculated first with the following equation: Ln W = a + b (Ln TL). Additionally, the t-test was conducted to test the isometric or allometric growth patterns.

Fulton's condition factor (K) and the relative weight (Wr) were also calculated. Fulton's condition factor (K) was determined with a formula to assess fish condition based on weight and total length (Jin et al. 2015), and it has been used in many fisheries studies (Fadli et al. 2022, Muchlisin et al. 2010, Wang et al. 2017). Fulton's condition factor (K) was calculated based on Blackwell et al. (2000) as follows:

$$K = WL^{-3} \times 100$$

where K is Fulton's condition factor, W is fish body weight (g), and L is fish total length (mm). Predicted weight (Ws) and relative weight (Wr) were calculated according to Rypel and Richter (2008):

$$Wr = W \times Ws^{-1} \times 100$$

where Wr is the relative weight, W is the direct fish body weight, Ws is the predicted fish weight.

Statistical analysis

The Kruskal-Wallis test was applied to compare the total length (TL) and body weight (W) of the mudskipper specimens among research station at $\alpha = 0.05$.

Results

One species of the mudskipper species caught in the research areas was *P. gracilis*. The number of *P. gracilis* caught at stations 1, 2, and 3 were 56, 106, and 61, respectively. The ranges of total length (TL) and body weight (W) were different at each station. The TL of *P. gracilis* at station 1 was 38.3–63.0 mm at a weight range of 2.0–13.0 g (mean 52.0 mm ± 6.3; 6.2 g ± 2.7); at station 2 these values were 37.2–68.1 mm and 2.0–12.0 g (mean 53.5 mm ± 8.0; 6.4 g ± 2.6), and at station 3 they were 35.0–66.4 mm and 2.0–14.0 g (mean 56.0 mm ± 5.6; 6.7 g ± 2.6). LWR regression showed that the b values were 2.99, 2.42, and 2.94 at stations 1, 2, and 3 (Table 1), respectively. The b values were less than 3 (b < 3) at all sampling stations, so the LWRs indicated negative allometric growth in which where increases in length were faster

Table 1
Total length, body weight, growth patterns, and condition factors of the mudskipper (*P. gracilis*) in the study areas. Data are presented as mean ± SD

Station	n	Total length (mm)		Body weight (g)		Relative weight (Wr)		Fulton's condition factor (K)		$W = aL^b$			Growth type
		mean ± SD	range	mean ± SD	range	mean ± SD	range	mean ± SD	range	a	b	r^2	
Station 1	56	52.0^a±6.3	38.3-63.0	6.2±2.7	2.0-13.0	103.8±26.5	41.3-153.3	2.7±0.61	1.28-3.62	0.00004	2.993	0.638	Negative allometric
Station 2	106	53.5^a±8.0	37.2-68.1	6.4±2.6	2.0-12.0	104.3±29.3	38.9-189.9	2.7±0.59	1.15-3.56	0.00039	2.423	0.601	Negative allometric
Station 3	61	56.0^b±5.6	35.0-66.4	6.7±2.6	2.0-14.0	104.1±28.2	29.8-190.9	2.7±0.57	1.05-3.89	0.00004	2.945	0.538	Negative allometric

Mean values in column marked with a different superscript letter index differ significantly statistically ($P < 0.05$).

than weight gain. The correlation coefficients (r) between TL and W at stations 1, 2, and 3 were 0.80, 0.78, and 0.73. These values indicated that the total body length greatly affected the total weight of the mudskipper (*P. gracilis*). The regression model for the three different sampling stations explained comparable growth patterns between those observed and those predicted (Fig. 2). Based on Kruskal-Wallis test, there were significant differences in the TL values for *P. gracilis* at the three stations ($P < 0.05$), but there were no significant differences in body weights ($P > 0.05$). The TL at the pair of stations 1 and 3 and the pair of stations 2 and 3 were significantly different ($P < 0.05$); however, no significant differences were noted between stations 1 and 2 ($P > 0.05$) (Table 1). Fulton's condition factor (K) was more than 1 at ranges of 1.28–3.62, 1.15–3.56, and 1.05–3.89 at stations 1, 2, and 3, respectively, at means of 2.7 ± 0.61, 2.7 ± 0.59, and 2.7 ± 0.57, respectively. Furthermore, the relative weight (Wr) mean was above 100 at all three stations. The values of Wr at stations 1, 2, and 3 were 103.8 ± 26.5, 104.3 ± 29.3, and 104.1 ± 28.2, respectively (Table 1).

Discussion

The LWRs of the mudskipper (*P. gracilis*) caught at the three research stations indicated negative allometric growth patterns, which meant that the body length increased faster than did body weight. This growth pattern is similar to that reported in previous studies on the same species. *P. argentilineatus* and *P. gracilis* exhibited negative allometric growth patterns (Taniwel et al. 2020), and so did P. *chrysospilos*, *P. gracilis*, *Periophthalmus novemradiatus* (Hamilton), and *Periophthalmodon septemradiatus* (Hamilton) (Khaironizam and Norma-Rashid 2002). Negative allometric growth patterns were common in the flattened mudskipper (Moslen and Daka 2017). In contrast, Abdullah and Zain (2019) and Taniwel et al. (2020) reported LWRs for *P. chrysospilos* in Bayan Bay, Malaysia and *P. kalolo* and *P. malaccensis* in Kairatu Beach, Maluku, Indonesia that indicated positive allometric growth patterns ($b > 3$). The different b values in mudskipper growth patterns usually depends on physiological and environmental habitat conditions, sampling technique, and geographic location (Jenning et al. 2001), but it can also depend on biological conditions such as food availability and gonad development (Froese 2006). The regression coefficient, or slope value (b), from the LWR provides information for estimating fish growth patterns.

Negative growth patterns in *P. gracilis* from the study areas were assumed to result from its behavior as suggested by Muchlisin et al. (2010); for example, fish that swim passively have higher b values

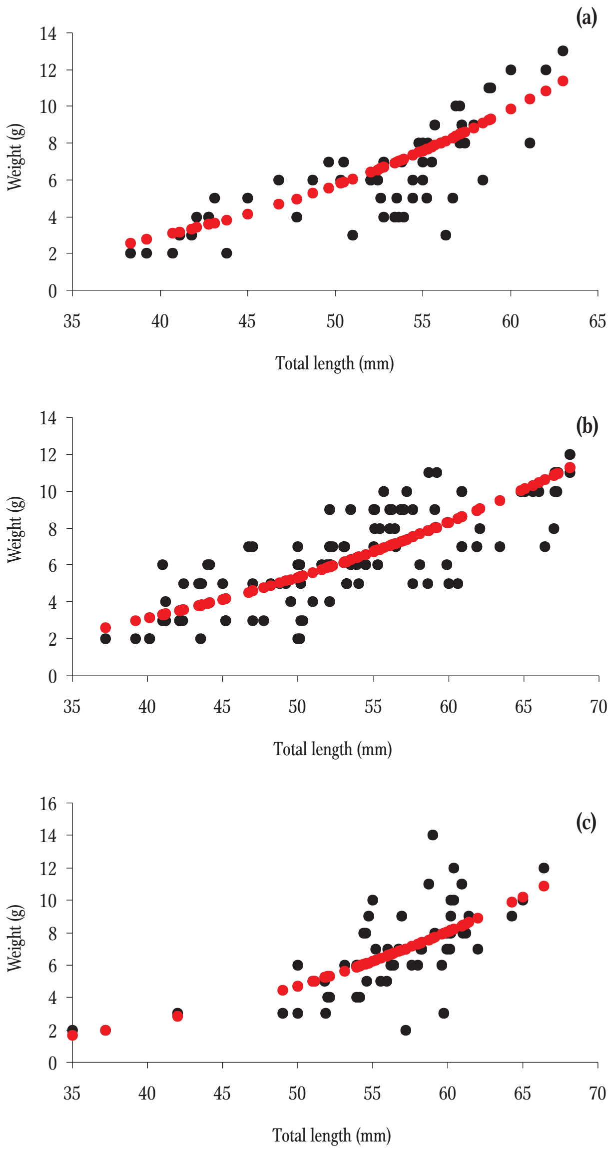

Figure 2. Comparison of observed (black dot) and predicted (red dot) growth of *P. gracilis* at stations 1 (a), 2 (b), and 3 (c).

compared to fish that swim actively. The mudskipper can adapt to intertidal habitats, and it is very active when out of water for feeding and interacting (Ansari et al. 2014). Furthermore, Okgerman (2005) also mentioned that differences in b values can be caused by the number and variations in the size of the fish observed. Correlation coefficient (r) values at stations 1, 2, and 3 were 0.80, 0.78, and 0.73, respectively, with higher correlation coefficients (r) indicating stronger correlations between fish length and body weight.

Fulton's condition factor (K) was analysed to assess overall fish health, productivity, and the physiological condition of the populations (Blackwell et al. 2000, Richter 2007). High K values indicate that environmental conditions are suitable for given fish species (Sunarni et al. 2019). Furthermore, K values can also be influenced by the number and density of predators (Blackwell et al. 2000). The K values observed in study areas were similar to those from a study in mangrove ecosystems in Sembilan Island, North Sumatera, where the K value for *P. gracilis* was 1.38. In the present study areas, the K value ranged from 1.05 to 3.89 at an mean of >1. Morton and Routledge (2006) reported that Ks values ranging from 1 to 2 indicated that the fish bodies were less flat. The K value was the lowest at station 3 (1.05) where the longest fish length was noted. Siddique et al. (2021) reported that there was a correlation between K and length, and the condition factor (K) decreased with increasing fish length. A fish population is in a good condition when the K value >1, while a relative weight (Wr) value of >100 indicates that the available prey is plentiful.

Moreover, the mean Wr was above 100 at each station, while themean Wr values at stations 1, 2, and 3 were 103.80, 104.30, and 104.12, respectively. If the Wr is above 100, the fish populations in these water are in very good condition; on the other hand, if the value is below 100, fishes populations in these areas are in poor condition (Anderson and Neuman 1996). Furthermore, Wr values above 100 indicated either excess prey availability or that predator density was low (Muchlisin et al. 2017, Batubara et al. 2019).

Blackweel et al. (2000) reported that not only food or predators, but also abiotic factors can influence variation in condition factor values. Kanejiya et al. (2017) confirmed that environmental parameters such as sediment composition, pH, temperature, and salinity can have significant effects on mudskipper distribution. Furthermore, biotic (prey, fish behavior, predator density) and abiotic (physicochemical water parameters) factors can significantly affect fish condition factors and growth patterns (Fadli et al. 2022, Muchlisin et al. 2010, Yulianto et al. 2020).

The water temperatures in the study areas ranged from 29–30°C. Previous studies reported that optimal water temperatures for the mudskipper ranged from 23.5–35.5°C (Mahadevan and Ravi 2015, Akinrotimi et al. 2019). Water temperature is an important factor that can attract some fish to estuaries and coasts to spawn (Elliott and Hemingway 2002). Salinity in the current study areas ranged from 18–25‰. According to Mai et al. (2019), salinity affects the mudskipper in their habitats. Dobson and Frid (2009) reported that mudskipper species that inhabit mangrove ecosystems can adapt well to salinity ranges of 5–18‰, while other researchers reported this range to be 10.01–14.88‰ (Akinrotimi et al. 2019). Ravi (2011), however, reported that the mudskipper can survive in mangrove ecosystems with a salinity range of 23.5–32.8‰. Despite this, the salinity values in the present study were higher than in previous studies, but the values were still within the tolerance range of the mudskipper. The main effect of salinity is the distribution of fish and attractiveness for larvae (Elliott and Hemingway 2002). The water pH value range was 7.8–8.3 in the current study. Some researchers reported that suitable pH ranges in aquatic ecosystems for the mudskipper are from 7–8 (Ip et al. 2004), while others reported a range of 7.1–8.1 (Elviana et al. 2019). This indicated that the pH levels in the research locations of the present study were still within a sufficient range for the mudskipper. The value of DO ranged from 4.9–7 mg L^{-1} in the present study, while Akinrotimi et al. (2019) reported that the mudskipper could survive at DO levels of 4.22–5.89 mg L^{-1}. Station 2 had a higher level of DO (7 mg L^{-1}) than did stations 1 and 3 (4.9 and 5.1 mg L^{-1}, respectively). It assumed that the large number of *P. gracilis* (106 specimens) was because of high DO values and the brackish salinity at station 2. Taniwel et al. (2020) reported that DO significantly influenced the presence of the mudskipper in mangrove ecosystems, and they noted the highest abundance of mudskipper at station 1 (133 specimens), where the DO value (7.5 mg L^{-1}) was higher in comparison to that at the other stations. It is also noteworthy that the largest number of *P. gracilis* at station 2 (106 specimens) could have been because of the amount of mangrove vegetation, which was the highest at this station at as many as 11–14 specimens per 100 m^2. Bidawi et al. 2017 reported that a high density mangrove ecosystem with enough light can support a high density mudskipper population in relation to food availability. Abundant mangrove vegetation contributed significantly to the total number of mudskipper specimens caught (Anneboina and Kavi Kumar 2017).

Based on the Kruskal-Wallis test, the TL was significantly different at each research station, and the longest fish length was noted at station 3, while body weight was not significantly different among the stations. Although the number of fish caught at station 3 was not too abundant, the mean lengths and weights were higher than at other stations. When fish abundance is not too dense, competition for food can decrease, which means that food availability is sufficient in an area to support fish growth. The mudskipper plays an essential role in the food web since it preys on small crustaceans such as crabs, and grazes on diatoms and algae from mudflats (Ansari et al. 2014). Furthermore, Bob-Manuel (2011) reported that adult *Periopthalmus barbarus* (L.) makes a dietary shift to crustaceans, and this researcher used crabs as bait to catch this fish. At stations 3, many holes and crabs were observed, and the mudskipper usually lives in mixed colonies with digging crabs.

Conclusion

The growth pattern of the mudskipper (*P. gracilis*) inhabiting mangrove ecosystem rehabilitation areas showed negative allometric growth as indicated by $b<3$, which signaled that length increased faster than body weight. Fulton's condition factor (K), which exceeded 1, and the mean of relative weight (Wr), which was above 100, indicated that food availability was sufficient, predator density was low, and the environment was in equilibrium. The environmental parameters of the waters of temperature, pH, salinity, and DO indicated that the conditions of the mangrove ecosystem rehabilitation areas were relatively good and that they can support *P. gracilis*. There were significantly different total lengths (TL) at each station, and the TL value of stations 1 and 3, and stations 2 and 3 were significantly different.

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Author contributions. I.D.: idea, conceptualization, design, methodology, data collection, analyzing, processing, writing-original draft; K.M.: design, methodology, data collection, analyzing, processing; S.A.: data collection, analyzing, processing, writing-original draft; A.D.: design, methodology; N.F.: writing-original draft; A.S.B.: writing-original draft; writing-review, validation.

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