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Analysis of morphology and population dynamics of giant mudskipper *Periophthalmodon schlosseri* (Gobiiformes: Oxudercidae) at Sungsang Estuaries, South Sumatra, Indonesia

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Abstract. *Melki, Ananta FD, Isnaini, Agustriani F, Apri R, Hartoni, Ningsih EN, Meiyerani J. 2025. Analysis of morphology and population dynamics of giant mudskipper* Periophthalmodon schlosseri *(Gobiiformes: Oxudercidae) at Sungsang Estuaries, South Sumatra, Indonesia. Biodiversitas 26: 2269-2277.* The giant mudskipper *Periophthalmodon schlosseri* is one of the most abundant mudskipper species, playing a vital role in the biomass of mangrove ecosystems. Mudskipper fish are also found in the Sungsang Coast, an estuary of the Musi River that is fed by river water from three provinces in Indonesia: South Sumatra, Lampung, and Bengkulu. This study aimed to analyze the morphology and population dynamics of mudskippers along with their environmental parameters in Sungsang Coastal, South Sumatra. For this study, mudskipper specimens were collected from five sampling sites along the Sungsang Coast and analyzed for morphometric characteristics, length-weight relationships, and their correlations with key environmental parameters like temperature, pH, and dissolved oxygen. The analysis of fifty-five specimens revealed an average total length of 20.08 cm, a standard length of 17.34 cm, and an average weight of 85.4 g. The growth pattern exhibited positive allometry (b>3), suggesting that as these fish grow, their body weight increases faster than their length. Condition factor analysis indicated that the fish sampled were healthy and in good nutritional condition. The Principal Component Analysis (PCA) further highlighted a strong association between dissolved oxygen and pH levels with the morphometric characteristics of the mudskippers, explaining 55.47% of the variation on the F1 axis and 24.70% on the F2 axis. This robust correlation between environmental factors and morphometric characteristics underscores the reliability of our findings. These findings provide crucial insights into the ecological health of the Giant Mudskipper and its dependence on specific environmental factors in the mangrove habitat are of utmost importance.

Keywords: Environmental parameter, length-weight relationship, morphometric, mudskipper, Sungsang Coast

INTRODUCTION

The mangrove ecosystem is an important area due to its role in providing a habitat for a wide variety of aquatic and terrestrial biota, as evidenced by the discovery of rare and previously unrecorded fish species such as the bearded gudgeon *Pogoneleotris heterolepis* in the Kapuas River Estuary, Kalimantan, Indonesia (Valen et al. 2022) and the small-eyed gudgeon *Prionobutis microps* in the Solo River Estuary, Java, Indonesia (Hasan et al. 2022), highlighting the ecological importance of these transitional zones as critical habitats for endemic and specialized aquatic species. This ecosystem is important from a variety of angles, including its environmental functions, such as protecting estuaries and coastlines from storms, stabilizing the shore, and reducing coastal soil erosion and flooding, as shown by successful restoration in Central Java (Setyawan and Winarno 2006) and Flores Island, Indonesia (Wirabuana et al. 2025). Restored mangroves in Pasar Banggi, Central Java, prevented erosion. In Flores, 10-year-old mangroves improved sediment retention and wave absorption. Additionally, it serves as a nursery habitat and breeding ground for a wide range of biota, and it provides sources that include essential commodities for both subsistence and commerce (Arulnayagam et al. 2021; Su et al. 2021; Jordan and Fröhle 2022; Waleed et al. 2024).

During periods of low tide, mangrove swamps and tidal flats formed in creeks, estuaries, and coastal waterways provide habitat for mudskippers (Mai et al. 2019; Ridho et al. 2019; Santoso et al. 2020; Darojat et al. 2023; Nathaniel et al. 2024). Mudskippers exhibit physiological, morphological, and behavioral adaptations that allow them to thrive in both aquatic and terrestrial environments (You et al. 2018; Tran et al. 2020; Corush and Zhang 2022; Steppan et al. 2022). Various factors, including food availability, habitat selection, human disturbance, and others influence the geographical distribution of each species. A notable example is the giant mudskipper *Periophthalmodon schlosseri*, which contributes significantly to the biomass value of the mangrove ecosystem (Zulkifli et al. 2012; Dewiyanti et al. 2022). According to the IUCN Red List of threatened species, this species is currently listed as Least Concern (LC), indicating that it is not under any immediate threat of population decline (IUCN 2023). *Periophthalmodon schlosseri* is widely distributed throughout the Indo-West Pacific region, including coastal and estuarine areas of Southeast Asia, Northern Australia, and parts of South Asia (Ansari et al. 2014; Parenti and Jaafar 2017).

Giant mudskippers are distinguished by their unique morphologies, which facilitate movement in both aquatic and terrestrial environments. Their pectoral fins are specialized for navigating on land, a crucial adaptation for survival in the intertidal zone (Pace and Gibb 2009; Zhou et al. 2023). The anatomical structure of these fins is not only important for movement but also reflects the evolutionary transition from aquatic to terrestrial life (Ziadi-Künzli et al. 2024). For example, the robust fin morphology allows mudskippers to generate thrust on land, which is crucial for escaping predators and foraging for food (Pace and Gibb 2009). Furthermore, studies have indicated that pelvic fin morphology varies among mudskipper species, affecting their climbing behavior and overall movement (Hidayat et al. 2022).

The giant mudskipper serves as a valuable bioindicator species, with its population dynamics reflecting both habitat quality and environmental stressors. Studies in Songkhla Lake, Thailand, demonstrate its sensitivity to ecosystem degradation, showing highest densities in undisturbed mangrove-associated mudflats and complete absence in seawall-modified habitats without mangroves (Pattaratumrong and Pompha 2024). This pattern mirrors findings from the Sungsang Estuary, where mudskipper presence correlates with heavy metal pollution levels, making them effective biomarkers for coastal contamination (Santoso et al. 2020, et al. 2024). Their ecological significance extends to reproductive biology, as population structure and fecundity studies reveal seasonal spawning synchronized with the southwest monsoon (Simon et al. 2012; Ridho et al. 2021), linking life-history traits directly to environmental cycles. Together, these studies establish the giant mudskipper as an integrative indicator of ecosystem health, responding to habitat integrity, pollution pressures, and climatic influences across its range.

The biodiversity of fish species in the Sungsang Estuary, including the giant mudskipper, is influenced by a variety of environmental factors. Numerous studies have documented the species diversity and community composition in this region, emphasizing the importance of mangrove ecosystems as critical habitats for mudskippers and other aquatic species (Fauziyah et al. 2019). However, the ongoing threat of human activities, such as deforestation and pollution, poses a significant threat to the ecosystem, thereby impacting mudskipper populations and their role. Consequently, conservation efforts are imperative to safeguard the habitat and ensure the long-term sustainability of mudskippers in South Sumatra (Septinar et al. 2023).

Several studies have been conducted on the foraging behavior of mudskippers in South Sumatra, encompassing research on their dietary habits (Ridho et al. 2019), gonad length and fecundity (Ridho et al. 2021), and range extension of *P. septemradiatus* (Iqbal et al. 2018). However, research on the length-weight relationship of *P. schlosseri* remains scarce, with most studies being based on field observations. Sungsang Coast, located in the estuary of the Musi River, Indonesia, is a well-known site for mudskippers. Despite numerous studies on the biology and ecology of mudskippers in Southeast Asia, data on length-weight relationships and morphometric-environment interactions of *P. schlosseri* in the Sungsang Estuary remain scarce. This study aims to fill this gap by analyzing the length-weight relationships and morphometric-environment interactions of *P. schlosseri* in the Sungsang Estuary.

MATERIALS AND METHODS

Study area

The research was carried out at five stations in the study area in the Sungsang Estuaries of South Sumatra, Indonesia (Figure 1 and Table 1). The Musi River is a major river with multiple uses for its resources. It flows through three provinces on Indonesia's Sumatra Island: South Sumatra, Lampung, and Bengkulu. The coast of Sungang is situated within the Musi River Estuary, where the river meets the sea (Melki et al. 2018a, b). Local fishermen depend on the rich aquatic life in the river and its estuary for their livelihoods. The Musi River Estuary is home to a variety of fish species, including freshwater stingrays, catfish, and other fish, which are not only a source of food but also contribute to the local economy and food security (Putri and Melki 2020). The mangrove ecosystem within the Musi Estuary is in a state of optimal health, providing an ideal environment for the proliferation of mudskippers (Iqbal et al. 2018; Ridho et al. 2019, et al. 2021).

Table 1. Description of sampling locations in the Sungsang Estuaries, South Sumatra, Indonesia

Sampling sites and names	Position		Description
	Longitudes (E)	Latitudes (S)	
1-Sungsang IV	104°53'22.65"	2°22'00.07"	Fisherman's village, but the population is not as large as in sites 2, 3 and 4. There is a healthy mangrove ecosystem, and this site is the mouth of the estuary.
2-Sungsang III	104°53'50.17"	2°21'56.30"	A fisherman village area with a moderate population, known for its active fishing community.
3-Sungsang II	104°54'01.76"	2°21'54.56"	Similar to Sungsang III, it’s a fisherman village with a high population density and active fishing activities.
4-Sungsang I	104°54'14.22"	2°21'47.61"	A fisherman village with a relatively larger population, also known for its significant fishing activities.
5-Marga Sungsang	104°54'21.17"	2°21'33.41"	Fisherman's village, but the population is not as large as in sites 2, 3 and 4. There is a good mangrove ecosystem, and this site is closer to the river

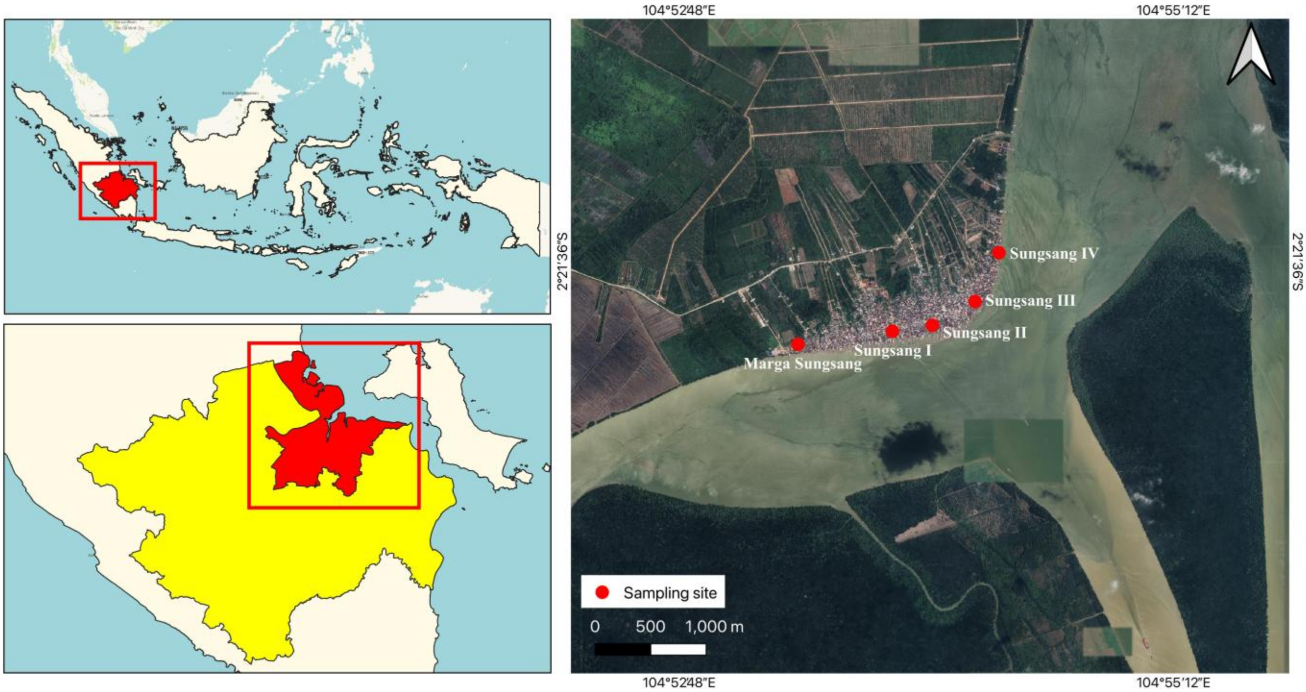

Figure 1. The study area of *Periophthalmodon schlosseri* in Sungsang Coast, South Sumatra, Indonesia

Sampling and preservation

A total of eleven individuals of *P. schlosseri* were collected at each site (n: 55 total) during a single sampling event in July 2024 to account for variation. Fish sampling was conducted using a 1×3 m seine net with a 1 mm mesh size suitable for capturing small estuarine species. After collection, the samples were immediately placed in labeled plastic bottles containing 8-10% formalin solution for initial preservation, and in the laboratory, the samples were transferred to 75% ethanol for long-term storage and further morphometric and meristic analyses (Sotola et al. 2019; Jawad et al. 2020; Tran and Nguyen 2023). The samples were collected at the Bioecology Marine Laboratory, Universitas Sriwijaya (UNSRI), South Sumatra (voucher code specimen: UNSRI, *P. schlosseri*, collected by Melki on 15 July 2024 at Sungsang Estuary, Indonesia).

Morphometric measurements

A total of seventeen morphometric measurements were recorded (Figure 2), including total length (TL), standard length (SL), eye diameter (ED), head diameter (HD), head length (HL), length of the dorsal fin 1 (LD1), the gap between D1 and D2 (GD1D2), second dorsal fin length (LD2), and distance between anal and caudal fin (DAC), length of anal fin (LA), least height of the pectoral fin (LPc), length of pectoral fin (PcF), the distance between pectoral and pelvic fin (DPI), length of pelvic fin (LPF), the width of pelvic fin (WPF), and length of caudal fin (LCF), and width of caudal fin (WCF) (Gangan et al. 2016; Rahman et al. 2022). Each measurement was measured to the nearest 0.1 cm, and body weight was measured on a digital scale with 0.1 g accuracy.

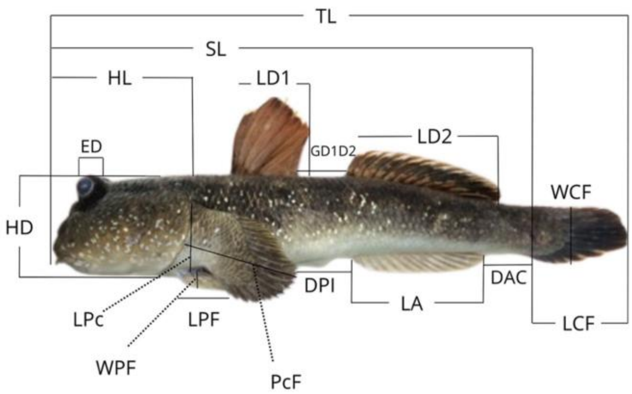

Figure 2. Morphometric measurements of mudskippers (Gangan et al. 2016; Rahman et al. 2022; Sokefun et al. 2022)

An allometric method (Rahman et al. 2022) was used to remove size-dependent variation from morphometric data. To do so, all of them were standardized using the formula: $M_{adj} = M(L_s/L_o)^b$, where M is the original measurement, M_{adj} is the adjusted measurement, L_o is the fish's standard length, L_s is the mean standard length for all samples, and b is the slope of the regression of logM on logL_o for all samples. The correlation between the transformed variables and the standard length of the samples was used to evaluate the results of the allometric method.

Environmental parameter measurements

Environmental parameters were measured in situ at each sampling site where fish samples were collected to assess the physicochemical characteristics of the habitat.

Water temperature, pH and dissolved oxygen were measured using a portable multiparameter instrument (Hanna Instruments Inc., USA) to ensure accurate and simultaneous measurements. Salinity was measured using a hand refractometer (ATAGO Co. Ltd, Tokyo, Japan). All measurements were performed in triplicate to ensure the accuracy and reliability of the data.

Data analysis

The following equation was used to approximate the length-weight relationships using the formula W = a x TLb (Tran et al. 2021; Vilchez et al. 2024), where W is the body weight (g), TL is the total length (cm), and a and b were estimated by the least-squares method based on logarithms using the formula Log (W) = log (a)+b log (TL) (Raeisi et al. 2011). Fish may exhibit isometric growth, characterized by equal growth in all three dimensions (b=3), or positive allometric growth, where width and height receive priority (b>3), or negative allometric growth, where length is prioritized (b<3) (Froese 2006). The effectiveness of linear regression can be quantified by the coefficient of determination (r2) (Tran et al. 2021).

The K of the fish was estimated using the equation K = (W) / (a x TLb), where W is the body weight (g), TL is the total length (cm), and a and b are the regression coefficients. A non-parametric Kruskal-Walli's test with a 5% threshold of significance was employed to determine whether there were any significant variations in mean Wrm between species because the assumptions of parametric statistics could not be met. For each statistical test, the significance level was set at $p<0.05$.

Principal Component Analysis (PCA) was performed using XLSTAT version 2021.4.1 (Addinsoft, New York, USA) integrated with Microsoft Excel. Prior to analysis, all morphometric and environmental data were standardized to eliminate unit bias and ensure comparability between variables. PCA was used to identify patterns and correlations between environmental parameters and morphometric traits of *P. schlosseri* across sampling sites. PCA reduces multidimensional data into principal components that explain the maximum variance in the data set. A biplot of the first two principal components was generated to visualize the distribution of active variables (environmental and morphometric parameters) and active observations (sampling sites). Variables with similar directions and vector lengths were interpreted as having a stronger influence or association within the same dimension.

RESULTS DAN DISCUSSION

Environmental parameters

The environmental parameters of samples in all experiments conducted in the Sungsang Coast area exhibited minimal fluctuation (Table 2). The environmental parameters that exert a substantial influence on the survival of mudskippers include temperature, salinity, acidity (pH), and Dissolved Oxygen (DO) content (Ansari et al. 2014; Ridho et al. 2021; Dewiyanti et al. 2022).

The temperature of the water varied from 29.8±0.1°C to 31.9±0.2°C. According to previous studies, the optimal water temperature range for mudskippers is between 23.5°C and 35.5°C (Ridho et al. 2021; Dewiyanti et al. 2022; Arevalo et al. 2023). However, mudskippers demonstrated a preference for milder water temperatures, with a mean of 26.7±2.1°C (Nay et al. 2018). The pH levels of the water ranged from 7.1±0.1 to 7.2±0.2, and the pH levels of the soil ranged from 6.8±0.3 to 7.0±0.2. According to several studies, the mudskipper exhibits optimal growth and reproductive capacity in aquatic environments with pH values ranging from 6 to 8 (Ridho et al. 2021; Dewiyanti et al. 2022; Darojat et al. 2023).

The present study examined the Dissolved Oxygen (DO) levels in the aquatic environment, with a range of 6.3±0.3 to 7.9±0.4 mg L^{-1}. This finding is notable when compared to the results reported by Ridho et al. (2021), that the mudskipper could survive at DO levels ranging from 4.2 to 6.2 mg L^{-1}. In accordance with the findings of Dewiyanti et al. (2022), the range of DO levels in this study was from 4.9 to 7 mg L^{-1}, indicating that mudskippers possess a considerable degree of tolerance to variations in DO levels. The salinity levels in the study areas ranged from 15.0±0.0 to 20.0±0.0 ppt. In contrast, Darojat et al. (2023) reported that mudskippers can survive in mangrove ecosystems with a salinity range of 1.7 to 2.58 ppt. Ridho et al. (2021) also reported a salinity range of 0 to 0.1 ppt. However, Dewiyanti et al. (2022) identified a higher salinity range, spanning from 18 to 25 ppt, and a more pronounced range of 24.4 to 34.4 ppt (Taniwel et al. 2020). The significance of these salinity levels is underscored by the observation that mudskippers are euryhaline, indicating their capacity to withstand a broad spectrum of salinities (Looi et al. 2021). However, pronounced fluctuations in salinity can exert an influence on their physiological processes and selection of habitat (Looi et al. 2021).

Table 2. The environmental parameters in the sampling sites

Sampling site	Temperature (°C)	pH (water)	pH (soil)	DO (mg L^{-1})	Salinity (ppt)
1	31.7±0.1	7.2±0.2	7.0±0.1	6.9±0.5	20.0±0.0
2	31.7±0.2	7.1±0.1	6.8±0.3	6.3±0.3	16.7±1.5
3	31.3±0.1	7.1±0.1	6.9±0.1	6.3±0.6	16.0±0.0
4	31.9±0.2	7.1±0.1	7.0±0.2	7.8±0.5	15.3±0.6
5	29.8±0.1	7.2±0.1	6.8±0.3	7.9±0.4	15.0±0.0

Temperature, salinity, and Dissolved Oxygen (DO) levels represent critical physical parameters that significantly influence the viability and growth potential of giant mudskippers. These fish exhibit a remarkable capacity for adaptability in response to fluctuating environmental conditions, as evidenced by their increased oxygen uptake rates in response to elevated temperatures (Pattaratumrong and Pompha 2024). Furthermore, they employ behavioral strategies to mitigate exposure to extreme conditions.

Morphometric characteristic

Periophthalmodon schlosseri observed in this study had a mean total length (TL) of 20.08 cm, ranging from 15.00 cm to 22.60 cm, while the mean standard length (SL) was 17.34 cm, with a range of 13.00 cm to 20.00 cm (Figure 3 and Table 3). The body size recorded at the sampling sites in the Sungsang Estuary is comparable to previous findings in the Musi River Estuary, South Sumatra, Indonesia (Ridho et al. 2019, et al. 2021). However, it is significantly larger than individuals reported from Cu Lao Dung Island, Soc Trang Province, Vietnam, which ranged from 12.10-18.65 cm (Tran et al. 2022), and slightly larger than those from Tanjung Piai, Pontian, Johor, Malaysia, which ranged from approximately 20 cm (Hui et al. 2019). This difference may be due to several ecological factors, including higher habitat productivity, greater availability of prey organisms, or potentially lower levels of anthropogenic disturbance in the Sungsang Estuary. In support of this, Dinh et al. (2020) suggested that food abundance plays an important role in shaping the growth of mudskippers. Furthermore, Tran et al. (2021) reported that the diet composition of mudskippers varied with fish size, season, and habitat, suggesting that local environmental conditions may significantly influence growth performance in different populations.

Figure 3. Sample of mudskipper. A. *Periophthalmodon schlosseri*; B. Morphometric measurement

Giant mudskippers display a distinctive body shape that is adapted for both swimming and terrestrial locomotion. Their bodies are generally elongated and laterally compressed, a trait that facilitates movement in both water and on land (Pattaratumrong and Pompha 2024). The total length of these creatures can exhibit significant variation based on environmental factors and habitat conditions. For instance, studies have documented lengths of up to 25 cm in certain specimens attributed to variations in habitat type and food availability (Zhou et al. 2023). In addition to morphometric measurements, giant mudskippers exhibit specific meristic traits that can be used to differentiate them from other mudskipper species. For instance, the dorsal fin composition, including the number of spines and soft rays, exhibits variation among populations, suggesting adaptations to local environmental conditions (Nor et al. 2023).

Length-weight relationship

The length-weight relationship of *P. schlosseri* was determined through the analysis of 55 specimens collected from five sampling sites along the Sungsang Coast. The total length (TL) ranged from 15.00 to 22.60 cm, and the body weight varied from 28.3 to 119.2 g (Table 4).

The findings of the regression analysis and the length-weight relationship graph (Figure 4) yielded the following equation: y: 0.0026x3.45. The b value of 3.45 indicates that the fish growth pattern is positive allometric (b>3), signifying that weight growth outpaces length increase. Positive allometric growth is indicated by a length-weight relationship (LWR) where the exponent (B) is greater than 3. Studies have demonstrated that *P. schlosseri* exhibits such a relationship, with documented values of b indicating positive allometry (Ridho et al. 2019; Abiaobo et al. 2021; Looi et al. 2021; Mussa et al. 2024). For instance, a study conducted in the Musi River Estuary found that the correlation coefficient for the length-weight relationship (LWR) of *P. schlosseri* was 98.2%, with an exponent value of 3.189, confirming its positive allometric growth (Ridho et al. 2019). This suggests that as the fish grows, it becomes relatively heavier compared to its length, which may be advantageous for buoyancy and mobility in its habitat. This positive allometric growth pattern of *P. schlosseri* is consistent with findings from related species within the same family. For example, *P. barbarus* also exhibited positive allometric growth in similar ecological contexts, reinforcing the notion that this growth strategy may be a common adaptive trait among mudskippers (Indarjo et al. 2020; Abiaobo et al. 2021). The implications of such growth patterns are critical, as they can influence the species' reproductive strategies, survival rates, and overall fitness in fluctuating environmental conditions typical of mangrove ecosystems (Dinh 2016).

In comparison with other species found in mangrove ecosystems, the allometric growth of *P. schlosseri* reflects typical trends in estuarine and intertidal species, where growth patterns are often influenced by environmental conditions such as temperature, food availability, and habitat structure (Chew et al. 2014; Looi et al. 2021). The positive allometry observed in the Sungsang population could be attributed to the productivity of the mangrove ecosystem, which provides abundant resources for these mudskippers. The Musi River Estuary is home to a diverse array of mudskipper species, which exhibit various adaptations to their mangrove habitat. For instance, studies have documented the reproductive biology and feeding habits of mudskippers in this region, emphasizing their role in the local food web (Ridho et al. 2019, et al. 2021).

Condition factor

The K value exhibited a maximum at sampling site 1 (K: 1.04) and a minimum at sampling site 5 (K: 0.94) (Figure 5). The variation in K values across the sampling sites was not statistically significant, suggesting that the fish samples were healthy and well-nourished at the time of the study. The K values in the Sungsang Coastal area are comparable to those found in the Tran De District, Soc Trang Province, Mekong Delta, Vietnam mangrove habitat, which range from 1.01 to 1.03 (Dinh 2016), and the West Coast of Peninsular Malaysia, which range from 0.41 to 1.29 (Looi et al. 2021).

Table 3. Morphometric measurement results of *Periophthalmodon schlosseri* on Sungsang Coast, South Sumatra, Indonesia

Morphometric measurements	Ranged (cm)	Mean±sd (cm)
TL	15.00-22.60	20.08±2.0
SL	13.00-20.00	17.34±1.7
ED	0.40-1.70	0.83±0.4
HD	2.40-4.80	3.44±0.6
HL	3.40-6.40	4.81±0.8
LD_1	1.50-3.00	2.67±0.4
GD_1D_2	0.90-2.60	1.47±0.4
LD_2	3.00-4.20	3.73±0.4
DAC	2.00-3.90	3.06±0.5
LA	2.60-4.30	3.49±0.4
LPc right	1.30-2.80	1.89±0.4
LPc left	1.40-2.80	2.05±0.4
PcF right	1.10-2.50	1.66±0.3
PcF left	1.50-3.00	1.91±0.5
DPI right	0.20-1.70	0.78±0.4
DPI left	0.50-1.80	0.96±0.4
LPF	0.80-2.80	1.63±0.7
WPF	1.50-3.00	2.36±0.5
LCF	2.00-4.70	3.40±0.8
WCF	1.30-3.00	2.32±0.5

Table 4. Range of total length (TL) and body weight (W) of *Periophthalmodon schlosseri* in Sungsang Coast, South Sumatra, Indonesia

Sampling site	TL (cm)	W (g)
1	19.5-21.5	67.8-102.5
2	15.0-21.0	28.3-103.7
3	19.0-20.5	61.8-92.8
4	20.0-22.5	87.7-108.3
5	19.5-22.6	82.1-119.2
Average	20.1	85.4

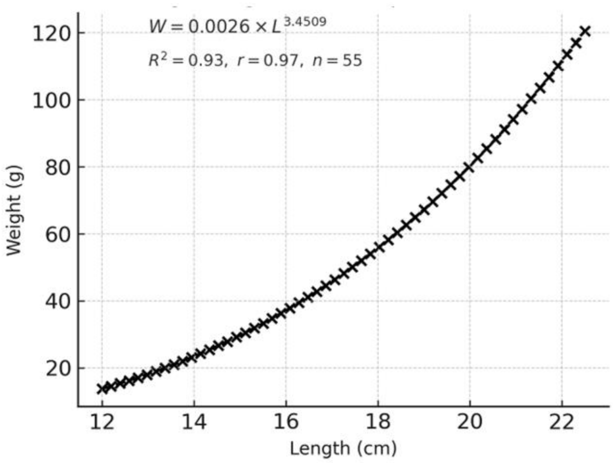

Figure 4. Relationship between total length and body weight of *Periophthalmodon schlosseri* in Sungsang Coast, South Sumatra, Indonesia

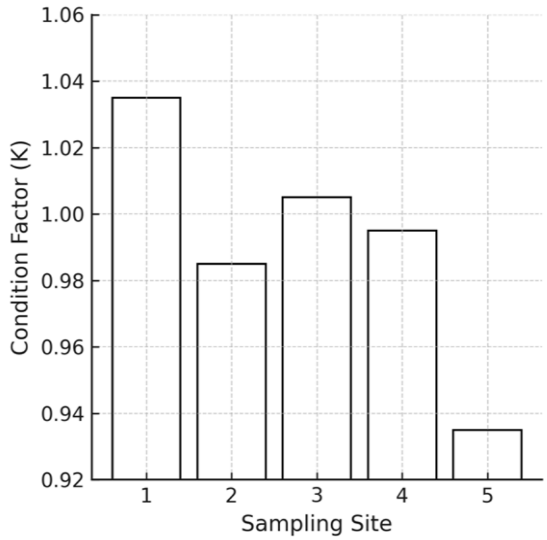

Figure 5. Condition factor of *Periophthalmodon schlosseri* in Sungsang Coast, South Sumatra, Indonesia

Furthermore, the condition factor (K), a metric of health and well-being, was evaluated and correlated with the length-weight relationship. The condition factor values indicated a range of nutritional status among the mudskippers, with most individuals displaying average to good health (Froese 2006). However, some specimens with lower condition factors were found to be lean, suggesting potential seasonal fluctuations in food availability that might influence the body mass-to-length ratio (Abdullah and Zain 2019; Tran et al. 2021; Nguyễn et al. 2022). Condition factors, which are used as an indicator of fish health, have been shown to vary with environmental conditions. This indicates that abiotic factors, such as temperature and salinity, as well as biotic factors, such as prey availability, significantly affect the growth patterns of these fishes (Dewiyanti et al. 2022; Dinh et al. 2022).

Principal Component Analysis (PCA)

Principal component analysis was employed to ascertain the correlation between seventeen *P. schlosseri* morphometric characteristics and environmental factors, including water pH and soil pH, Dissolved Oxygen (DO), temperature, and salinity. The analysis yielded significant findings concentrated on two primary axes: F1 by 55.47% and F2 by 24.70%, with 80.17% representing the maximum amount of information (Figure 6).

The environmental parameter on the positive F1 axis is characterized by DO, which for sampling site 5 is high at 7.9 mg L^{-1}. According to Kumar et al. (2021) and Mulyasari et al. (2023), a very strong correlation relationship can mean that as the value of the comparison character increases, the length of a morphometric character in fish will also increase. Consequently, elevated levels of dissolved oxygen at the Sungsang Coast could potentially influence the growth of morphometric characteristics in *P. schlosseri*. A study by Khater et al. (2021) and Heriyati et al. (2022) indicated that low DO levels can lead to a reduction in fish appetite and growth. The findings indicate that salinity exerts minimal influence on the morphometric growth of *P. schlosseri*. The classification of mudskippers as euryhaline organisms is attributed to their capacity to respond to variations in salt concentration (Taniwel et al. 2020; Kim et al. 2021; Hamidah et al. 2024).

The positive F2 axis is characterized by sampling site 1, which is associated with the environmental parameter component of soil pH and the morphometric characteristics of WPF, defined as the width of the pelvic fins utilized during locomotion by mudskippers. This parameter is believed to be closely related to their biological functions (Hidayat et al. 2022; Quigley et al. 2022). The pH value of the soil at sampling site 1 is 7, indicating a high value within the threshold of the giant mudskipper life. The measurement of soil pH is crucial as the mudskipper habitat is located in the sediment. A low pH value in the mudskipper habitat prompts the fish to allocate their energy toward environmental adjustments rather than growth and foraging (Smith and Nobriga 2023).

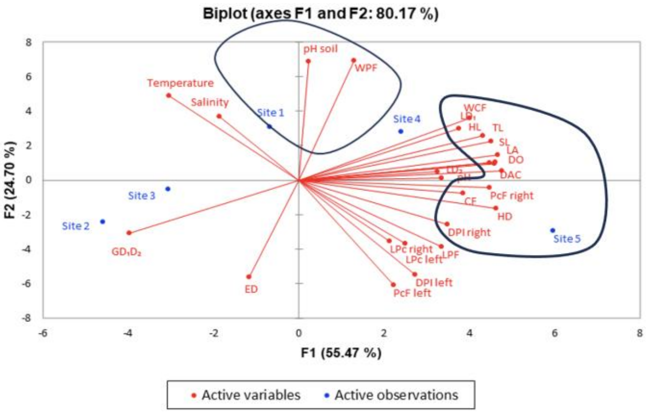

Figure 6. PCA was examined to determine morphometric characteristics related to environmental factors of *Periophthalmodon schlosseri* on Sungsang Coast, South Sumatra, Indonesia

This study analyzed the giant mudskipper on Sungsang Coast, revealing positive allometric growth (b>3) and healthy condition factors. Dissolved oxygen and pH exhibited a strong influence on morphometric characteristics, while temperature and salinity supported optimal habitats. The findings emphasize the critical role of mangroves in sustaining giant mudskipper populations and offer insights into mangrove ecosystem management. This study highlights that dissolved oxygen and pH are the most influential environmental variables affecting the morphometric variation of *P. schlosseri*, suggesting their potential as key indicators in mangrove ecosystem monitoring.

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REFERENCES

Abdullah MIC, Zain KM. 2019. Length-weight relationships, condition factor and growth parameters of *Periophthalmus chrysospilos* (Bleeker, 1852) (Gobiiformes: Gobiidae), in Bayan Bay, Penang, Malaysia. Sains Malays 48 (2): 271-279. DOI: 10.17576/jsm-2019-4802-02.

Abiaobo N, Asuquo IE, Ejiogu IN, James EJ. 2021. Aspects of the biology of *Periophthalmus barbarus* (mudskipper), from Jaja Creek, Niger Delta, Nigeria. Ecol Evol Biol 6 (1): 15. DOI: 10.11648/j.eeb.20210601.14.

Ansari AA, Trivedi S, Saggu S, Rehman H. 2014. Mudskipper: A biological indicator for environmental monitoring and assessment of coastal waters. J Entomol Zool Stud 2 (6): 22-33.

Arevalo E, Cabral HN, Villeneuve B, Posséme C, Lepage M. 2023. Fish larvae dynamics in temperate estuaries: A review on processes, patterns and factors that determine recruitment. Fish Fish 24 (3): 466-487. DOI: 10.1111/faf.12740.

Arulnayagam A, Khim JS, Park J. 2021. Floral and faunal diversity in Sri Lankan mangrove forests: A systematic review. Sustainability 13 (17): 9487. DOI: 10.3390/su13179487.

Chew SF, Hiong KC, Lam SP, Ong SW, Wee WL, Wong WP, Ip YK. 2014. Functional roles of Na+/K+-ATPase in active ammonia excretion and seawater acclimation in the giant mudskipper, *Periophthalmodon schlosseri*. Front Physiol 5: 158. DOI: 10.3389/fphys.2014.00158.

Corush JB, Zhang J. 2022. One size does not fit all: Variation in anatomical traits associated with emersion behavior in mudskippers (Gobiidae: Oxudercinae). Front Ecol Evol 10: 0108. DOI: 10.3389/fevo.2022.967067.

Darojat AZ, Marhendra APW, Kurniawan N. 2023. Identification of mudskipper species in mangrove area of Luwu Timur, Luwu Utara, and Wajo South Sulawesi Indonesia. Biotropika 11 (2): 74-83. DOI: 10.21776/ub.biotropika.2023.011.02.02.

Dewiyanti I, Melanie K, Almuniro S, Damora A, Nufadillah N, Batubara AS. 2022. Growth patterns and condition factor of the mudskipper (*Periophthalmus gracilis*) in mangrove ecosystem rehabilitation areas in Banda Aceh and Aceh Besar, Indonesia. Fish Aquat Life 30 (2): 85-94. DOI: 10.2478/aopf-2022-0008.

Dinh QM, Nguyen THD, Truong NT, Doan DX, Nguyen TTK. 2022. Monthly variations in growth pattern and condition factor of *Periophthalmodon septemradiatus* (Gobiiformes: Periophthalminae) living along the Bassac River in Viet Nam. PeerJ 10: e13880. DOI: 10.7717/peerj.13880.

Dinh QM, Tran LT, Tran TTM, To DK, Nguyen TTK, Tran DD. 2020. Variation in diet composition of the mudskipper, *Periophthalmodon septemradiatus*, from Hau River, Vietnam. Bull Mar Sci 96 (3): 487-500. DOI: 10.5343/bms.2018.0067.

Dinh QM. 2016. Growth and body condition variation of the giant mudskipper *Periophthalmodon schlosseri* in dry and wet seasons. Tap Chi Sinh Hoc 38 (3): 7425. DOI: 10.15625/0866-7160/v38n3.7425.

Fauziyah F, Nurhayati N, Bernas SM, Putera A, Suteja Y, Agustiani F. 2019. Biodiversity of fish resources in Sungsang Estuaries of South Sumatra; IOP Conference Series: Earth and Environmental Science 278 (1): 012025. DOI: 10.1088/1755-1315/278/1/012025.

Froese R. 2006. Cube law, condition factor and weight-length relationships: History, meta-analysis, and recommendations. J Appl Ichthyol 22 (4): 241-253. DOI: 10.1111/j.1439-0426.2006.00805.x.

Gangan SS, Kumar R, Ramteke KK, Kumar AP, Jaiswar AK. 2016. Study of morphological variation discernible by multivariate analysis between the species of genus *Setipinna* (Teleostei: Clupeiformes). Ecol Environ Conserv 22: S11-S16.

Hamidah A, Murni P, Said M. 2024. The diversity of mudskipper fish family Gobiidae in mangrove area, Seberang District, Tanjung Jabung Regency, West Jambi. J Surv Fish Sci 11 (1): 2045. DOI: 10.53555/sfs.v11i01.2045.

Hasan V, South J, Katz A, Ottoni FP. 2022. First record of the Small-eyed loter *Prionobutis microps* (Weber, 1907) (Teleostei: Eleotridae: Butinae) in Java, Indonesia. Cybium 46 (1): 49-51. DOI: 10.26028/CYBIUM/2022-461-008.

Heriyati E, Rustadi R, Isnansetyo A, Triyatmo B, Istiqomah I, Deendarlianto D, Budhijanto W. 2022. Microbubble aeration in a Recirculating Aquaculture System (RAS) increased dissolved oxygen, fish culture performance, and stress resistance of Red Tilapia (*Oreochromis* sp.). Trends Sci 19 (20): 6251. DOI: 10.48048/tis.2022.6251.

Hidayat S, Wicaksono A, Raharjeng ARP, Jin DSM, Alam P, Retnoaji B. 2022. The morphologies of mudskipper pelvic fins in relation to terrestrial and climbing behaviour. Proceedings of the Zoological Society. The University of Edinburgh, Edinburgh, 8 February 2022. DOI: 10.1007/s12595-021-00422-1.

Hui NY, Mohamed M, Othman MNA, Tokiman L. 2019. Diversity and behaviour of mudskippers of Tanjung Piai, Pontian, Johor. IOP Conf Ser Earth Environ Sci 269 (1): 012037. DOI: 10.1088/1755-1315/269/1/012037.

Indarjo A, Salim G, Zein M, Susiyanti S, Soejarwo PA, Nugraeni CD, Bija S, Pham YTH. 2020. Characteristics of Von Bertalanfy growth, allometric, condition index and mortality of *Periophthalmus barbarus* in mangrove and probiotics conservation area (KKMB), Tarakan, North Kalimantan. Ilmu Kelautan 25 (1): 31-38. DOI: 10.14710/ik.ijms.25.1.31-38.

Iqbal M, Halim A, Adriani D, Pormansyah, Saputra RF. 2018. Range extension of *Periophthalmodon septemradiatus* (Gobiidae) in southern Sumatra, Indonesia. Cybium 42 (4): 376-378. DOI: 10.26028/cybium/2018-424-009.

IUCN. 2023. *Periophthalmodon schlosseri*. The IUCN Red List of Threatened Species 2023: e.T196314A153206425. www.iucnredlist.org/species/196314/153206425.

Jawad LA, Koya A, Gnohossou P. 2020. Fixation, preservation and freezing effects on morphometrics of two fish species collected from Lake Ganvie, Benin, West Africa. Thalass Sal 42: 75-82. DOI: 10.1285/i15910725v42p75.

Jordan P, Fröhle P. 2022. Bridging the gap between coastal engineering and nature conservation? A review of coastal ecosystems as nature-based solutions for coastal protection. J Coast Conserv 26 (2): 4. DOI: 10.1007/s11852-021-00848-x.

Khater ES, Bahnasawy AH, Elghobashy H, Shaban Y, El-Sheikh FM, El-Reheem SA, Aboegela M. 2021. Mathematical model for predicting oxygen concentration in Tilapia fish farms. Sci Rep 11: 24130. DOI: 10.1038/s41598-021-03604-1.

Kim J, Lee C, Yoo D, Kim H. 2021. Genetic adaptations in mudskipper and tetrapod give insights into their convergent water-to-land transition. Animals 11 (2): 584. DOI: 10.3390/ani11020584.

Kumar GR, Bano F, Serajuddin M. 2021. Effect of formalin preservation on studies on morphology and condition factor of the freshwater Shark *Wallago attu* (Bloch and Schneider, 1801) using truss network system. Indian J Fish 68: 3. DOI: 10.21077/ijf.2021.68.3.98695-16.

Looi LJ, Aris AZ, Isa NM, Yusoff, FM, Haris H. 2021. Elemental composition and health risk assessment of giant mudskipper (*Periophthalmodon schlosseri*) from the intertidal zone of the west coast of Peninsular Malaysia. Front Mar Sci 7: 618284. DOI: 10.3389/fmars.2020.618284.

Mai HV, Tran LX, Dinh QM, Tran DD, Murata M, Sagara H, Yamada A, Shirai K, Ishimatsu A. 2019. Land invasion by the mudskipper, *Periophthalmodon septemradiatus*, in fresh and saline waters of the Mekong River. Sci Rep 9: 14227. DOI: 10.1038/s41598-019-50799-5.

Melki, Isnansetyo A, Widada J, Murwantoko M. 2018a. The significance of water quality parameters on the diversity of ammonia-oxidizing bacteria in the water surface of Musi River, Indonesia. AACL Bioflux 11 (6): 1908-1918.

Melki, Isnansetyo A, Widada J, Murwantoko M. 2018b. Distribution of ammonium-oxidizing bacteria in sediment with relation to water quality at the Musi River, Indonesia. Hayati 25 (4): 198-205. DOI: 10.4308/hjb.25.4.198.

Mulyasari N, Subaryono N, Utomo BSB, Taufik I, Kusmini II, Yosmaniar N. 2023. Morphometric and genetic characterization of dominant fish species in Progo River, Yogyakarta, Indonesia. Sci World J 38 (2): 111-120. DOI: 10.1155/2023/7197251.

Mussa ZJ, Aziz BAAA, Saleh SM, Abbas AH, Al-Asadi MK, Jumah AAK. 2024. Mudskippers a good bioindicator for polluted soils in the mudflat region of Southern Iraq. Mesop J Mar Sci 38 (2): 111-119. DOI: 10.58629/mjms.v38i2.354.

Nathaniel AM, Gbobo BMFO, Raimi MO. 2024. Food and feeding of Atlantic mudskipper *Periophthalmus barbarus* in Ogbo-Okolo mangrove forest of Santa Barbara River, Bayelsa State Niger Delta, Nigeria. Qeios ID: QNW7VZ. DOI: 10.32388/QNW7VZ.

Nay TJ, Gervais CR, Hoey AS, Johansen JL, Steffensen JF, Rummer JL. 2018. The emergence emergency: A mudskipper's response to temperatures. J Therm Biol 78: 65-72. DOI: 10.1016/j.jtherbio.2018.09.005.

Nguyễn NT, Ha LM, Nguyen ATN, Chu NH, Tran HD, Hưng NP, Ta TT. 2022. Variation in the allometry of morphometric characteristics, growth, and condition factors of wild *Bostrychus sinensis* (Butidae) in Northern Vietnam. Pak J Zool 55 (2): 1-10. DOI: 10.17582/journal.pjz/20200917140936.

Nor NM, Saifuzzaman S, Azmir IA, Hussin N. 2023. Morphological characteristics and reproductive organs assessment of blue-spotted mudskipper *Boleophthalmus boddarti* in Peninsular Malaysia. Biotropia 30 (1): 21-36. DOI: 10.11598/btb.2023.30.1.1561.

Pace CM, Gibb AC. 2009. Mudskipper pectoral fin kinematics in aquatic and terrestrial environments. J Exp Biol 212 (14): 2279-2286. DOI: 10.1242/jeb.029041.

Parenti LR, Jaafar Z. 2017. The natural distribution of mudskippers. In: Jaafar Z, Murdy EO (eds). Fishes Out of Water. CRC Press, Florida. DOI: 10.1201/9781315119861.

Pattaratumrong MS, Pompha T. 2024. Habitat of the amphibious mudskipper *Periophtalmodon schlosseri* in Songkhla Lake, Thailand. Biodiversitas 25 (5): 1875-1881. DOI: 10.13057/biodiv/d250503.

Putri WAE, Melki. 2020. Study of the water quality of the Musi River Estuary, South Sumatra. J Mar Aquat Sci 6 (1): 36. DOI: 10.24843/jmas.2020.v06.i01.p05. [Indonesian]

Quigley ZMG, Blob RW, Kawano S. 2022. Kinematic comparisons between mudskipper fins and Salamander limbs during terrestrial locomotion. J Exp Zool A Ecol Integr Physiol 337 (6): 612-625. DOI: 10.1002/jez.2594.

Raeisi H, Daliri M, Paighambari SY, Shabani MJ, Bibak M, Davoodi R. 2011. Length-weight relationships, condition factors and relative weight of five fish species of Bushehr waters, Northern Persian Gulf. Afr J Biotechnol 10 (82): 19181-19186. DOI: 10.5897/AJB11.2650.

Rahman MAF, Azmir IA, Hussin NJ. 2022. Morphological study of selected mudskipper species (Family: Oxudercidae) and development of key pictorial. Iran J Ichthyol 9 (4): 180-194. DOI: 10.22034/iji.v9i4.808.

Ridho MR, Patriono E, Rahmawati D, Pratama R, Avesena M. 2021. Short communication: Investigating gonad length and fecundity in mudskippers (Gobiidae) at the Musi River Estuary, South Sumatra, Indonesia. Biodiversitas 22 (10): 4413-4420. DOI: 10.13057/biodiv/d221034.

Ridho MR, Patriono E, Solikha M. 2019. Food habits of three species of mudskippers in the Musi River Estuary, South Sumatra, Indonesia. Biodiversitas 20 (8): 2368-2374. DOI: 10.13057/biodiv/d200835.

Santoso HB, Krisdianto K, Yunita R. 2024. Iron bioaccumulation and ecological implications in the coastal swamp wetlands ecosystem of South Kalimantan: Insights from giant mudskipper fish as bioindicators. J Degrad Min Lands Manag 11 (3): 5539-5550. DOI: 10.15243/jdmlm.2024.113.5539.

Santoso HB, Suhartono E, Yunita R, Biyatmoko D. 2020. Mudskipper fish as a bio-indicator for heavy metals pollution in a coastal wetland. Egypt J Aquat Biol Fish 24 (7): 1073-1095. DOI: 10.21608/ejabf.2020.144402.

Septinar H, Putri YP, Midia KR, Bianto B. 2023. Mangrove forest conservation efforts through nurseries in Sungsang IV village, Banyuasin Regency. Jurnal Ilmu Lingkungan 1 (2): 77-88. DOI: 10.31851/esjo.v1i2.11920. [Indonesian]

Setyawan AD, Winarno K. 2006. The direct exploitation in the mangrove ecosystem in Central Java and the land use in its surrounding: Degradation and its restoration effort. Biodiversitas 7 (3): 282-291. DOI: 10.13057/biodiv/d070318.

Simon KD, Bakar Y, Mazlan AG, Zaidi CC, Samat A, Arshad A, Temple SE, Brown-Peterson NJ. 2012. Aspects of the reproductive biology of two archer fishes *Toxotes chatareus*, (Hamilton 1822) and *Toxotes jaculatrix* (Pallas 1767). Environ Biol Fishes 93 (4): 491-503. DOI: 10.1007/s10641-011-9944-6.

Smith WE, Nobriga MK. 2023. A bioenergetics-based index of habitat suitability: Spatial dynamics of foraging constraints and food limitation for a rare estuarine fish. Trans Am Fish Soc 152 (5): 650-671. DOI: 10.1002/tafs.10427.

Sokefun O, Gan HM, Tan MP. 2022. Morphometrical characterization of the Atlantic mudskipper species (*Periophthalmus barbarus*) (Linnaeus, 1766) (Perciformes; Gobiiae) from Abonema in Port Harcourt, Rivers State, Nigeria. Intl J Fish Aquac 10 (3): 72-76. DOI: 10.22271/fish.2022.v10.i3a.2719.

Sotola VA, Craig CA, Pfaff PJ, Maikoetter JD, Martin NH, Bonner TH. 2019. Effect of preservation on fish morphology over time: Implications for morphological studies. Plos One 14 (3): e0213915. DOI: 10.1371/journal. pone.0213915.

Steppan SJ, Meyer AA, Barrow LN, Alhajeri BH, Al-Zaidan ASY, Gignac PM, Erickson GM. 2022. Phylogenetics and the evolution of terrestriality in mudskippers (Gobiidae: Oxudercinae). Mol Phylogenet Evol 169: 107416. DOI: 10.1016/j.ympev.2022.107416.

Su J, Friess DA, Gasparatos A. 2021. A meta-analysis of the ecological and economic outcomes of mangrove restoration. Nat Commun 12: 5050. DOI: 10.1038/s41467-021-25349-1.

Taniwel D, Leiwakabessy F, Rumahlatu D. 2020. Short communication: Density and length-weight relationship of mudskipper (*Periophthalmus* spp.) in the mangrove area of Kairatu Beach, Maluku, Indonesia. Biodiversitas 21 (11): 5465-5473. DOI: 10.13057/biodiv/d211155.

Tran HD, Nguyen HH, Ha LM. 2021. Length-weight relationship and condition factor of the mudskipper (*Periophthalmus modestus*) in the Red River Delta. Reg Stud Mar Sci 46: 101903. DOI: 10.1016/j.rsma.2021.101903.

Tran LX, Maekawa Y, Soyano K, Ishimatsu A. 2020. Morphology of the feeding apparatus in the herbivorous mudskipper, *Boleophthalmus pectinirostris* (Linnaeus, 1758). Zoomorphology 139 (2): 231-243. DOI: 10.1007/s00435-020-00476-3.

Tran LX, Nguyen TTK, Vo TT. 2022. Morphological comparison of the cranial movement apparatus in mudskippers (Gobiidae: Oxudercinae). Zoology 154: 126042. DOI: 10.1016/j.zool.2022.126042.

Tran LX, Nguyen TTK. 2023. Morfology of the buccal and opercular sealing apparatus in mudskippers (Gobiidae: Oxudercinae). J Ichthyol 63 (4): 605-615. DOI: 10.1134/S0032945223040197.

Valen FS, Hasan V, Ottoni FP, Nafisyah AL, Erwinda M, Annisa AN, Adis MA. 2022. First country record of the bearded gudgeon *Pogoneleotris heterolepis* (Günther, 1869) (Teleostei: Eleotridae) from Indonesia. IOP Conf Ser Earth Environ Sci 1036: 012074. DOI: 10.1088/1755-1315/1036/1/012074.

Vilchez M, Dattilo J, Brewer SK. 2024. Length-weight relationships of native and non-native fishes in the lower Red River Cathment, USA. J Appl Ichthyol 2024: 5578825. DOI: 10.1155/2024/5578825.

Waleed TA, Abdel-Maksoud YK, Kanwar RS, Sewilam H. 2024. Mangroves in Egypt and the Middle East: Current status, threats, and opportunities. Intl J Environ Sci Technol 22: 1225-1262. DOI: 10.1007/s13762-024-05788-1.

Wirabuana PYAP, Baskorowati L, Pamungkas B, Mulyana B, South J, Purnobasuki H, Andriyono S, Hasan V. 2025. Mangroves, fauna compositions and carbon sequestration after ten years restoration on Flores Island, Indonesia. Sci Rep 15: 4866. DOI: 10.1038/s41598-025-87307-x.

You X, Sun M, Li J, Bian C, Chen J, Yi Y, Yu H, Shi Q. 2018. Mudskippers and their genetic adaptations to an amphibious lifestyle. Animals 8 (2): 24. DOI: 10.3390/ani8020024.

Zhou H, Donatelli CM, Laneuville O, Standen EM. 2023. Skeletal anatomy of the pectoral fin in mudskipper species from terrestrial and aquatic habitats. J Morphol 284 (8): e21612. DOI: 10.1002/jmor.21612.

Ziadi-Künzli F, Maeda K, Puchenkov P, Bandi M. 2024. Anatomical insights into fish terrestrial locomotion: A study of barred mudskipper (*Periophthalmus argentilineatus*) fins based on µct 3d reconstructions. J Anat 245 (4): 593-624. DOI: 10.1111/joa.14071.

Zulkifli SZ, Mohamat-Yusuff F, Ismail A, Miyazaki N. 2012. Food preference of the giant mudskipper *Periophthalmodon schlosseri* (Teleostei: Gobiidae). Knowl Manag Aquat Ecosyst 405: 7. DOI: 10.1051/kmae/2012013.