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Habitat of the amphibious mudskipper *Periophtalmodon schlosseri* in Songkhla Lake, Thailand

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Abstract. *Pattaratumrong MS, Pompha T. 2024. Habitat of the amphibious mudskipper* Periophtalmodon schlosseri *in Songkhla Lake, Thailand. Biodiversitas 25: 1875-1881.* This study aimed to investigate the preferred habitat of giant mudskippers, *Periophtalmodon schlosseri* Pallas 1770. It was conducted from August to October 2022 at six sampling stations in Koh Yoh, a small island in the Lower Songkhla Lake. Environmental parameters such as organic matter and organic carbon in sediment, temperature, salinity, dissolved oxygen, and substrate were observed. The results indicate that the density of giant mudskipper weak to moderate correlates with all studied environmental parameters ($P<0.05$). Within the study area, the highest population density of *P. schlosseri* was recorded in the mudflat habitat adjacent to mangroves, and the lowest density was recorded in the mudflat habitat with a seawall, absent with nearby mangroves. This study suggests that environmental conditions affect the abundance of giant mudskippers, but this does not reach the limiting threshold; the more influential factor for this species is the character of the habitat. The mangrove habitat should be conserved and protected from development and urbanization. These results provide insights into the preferred habitat and offer a better understanding of the ecology of these fishes in the estuarine lake.

Keywords: Conservation, habitat, mudskipper, Songkhla Lake, threatened animal

INTRODUCTION

Mudskipper is an intertidal fish that lives in daily immersion, transitioning between terrestrial eating and migration into water and emersion following the tidal cycle (Katayama et al. 2022; Dinh and Nguyen 2023). The mudskipper belongs to the Family Gobiidae, which has four genera: *Baleophthalamus, Periophthalmus, Periophthalmadon*, and *Scartelaos* (Radkhah and Eagderi 2019). Mudskipper is important to estuarine food webs and fisheries; it is a secondary consumer in estuarine food webs and contributes to the structure of benthic ecosystems, and the potential food sources include mangrove leaves, benthic microalgae, and sediment organic materials (Shojaei et al. 2022). In fisheries, fish are widely consumed as traditional medicine in India and as drugs in China and Japan; it is consumed or used as ornamental fish in Bangladesh, Thailand, Philippines, China, Taiwan, and Japan (Dewiyanti et al. 2022) and as an essential component of human food and protein source in Nigeria (Princewill and Edet 2019). Recent research found that mudskipper (*Periophthalmus chrysospilos* Bleeker 1853, *Boleophthalmus boddarti* Pallas 1770, and *Boleophthalmus dussumieri* Valenciennes 1837) has bioactive compounds, including steroids, carotenoids, terpenoids, cannabinoids, and alkaloids that potentially treat children with enuresis, inflammatory diseases, and allergy (Ridho et al. 2020). Furthermore, they are important for ecotoxicological studies and bioindicators for heavy metals, are resistant to contamination, and can accumulate heavy metals in their tissue (Santoso et al. 2020). Heavy metal accumulation can affect the structure of gills, livers, and muscles, causing changes in edema (fluid retention or swelling) and necrosis without physical stress (Sangur et al. 2021) and decomposing them into ecologically favorable elements (Dewiyanti et al. 2022). However, studies on the west coast of Peninsular Malaysia show that the contamination in fish is still below the national and international food permission limits (Looi et al. 2021). They are often used as model organisms to investigate aquatic ecotoxicology in coastal areas (Santoso et al. 2020). To date, the population of mudskippers has gradually decreased. They are threatened animals in Singapore (Wild Fact Sheets 2020) and India due to overfishing, habitat destruction, urbanization, and climate change (Dinh et al. 2020b; Mahadevan et al. 2021; Pan et al. 2021).

Songkhla Lake is the second-largest lake in Southeast Asia and covers an area of 1,082 km^2. It is in southern Thailand and covers three provinces: Songkhla, Phatthalung, and Nakhon Si Thammartat. It is considered a unique ecosystem with three water ecosystems: fresh, brackish, and saline water; depending on the season, the salinity varies over a wide range altered by tidal currents and rainfall (Somboonsuke et al. 2018; Dong et al. 2021; Sinso et al. 2023). Thus, the lake provides ecological value, is rich in biodiversity, and is an essential resource for fishing and aquaculture (Dong 2021; Doungsuwan et al. 2022). In the past, there were more than 770 kinds of aquatic animals and plants; nowadays, the number is continuously decreasing (Ramarn et al. 2020). The lake faces various ecological problems due to human activities. From 2000 to 2019, the lake faced degradation problems, including contamination of trace metals (Pb, Hg, As, Zn, Ni) from poor sewage treatment from urban wastewater, industrial effluent, fishery discharge, and rapid development (Dong 2021). Additionally, microplastic contamination has also been reported in the stomachs of common fish (*Arius maculatus* Thunberg 1792) and shrimp species (*Parapenaeopsis hardwickii* Miers 1878 and *Metapenaeus brevicornis* H.Milne Edwards 1837) in Songkhla Lake (Pradit et al. 2021). Due to the lake being an important fishing ground for fishing communities, stationary fishing gear, e.g., the standing trap, is widely used, which impacts sediment and benthic macroinvertebrate assemblages, influencing food chain dynamics and diversity of bivalve species that are usually found in muddy fine sand in the lake (Sinso et al. 2023). Furthermore, due to climate change, Songkhla Lake experiences erratic rainfall patterns; a strong southwest monsoon generates heavy rainfall and severe flooding, affecting fisheries and biodiversity loss in the aquatic ecosystem (Somboonsuke et al. 2018). Recently, due to environmental hazards and intertidal habitat destruction, the mudskipper is one of the species in Songkhla Lake that faces stress and habitat loss.

Several decades ago, mudskippers were common fish around Koh Yoh and Songkhla Lake and were usually found on mudflats during low tide. However, presently, they have disappeared and are hard to find. This evidence concerns the decline in their populations, most likely due to the intertidal habitat modification caused by human activities, reclamation, and pollution. Despite their ecological significance, data on their habitat preferences and ecology are yet to be well understood. Therefore, this study aims to address this critical gap by investigating the preferred habitat characteristics of mudskippers in Songkhla Lake by observing the fish's appearance and relevant environmental factors. Understanding these habitat preferences was useful for protection, conservation, and management to build efficient conservation strategies and preserve their ecological value.

MATERIALS AND METHODS

Study area

Songkhla Lake is located in southern Thailand and consists of four parts: (i) Thale Noi; (ii) Upper Lake; (iii) Middle Lake; and (iv) Lower Lake. This study focuses on Koh Yoh, a small island in the lower part of the lake connected to the Gulf of Thailand. Koh Yoh has an area of 17.95 km^2; it is known for its traditional way of life and its production of pottery, weaving, fruit, and seabass aquaculture. Since the construction of the Tin Su Lanon Bridge in 1986, connecting the island to the Songkhla mainland, significant changes in the community's way of life, physical landscape, and biodiversity affecting mangrove areas were destroyed due to urban development. In 2019, over 80 seawall projects were constructed, ranging from 10 to 400 m, with a total length of over 8,000 m (Marine and Coastal Resources Office (Songkhla), unpublished data). These constructions were implemented to address the issue of coastal erosion. However, these structures have also significantly impacted the local coastal ecosystem. Thus, the six sample sites around Koh Yoh were selected to represent the different habitat characteristics: stations 1 and 2 represent mudflats adjacent to the mangrove area, stations 3 and 4 represent mudflats with seawalls, and stations 5 and 6 represent mudflats with seawalls adjacent to the mangrove area (Figure 1). This area is influenced by southwest or light rainy seasons (May to October) and northeast monsoons or heavy rainy seasons (October to February).

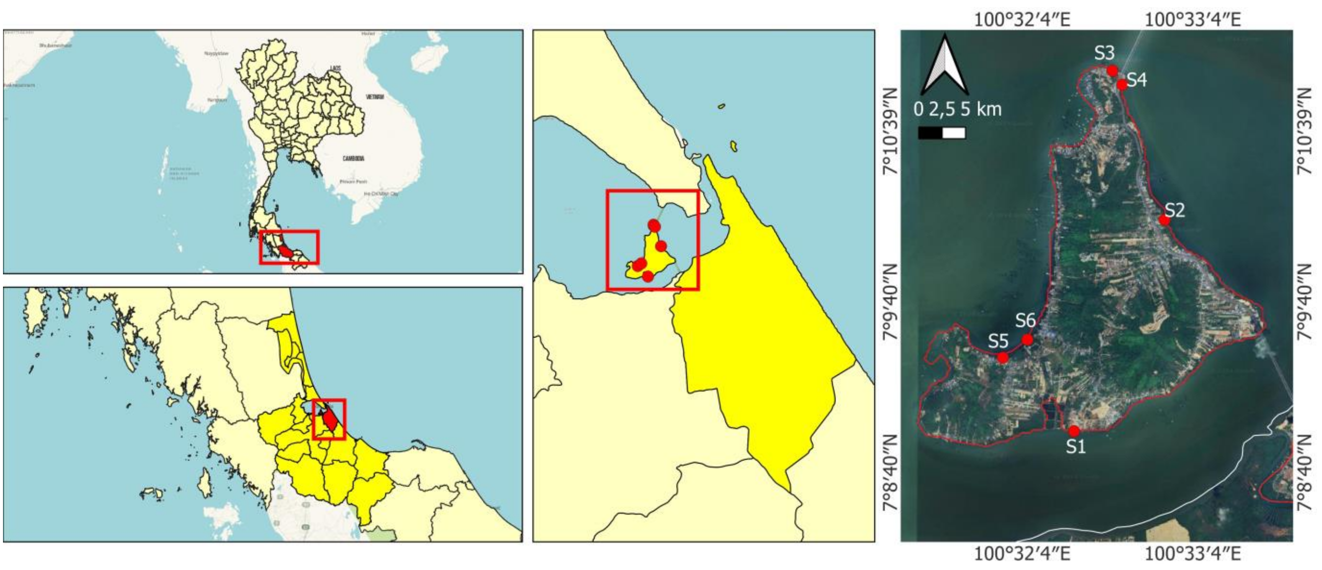

Figure 1. Location of Songkhla Lake, indicating the sampling sites of mudskippers: station 1 (7° 8'54.62"N, 100°32'22.28"E), station 2 (7°10'8.20"N, 100°32'53.83"E), station 3 (7°11'0.12"N, 100°32'35.64"E), station 4 (7°10'55.18"N, 100°32'39.10"E), station 5 (7° 9'20.61"N, 100°31'57.44"E) and station 6 (7°9'26.50"N, 100°32'6.03"E)

Procedures

Mudskipper sampling and observations

Fish occurrence was observed monthly in the field during the southwest monsoon from August to October 2022. Each observation lasted for four continuous hours during the low tide in an area of 100 m^2 (50 m along the shoreline and 2 m from the shoreline to the water) on mudflats on spring tide days. The observation ended as water began to cover the mudflat. The number of individuals detected was counted. Two samples of mudskipper were randomly collected from each station, with each specimen caught using a fishnet and handled with care before being kept in separated plastic cages for classification and then released back to their habitat after classification. Species identification was conducted in the field according to the description given by Murdy (1989) and Darumas (1997). The external characteristics used for classification include the teeth on the upper jaw, the arrangement and shapes of fins, the number of fin rays and soft fin spines, and the shape of the pelvic fin.

Environmental parameters

The environmental parameters, including pH, salinity, water temperature, and Dissolved Oxygen (DO), were measured using a multiparameter AAQ-Rinko (JFE Advantage). In August, each station used continuous vertical data sampling at 0.5 m/s with a delay of 5 minutes.

Sediment sampling

Five sediment cores were collected from each station using push cores and carried to the laboratory for further analysis. The sediment samples were oven-dried at 60°C for three days and ground to a fine powder. Samples were sieved through a 0.5 mm mesh and dried at 105°C until constant weight was reached. Particle size distribution (%sand, %silt, %clay) was analyzed using a hydrometer method. An online soil calculator using a soil texture triangle was used to determine the soil texture (Agricultural Technology Centre Pvt. Ltd.).

Total organic matter and organic carbon were measured using the standard method by Walkley and Black (1934). Samples were oven-dried at 105°C for 24 hours, then ground and sieved through a 2 mm mesh. The Walkley-Black method estimates soil organic carbon (OC) content by oxidizing organic matter with a potassium dichromate solution ($KCrO_7$) in sulfuric acid (HSO_4).

Data analysis

All data is expressed as mean±standard error. Statistical analysis with a significant level of 95% was used in the calculation. One way analysis of variance and PostHoc Tukey were used to test the significant differences among sites in pH, salinity, water temperature, DO, organic matter, and organic carbon. Pearson correlation was performed to test the relationships among the variables.

RESULTS AND DISCUSSION

Mudskipper

A total of 110 fish were observed in this study. Out of these, 12 fish were randomly selected for classification. One mudskipper species caught in this study was *Periophtalmodon schlosseri* Pallas 1770. *P. schlosseri* at Koh Yoh had a brown body, black stripes on the dorsal trunk starting from the eyes to the tail in a posterior direction, two rows of teeth on the upper jaw, a round head, pelvic fins forming a rounded disk, rays of pelvic fin connected by a membrane, and the first dorsal fin rays were spinous. The pectoral, pelvic, and anal fins are separate (Figure 2).

Across station 1, 2, 3, 5, and 6, the average number of fish observedwere 13±5.0, 13±6.8, 3±2.5, 5±4.0, and 5±4.0 individuals/100 m^2, respectively. Notably, no fish were found at station 4.

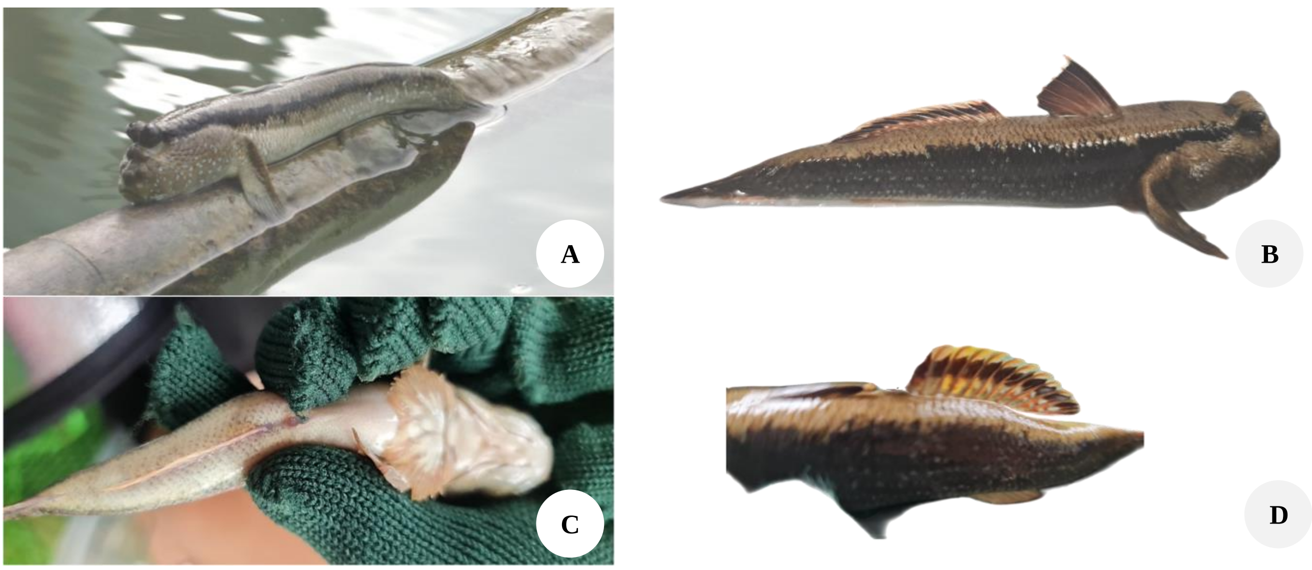

Figure 2. The specimen of A. *P. schlosseri was* caught in this study; B. First dorsal fin; C. Pelvic fin; and D. Second dorsal fin

Environmental parameters

The environmental parameters, including pH, salinity, water temperature, and DO, were significantly different at all stations ($P<0.05$) (Table 1). The pH varied from 7.62 to 8.04, with the maximum observed at station 4 and the minimum at stations 1 and 5. Salinity varied from 25.61 to 30.85 ppt, with the maximum observed at station 4 and the minimum at station 5. Water temperature varied from 29.75 to 32.86°C, with the maximum observed at station 2 and the minimum at station 6. DO varied from 4.48 to 8.14 mg/L. The maximum was observed at station 2, and the minimum was at station 1.

The results show a correlation between mudskipper density and environmental parameters (Figure 3). Mudskipper density and temperature have a moderate positive correlation (R^2=0.32), while the other parameters show a negative correlation. Additionally, the results indicate a moderate negative correlation between pH and mudskipper density (R^2=0.36) and a weak negative correlation between mudskipper density and salinity (R^2=0.25) and DO (R^2=0.07).

Sediment characteristics

The substrate composition at the six sites varied. Station 1 was mostly clay (63.54%), stations 2-4 were mostly sand (71.32, 42.06, 81.93%, respectively), and stations 5-6 were mostly silt (37.75, 41.40%, respectively). The substrate type is shown in Table 1, and all stations have soft substrates ranging from clay to loam.

Organic content

Organic matter and organic carbon in sediment from station 1 were significantly higher than the other sites, followed by stations 6, 5, 3, 2, and 1, respectively ($P<0.05$) (Table 1). A moderate positive correlation was found between organic matter, organic carbon, and mudskipper density with R^2 = 0.48 (Figure 3).

Discussion

This research revealed that the mudskipper found on Koh Yoh was the giant mudskipper *P. schlosseri*, belonging to the genus *Periophthalmodon*. The mudskipper *Periophthalmodon* is a genus of the subfamily Oxudercinae (Gobiidae) (Dinh et al. 2020b) distributed in tropical and subtropical in the Indo-Pacific region, widely from brackish to marine waters and mainly in mangrove forest (Tran and Dinh 2021). Species of *Periophthalmodon* are carnivorous and are known to traverse upriver to areas unaffected by tidal cycles (Dinh et al. 2021). The giant mudskipper is widely recorded in Thailand, Vietnam, Malaysia, and Indonesia. This species is the most abundant mudskipper in the Bang Pu mangrove forest in the Upper Gulf of Thailand (Jittalerk and Babel 2024). In the Mekong Delta, Vietnam, the giant mudskipper is one of the important economical fish species, selling for between 7-12 USD/kg (Tran et al. 2020) and commonly found in brackish water (Mai et al. 2019). It is also commonly found in the estuary of Merauke District (Elviana et al. 2019) and Tanjung Jabang District (Hamidah et al. 2024), Indonesia. This indicates that finding the giant mudskipper in Songkhla Lake should be common.

This research compares three types of habitats in Koh Yoh. The environmental parameters do not depend on microhabitat character but vary by station. The same habitat types show differences in pH, salinity, water temperature, DO, organic matter, and organic content. However, the Pearson correlation shows the significance of the correlation between the environment and the mudskipper density. This study finds that microhabitats with higher temperatures and higher organic matter have more fish than habitats with low temperatures and low organic matter. The giant mudskipper lives in a habitat with a vast difference of environmental parameters: pH from 7.62 to 8.04, salinity from 25.61 to 30.85 ppt, water temperature from 29.75 to 32.86°C, DO from 4.48 to 8.14 mg/L, organic matter from 0.48-11.43%, and organic carbon from 0.28 to 6.64%. In line with Santoso et al. (2020), giant mudskippers can tolerate a very wide range of fluctuations in salinity and temperature. A study of this species in the Mekong Delta also reports different salinity levels in their habitat between dry and wet seasons, which vary from 6.33 to 9.0 ppt (Tran et al. 2020). Another study of giant mudskipper habitats in Tanjung Jabang District, Indonesia, reports environmental conditions including water temperature 31-33°C, soil temperature 28-35°C, salinity 13-15 ppt, water pH 6.8, soil pH 6.2-6.8, and DO 5.9-6.8 mg/L (Hamidah et al. 2024). Meanwhile, a study conducted in the estuary in Merauke, Indonesia, reports a temperature variation of 23-30°C, salinity 20-30 ppt, pH 7.1-8.1, and DO 1.55-2.16 mg/L (Elviana et al. 2019). Moreover, the substrates in the present study were quite similar at all stations: soft substrates (clay and loam). This is consistent with previous findings, indicating that sediment plays an important role in mudskippers' habitat selection. The mudskipper prefers clay and soft mud for burrowing (Kanejiya et al. 2017). The substrate's moisture and softness also affect the burrow's structure, egg deposition, and development (Dinh and Nguyen 2023). The giant mudskipper in Tanjung Jabang District, Indonesia, also lives in soil texture clay and dusty loam (Hamidah et al. 2024), while another study in Thailand found the burrows of giant mudskipper in soft intertidal mud (Jittalerk and Babel 2024). This indicates that the sediment on Koh Yoh is suitable for giant mudskippers since a previous study indicated that clay (muddy) substrate strongly supports mudskippers living in the estuary (Elviana et al. 2019). Although the giant mudskipper can live in a large fluctuation of environmental conditions by biochemical and physiological processes such as increased oxygen uptake rate to respond to a higher temperature or adopting behavioral strategies to minimize their exposure to unfavorable environment temperatures (Nay et al. 2018), they still need a perfect habitat which significantly affects mudskipper distribution which is determined by temperature, salinity, water, pH, DO, and land substrate (Elviana et al. 2019; Dewiyanti et al. 2022). According to Kumaraguru et al. (2020), different mudskippers inhabit different microhabitats, with preference factors such as salinity, temperature, and light.

Furthermore, the comparison between types of microhabitats found that the highest density of giant mudskippers occurs in mudflats adjacent to mangroves, followed by mudflats with a seawall near the mangrove, and finally a mudflat with a seawall without a nearby mangrove, respectively. This result is in line with research conducted in Banda Aceh and Aceh Basar, Indonesia, which found that large mangroves without human activity had the highest density of mudskippers, followed by moderate levels of mangrove near villages and habitats with small amounts of mangroves near communities had the lowest density (Dewiyanti et al. 2022).

Table 1. Environmental conditions of the sampling station

Station	Substrate	pH	Salinity (Ppt)	Temperature (°C)	DO (Mg/L)	OM (%)	OC (%)
1	Clay	7.62±0.03d	27.47±0.40c	30.17±0.02d	4.48±0.45e	11.43±2.00a	6.64±1.18a
2	Sandy loam	8.00±0.01ab	29.32±0.06b	32.86±0.13a	8.14±0.09a	0.82±0.12d	0.48±0.07d
3	Clay loam	7.99±0.02b	30.67±0.04a	30.68±0.02c	6.39±0.21c	1.92±0.08d	1.12±0.04d
4	Sandy loam	8.04±0.02a	30.85±0.10a	31.23±0.05b	7.18±0.19b	0.48±0.03d	0.28±0.01d
5	Clay loam	7.62±0.04d	25.61±0.01d	29.75±0.03f	5.18±0.53d	3.98±0.49c	2.32±0.20c
6	Clay loam	7.87±0.02c	25.85±0.02d	29.84±0.04e	5.32±0.38d	6.61±1.77b	3.84±1.03b

Notes: mean±SD, superscript shows statistical differences at P<0.05

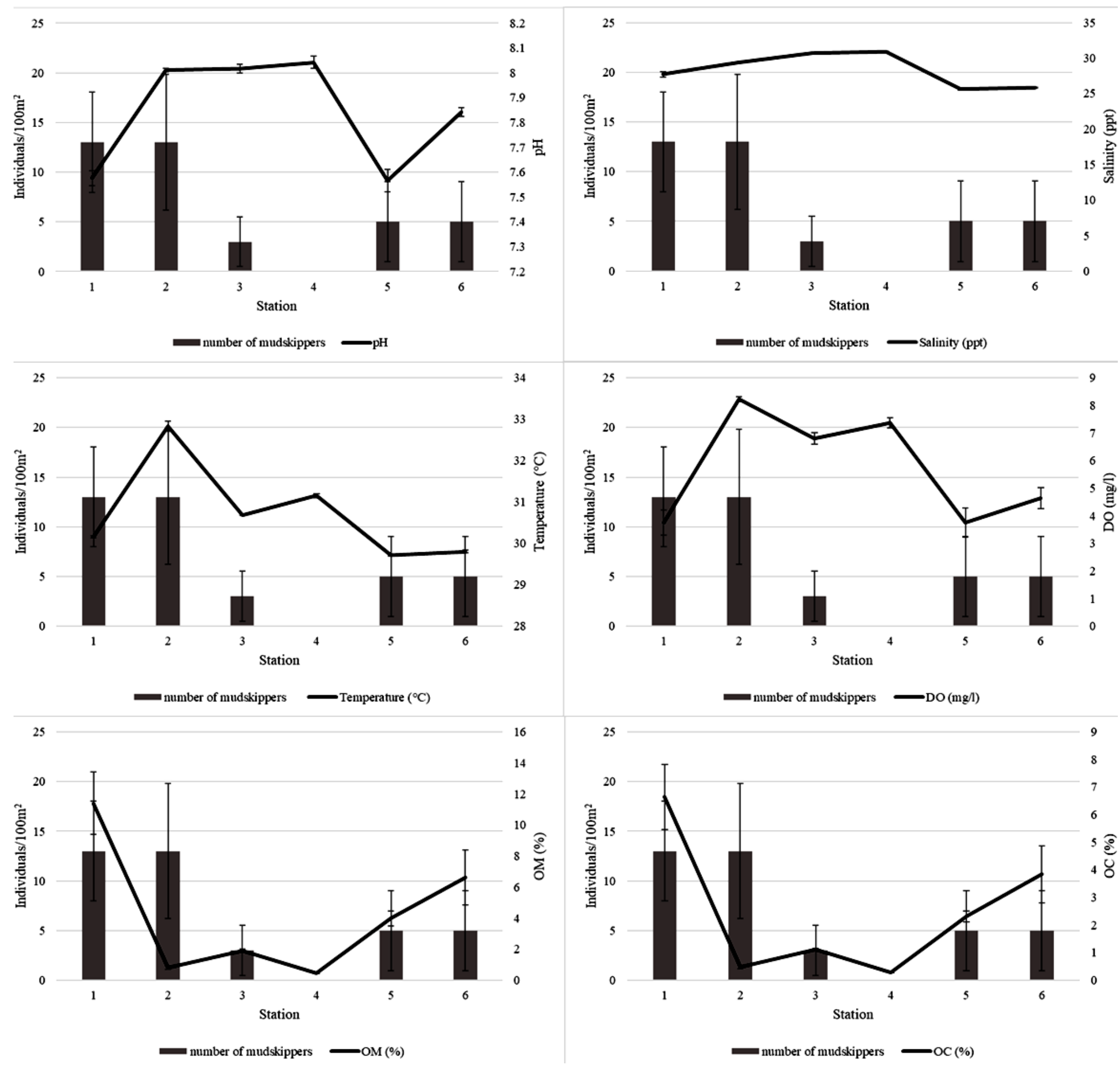

Figure 3. Relation between mudskippers' density and environmental parameters

This finding is similar to Tran et al. (2020) and Jittalerk and Babel (2024), which found burrows of giant mudskippers in soft intertidal mud between mangrove trees or areas beneath trees. The daily behavior of mudskippers is closely related to mangroves. For example, *Periophthalmus gracilis* Eggert 1935 inhabits muddy substrates linked to mangrove vegetation and occupies mangroves as feeding grounds (Dewiyanti et al. 2022). Mangroves are also sheltered, which protects them from predators and coastal hazards. *Periophthalmodon septemradiatus* Hamilton 1822 is typically found to live and burrow in mangrove areas because the plants protect the riverbank from landslides (Dinh et al. 2020a). This study highlights the importance of mangrove conservation for the mudskipper population; the persistence of mangroves is essential to giant mudskippers, and even if that habitat has seawalls, mudskippers can still live there.

Additionally, human activities such as urbanization and development can significantly impact the habitat and population of mudskippers. On Koh Yoh, the construction of the Tin Su Lanon Bridge in 1986 affected the intertidal zone; after the bridge construction, many roads were constructed around the island, which caused coastal erosion. From that part of the issue, many seawalls were established, and mudskippers' habitats were destroyed. In other words, the literature shows that in the past decade, biodiversity in Songkhla Lake has decreased, and the fishery resources have decreased; this may affect the decrease of mudskippers' food, which may result in the decline.

In conclusion, the results of the present study describe the microhabitat of the giant mudskipper, *P. schlosseri*, on Koh Yoh, lower Songkhla LakeThe highest densities were found in mudflats adjacent to mangroves. Conversely, no fish were observed in mudflat areas with seawalls and no mangroves nearby. These highlight the potential importance of mangroves for this species. The giant mudskipper prefers mangrove habitats with soft substrate (clay to loam), high temperature, and high organic matter. Additionally, the present environmental conditions of Koh Yoh continue to support mudskipper life, and none of the environmental parameters in this study appear to limit fish distribution. Due to mudskippers' ecological importance and gradual population decrease, these results provide valuable data for further projects on this species' conservation and management-protection policies. To date, limited data on mudskippers in Songkhla Lake is available. Further research on mudskippers' population structure, growth patterns, and condition factors is required to ensure the species' sustained existence. Comparative studies in other regions and different mudskipper populations should be done to understand better their adaptation and how they respond to different environmental pressures.

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