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Article

Morphometric identification of mudskippers recorded from the Cox's Bazar coast, Bay of Bengal, Bangladesh: Challenges and recommendations

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Abstract: Mudskippers are amphibious fishes that can voluntarily leave the water and spend a considerable amount of time on the mudflats and are considered to have high ecological value in the mudflat environment. The present study was conducted in Cox's Bazar coast to identify the mudskipper species. This study also points out the challenges in the field and provides possible recommendations. The mudskippers were collected from Rezu Khal, Inani, Patuartek, Imamer Dail, Monkhali, Shaplapur, Naf Jetty, Keari Ghat, and Shaporir Dwip during December 2023 to February 2024 by using cast net, thela jhal, scoop net and hand picking. Most of the samples were collected during low tide. A total of 15 mudskippers were recorded in this study and most of the species belong to the genus *Periophthalmus* (8 species) followed by *Boleophthalmus* (2 species), *Periophthalmodon* (2 species), *Pseudapocryptes* (1 species), *Parapocryptes* (1 species), and *Apocryptodon* (1 species). *Boleophthalmus boddarti* was found commonly distributed in all the stations, which is considered edible by a few coastal people and the Rohingya community. The size of this species is considerably bigger than the other recorded species and it can be farmed. Further, an extensive survey is needed to be undertaken in the other parts of Bangladesh coast to document more species and identify the species richness. It can be a possible component of the blue economy.

Keywords: morphometric; identification; mudskipper; mudflats; Cox's Bazar coast

1. Introduction

The ability of mudskippers to move, climb, and "skip" out of water has given them their name. To aid in movement, their sizable pectoral fins have a leg-like form [1–3]. They have independent eye movement and both terrestrial and underwater vision. They are confined to coastal and estuarine areas and are only found in tropical and subtropical climates; their geographic range extends from the Indo-Pacific region to the Atlantic coast of Africa. They are members of the subfamily Oxudercinae, the family Gobiidae [4,5]. There are 40 species and 10 genera in the subfamily Oxudercinae. Typically, they emerge from the water to forage, mate, and evade predators. Their skin allows them to hold onto water for extended periods, allowing them to stay on the ground [6].

Belonging to the Gobie family of fish, they underwent evolution approximately 140 million years ago. *Periophthalmus*, *Periophthalmodon*, *Boleophthalmus*, and *Scartelaos* are the four genera that comprise the approximately thirty species of

mudskippers that are found worldwide [7]. They are amphibious fish in the goby family Oxudercidae subfamily [8–10]. The most varied and common genus of mudskippers is *Periophthalmus*. Among the most common and well-known species is *Periophthalmus argentilineatus*. The distribution of this species extends from the mangrove environments and mudflats of Madagascar and East Africa to the Sundarbans of Bengal, Southeast Asia, Taiwan, the Ryukyus, Northern Australia, Samoa, and Tonga Islands.

Mudskippers usually reside in burrows in the mangrove ecosystems and the intertidal mudflats' habitats [11]. Fish that dig deep tunnels in soft sediments can lay their eggs, avoid being eaten by marine predators during high tide, and control their body temperature. Some species of mudskippers keep an air pocket inside their burrow when it is buried, which enables them to breathe in extremely low-oxygen environments. Small prey includes fish eggs, crabs, insects, sandworms, diatoms, nematodes, polychaetes, algae, and mud/sand particles [12].

They have combinations of morphological and physiological adaptations that enable them to lead amphibian lives [13–15]. Of all the aquatic vertebrates, both extant and in the present, mudskippers are the most specialized to amphibious life, which makes them extremely unique. The ability to breathe through their skin, mouth, and throat, the ability to dig deep burrows in soft sediments that allow them to thermoregulate, the ability to avoid marine predators during high tide when the fish and burrow are submerged, and behavioral and anatomical adaptations that enable them to move effectively both on land and in the water are a few of these [16].

The biological and ecotoxicological studies conducted on mudskippers make them valuable for ecological studies [17]. They are also acknowledged as possible bioindicators in environmental monitoring and evaluations of coastal waters and tropical or subtropical soft-bottom intertidal systems [18]. Because of its food value, it has the potential for aquaculture.

To facilitate and improve fish species identification, the morphological traits of fish, particularly their structural aspects, should be researched [19,20]. One of the most significant conventional types of biological research is morphological variation, which has applications in resource management, evolution, behavior, ecology, and phenotypic plasticity [19,21,22].

There are very few studies on the distribution and diversity of mudskippers in Bangladesh. Rahman et al. [23] studied the feeding habit and length-weight relationship of *Apocryptes bato* (Hamilton, 1822) from the Coast of Chittagong. Rahman et al. [24] studied the population dynamics of *Periophthalmus novemradiatus* from the Bakkhali River estuary. Rahman et al. [25] also studied on reproductive biology of the *Apocryptes bato* collected from the Chittagong coast while Ahamed et al. [26] studied the same but the sample was collected from the Payra River. Siddique et al. [27] studied the heavy metal toxicity of three mudskipper species collected from Hatiya Island. Chakma et al. [28] researched the nutritional compositions of *Apocryptes bato* collected from the Payra River. The present study was conducted to identify the available mudskipper species on the Cox's Bazar coast using morphometric characteristics. The study also emphasizes the challenges during the study and provides recommendations to overcome some of the challenges.

2. Materials and methods

2.1. Study area

This study was conducted in the Teknaf peninsula, Cox's Bazar, Bangladesh. Teknaf Peninsula is one of the longest sandy beach ecosystems (80 km) in the world. There is an 80-kilometer-long road named 'Marine Drive' connecting Cox's Bazar town and Teknaf peninsula. The sample was collected from Rezu Khal, Inani, Patuartek, Imamer Dail, Monkhali, Shaplapur, Naf jetty, Keari ghat and Shaporir Dwip (**Figure 1**). Rezu Khal, Inani, Patuartek, Imamer Dail, Monkhali, and Shaplapur were situated along the Marine Drive Road while Naf jetty, Keari Ghat, and Shaporir Dwip were located far away from Marine Drive Road.

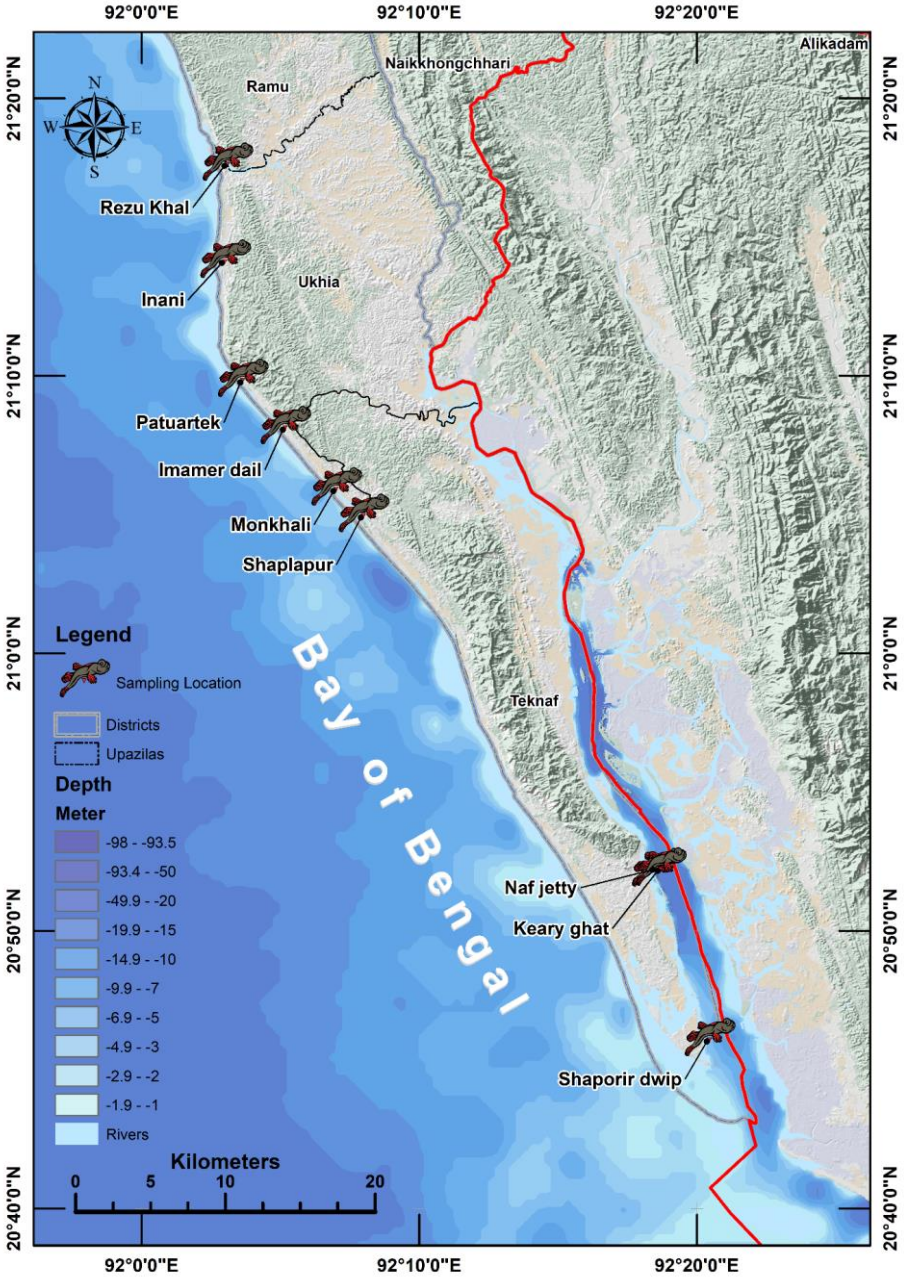

Figure 1. Map showing the study area.

2.2. Field survey findings

Mudskippers typically live in burrows in the environments of intertidal mudflats and mangrove ecosystems. Fish can adjust their body temperature, lay their eggs, and evade being eaten by marine predators during high tide by excavating deep tunnels in soft sediments (**Figure 2**). Certain mudskipper species can breathe in extremely low-oxygen situations because they maintain an air pocket inside their burrow while it is submerged.

Figure 2. Habitat of mudskipper.

2.3. Sample collection and preservation

Sample collected from the study area during December 2023 – February 2024. Cast net, thela jhal, scoop net, and bare hand were used to catch mudskippers (**Figure 3**).

(a) **(b)** **(c)** **(d)**

Figure 3. Different types of catching methods. **(a)** & **(b)** cast net; **(c)** scoop net; **(d)** Thela Jhal.

Catching mudskippers was challenging due to their cunning nature. There were 20–30 small holes in around 50–60 cm area. They were seen to skip above the holes but when we approached them, they quickly hid in the holes (**Figure 4**). Since there were many holes so it was very difficult to find them. We also dig in the mud during low tide to catch. Mudskippers were caught mostly during the low tide.

Figure 4. Holes in mud as habitat of mudskippers.

After collection, we kept the mudskippers in the plastic jar containing water. Then the samples were preserved with 10% formalin and brought to the Biological Oceanography Division of Bangladesh Oceanographic Research Institute.

2.4. Identification

Photographs were taken of each collected sample for identification. Mudskippers were identified using morphometric characteristics. The mudskippers were identified following the websites (http://www.mudskipper.it/, https://www.fishbase.se/ and https://www.marinespecies.org/). Articles, books, and conference papers were also used to identify the species.

3. Results and discussion

In the present study, a total of 15 mudskipper species have been identified from the study area and the description of the identified species has been described as comprising their salient features.

Classification and characteristics of identified mudskippers

1) *Boleophthalmus boddarti*

Classification

Phylum: Chordata

Class: Actinopterygii

Order: Perciformes

Family: Gobiidae

Genus: *Boleophthalmus*

Species: *B. boddarti*

Key characteristics

(1) Color of the ground black lines and black dots on the body and fins; dorsally and laterally, brown to greenish; ventrally, whitish to grey; and darker behind the head and the anus (**Figure 5**);

(2) Google's eyes appeared over its head;

(3) There is a lengthy spine extending from the fin border of the first dorsal fin;

(4) Pectoral fin muscle base with many sporadic whitish to bluish speckles; pelvic fins partially pigmented dorsally, whitish and pigmented ventrally proximally.

Figure 5. *Boleophthalmus boddarti*.

2) *Boleophthalmus birdsongi*

Classification

Phylum: Chordata

Class: Actinopterygii

Order: Perciformes

Family: Gobiidae

Genus: *Boleophthalmus*

Species: *B. birdsongi*

Key characteristics

- Greyish black to brown ground color; ventrally and below the midline, whitish to grey;
- There may be an uneven, alternating pattern on the head and nape, but never below the lateral midline;
- Numerous tiny white dots are dispersed throughout the gill cover, cheek, and muscular part of the pectoral fins; some are found on the trunk (**Figure 6**);
- Not always visible are blotches and a dark lateral stripe on the dorsum;
- Much thicker head and dorsum epidermis, protected by dermal papillae and a rectangular piece of cartilage that spans the pelvic girdle's width.

Figure 6. *Boleophthalmus birdsongi*.

3) *Periophthalmodon schlosseri*
Classification
Phylum: Chordata
Class: Actinopterygii
Order: Perciformes
Family: Gobiidae
Genus: *Periophthalmodon*
Species: *P. schlosseri*

Figure 7. *Periophthalmodon schlosseri*.

Key characteristics

- There is a longer lower jaw and two rows of teeth in the upper jaw;
- It is even yellow or buff, with spots of blue on the flanks;

- A wide, uninterrupted black longitudinal stripe that starts at the rear edge of the eye and extends to the caudal base on each side of the body (**Figure 7**);
- A thin, black line runs from the eye to the caudal peduncle;
- Prominent pelvic frenum and fully fused pelvic fins; dorsal fins never contiguous.

4) *Periophthalmodon septemradiatus*

Classification

Phylum: Chordata

Class: Actinopterygii

Order: Perciformes

Family: Gobiidae

Genus: *Periophthalmodon*

Species: *P. septemradiatus*

Figure 8. *Periophthalmodon septemradiatus*.

Key characteristics

- Specimens that have just died had dusky grey heads, brown dorsum, white ventrum, and a large number of light red and pastel blue markings on the opercle, trunk, and snout (**Figure 8**);
- Pelvic fins fully separated, no pelvic frenum;
- The isthmus is fully scaled, but the nose is scaleless; the body is covered in massive, cycloid scales;
- Upper jaw teeth are arranged in two rows: smaller canine teeth in the inner row and smaller anterior teeth in the outer row;
- Only a few species have the dusky stripe and black dots on their bodies.

5) *Periophthalmus walailakae*

Classification

Phylum: Chordata

Class: Teleostei

Order: Gobiiformes

Family: Gobiidae

Genus: *Periophthalmus*
Species: *P. walailakae*
Key characteristics

- Brownish-dorsal and laterally, with a lot of erratic white or yellow spots on the cheeks, opercula, and flanks (**Figure 9**);
- One row of teeth on the upper jaw; the ventral head and the isthmus are white;
- Erratic patches of blackish color and broken saddle-shaped bars on the flanks and dorsum;
- Many dark-brown speckles running down the rays are present on the caudal and pectoral fin parts;
- Pelvic fins, ventrally white, dorsally pale brown; anal fin, white.

Figure 9. *Periophthalmus walailakae*.

6) *Periophthalmus darwini*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. darwini*
Key characteristics

- Dark brown lines and patches on the back of the head (**Figure 10**);
- Except for a somewhat darker base and a narrow whitish edge, the simple blackish first dorsal fin is sharply pointed and has a distinct fraenum;
- Transparent second dorsal fin with a wide black band along the submarginal edge and a row of black dots or blotches near the base of the fin;
- The pelvic fins are white or slightly speckled; the caudal fin is greyish with a row of brown spots running along its rays; the anal fin lacks melanophores.

Figure 10. *Periophthalmus darwini*.

7) *Periophthalmus argentilineatus*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. argentilineatus*
Key characteristics

- Ground hue ventrally pale to dusky, dorsally and laterally grey to dark brown (**Figure 11**);
- The ventral part of the sides is more likely to have vertical silvery stripes, and the dorsal banded pattern is usually dark and uneven. Three to eight dorsal dark brown saddle-like irregular bars may be seen;
- Pelvic fins are white ventrally, dusky dorsally, and have a series of dark speckles on the rays of the caudal fin. The white anal fin.

Figure 11. *Periophthalmus argentilineatus*.

8) *Periophthalmus kalolo*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. kalolo*
Key characteristics

- Background color: ventrally paler, light brown to grayish on the head, dorsum, and flanks (**Figure 12**);
- Several white patches on the opercula, cheekbones, and nose;
- 3–6 dark brown to black on the dorsum, extremely erratic diagonal bars that resemble saddles may be seen;
- Pectoral and caudal fins are dark with several black specks on the rays;
- A basal membrane that is roughly half the length of the innermost rays unites the pelvic fins.

Figure 12. *Periophthalmus kalolo*.

9) *Periophthalmus* sp.
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *Periophthalmus* sp.
Key characteristics

- Head in a cylindrical shape; body slender, with a compressed trunk and large eyes devoid of a dermal cup; maxilla with one row of teeth (**Figure 13**);
- Pelvic fin, either absent or present;

- The first dorsal fin is taller than the second;
- Pelvic fins are separated along their whole length, and the innermost pelvic rays are not joined by a basal membrane.

Figure 13. *Periophthalmus* sp.

10) *Periophthalmus malaccensis*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. malaccensis*
Key characteristics

- Grey to dark brown ground color on the flanks and dorsum, lighter ventrally (**Figure 14**);
- Ventrally, tiny, pale speckles may be seen on the head; the dorsal banded pattern may still be present;
- Dorsal fins without a membrane connecting them;
- Large speckles run the length of the rays on the caudal fin; tiny, sky-blue speckles on the head and iridescent, bluish speckles on the flanks;
- Pelvic fins with a conspicuous frenum connecting the two spines and a basal membrane that partially unites them.

Figure 14. *Periophthalmus malaccensis*.

11) *Periophthalmus variabilis*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. variabilis*
Key characteristics

- The color of the ground is whitish to grayish ventrally and light to dark brown dorsally and laterally (**Figure 15**);
- Typically, there are uneven saddle bars and sporadic darker markings on the head and trunk;
- Pelvic fins that are less than half of their length, with a pronounced frenum and inner rays connected by a basal membrane;
- Anal fins are whitish to hyaline, pectoral fins are dusky, pelvic fins are whitish to dusky, and branchiostegal membranes are pigmented. Caudal fin rays are dusky with darker speckles on rays.

Figure 15. *Periophthalmus variabilis*.

12) *Periophthalmus chrysospilos*
Classification
Phylum: Chordata
Class: Teleostei
Order: Gobiiformes
Family: Gobiidae
Genus: *Periophthalmus*
Species: *P. chrysospilos*
Key characteristics

- Grey to tan brown dorsally and laterally, whitish to yellowish ventrally;
- Spots of white can occasionally be seen on the throat and opercula; the posterior region of the body rarely displays a banded pattern (**Figure 16**);
- Noticeable pelvic frenum; pelvic fins completely fused into a disc;
- Dorsal fins are not membrane-connected;
- Pectoral and caudal fins are dark.

Figure 16. *Periophthalmus chrysospilos*.

13) *Pseudapocryptes elongatus*
Classification
Phylum: Chordata
Class: Teleostei

Order: Gobiiformes
Family: Gobiidae
Genus: *Pseudapocryptes*
Species: *P. elongatus*
Key characteristics

- Color of the ground: yellow-brown ventrally, pale brown dorsally;
- Large, persistent dark brown spots and bars on the caudal peduncle and dark brown spots on the head (**Figure 17**);
- Except for the caudal fin, which is primarily transparent, dorsal fins can occasionally retain some dusky patches;
- Caudal fin patterns are often kept;
- The genus is distinguished by a longitudinal scale count of more than 150 scales; the body has very few brown markings.

Figure 17. *Pseudapocryptes elongatus*.

14) *Parapocryptes serperaster*
Classification
Phylum: Chordata
Class: Actinopterygii
Order: Perciformes
Family: Gobiidae
Genus: *Parapocryptes*
Species: *P. serperaster*
Key characteristics

- Greenish-colored ground yellow ventrally, greyish dorsally and laterally, with a darker isthmus and throat (**Figure 18**);
- Five sizable, mid-lateral brown dots are typically discernible;
- Frequently, there are additional five dark brown, saddle-shaped spots on the dorsum;

- The anal fin is hyaline, the caudal fin membrane is black with a yellow dorsal and ventral margin, and the D1 and D2 membranes are yellowish basally, transparent for the remainder, and the elements are green up top;
- Small red dots on the pectoral fin base;
- Yellowish fins proximally with a red ventroposterior edge;
- Yellow pelvic fins.

Figure 18. *Parapocryptes serperaster*.

15) *Apocryptodon* sp.
Classification
Phylum: Chordata
Class: Actinopterygii
Order: Gobiiformes
Family: Oxudercidae
Genus: *Apocryptodon*
Species: *Apocryptodon* sp.
Key characteristics

- Dorsal fin with spines;
- Anal fins 21–23: the final ray is inserted vertically into the second dorsal fin's last ray;
- Medial rays are the longest, ventralmost rays are the shortest, and pectoral fin 17–24;
- Pelvic fin I, 5, and fin of opposing side connected by a membrane; frenum well developed;
- With seven segmented rays on the ventral and dorsal procurrent rays and fifteen branched rays, the caudal fin is slightly elongated (**Figure 19**);
- Largest scales are located posteriorly, smaller scales are implanted on the superior surface of the head. Cycloid scales cover the majority of the body, except the pectoral fin bases, interorbital region, tip of the nose, and ventral surface of the head;

- Gill opening constricted, extending from a position equal to the pectoral fin base's dorsalmost aspect to the pectoral fin base's terminus, just slightly ventral. Wide isthmus;
- A single, discontinuous row of teeth in both jaws; medial bigger and overlapping lower jaw teeth, and 15–30 caninoid teeth with sharply rounded ends in the upper jaw.

Figure 19. *Apocryptodon* sp.

3.1. Challenges

(1) The study area was very difficult to reach due to huge mud. In some places, mud depth was recorded 30–35 cm;
(2) Catching is only feasible during low tide; mudskipper was hardly seen during high tide. So, most of the catches we have to finish within 5–6 hours. The rest of the time we have to struggle with the catch;
(3) They were not seen in high numbers during strong sun;
(4) Mudskipper was found to be very clever, so it was very hard to catch them. They hide in the holes instantly when they feel something unusual;
(5) There were recorded 20–30 small holes in around 50–60 cm area. They were seen to skip above the holes but when we approached them, they quickly hid in the holes;
(6) In mangrove areas, it is very hard to catch them since there are many holes and a lot of mangrove trees;
(7) There was occurrence variation in terms of month, species found in one month while that was not seen in the next month in the same place;
(8) Instant photography in the field was a difficult task;
(9) Ice preservation is good for photography but it was difficult to manage;
(10) The specimen's color was faded due to formalin preservation which made it difficult to take good photos for identification.

3.2. Recommendations

(1) The study should be seasonal or monthly to know the exact species available in the study area;
(2) Enough budget (funding) is needed to conduct the study;
(3) The study should be conducted in other coastal areas where mud and mangroves are available;
(4) Since they have nutritional value (from the literature study), few species should be brought under indoor culture on a pilot basis.

4. Conclusion

Mudskippers are not particularly important economically, but they are important bio-indicators of coastal water ecosystems. Their importance as bio-indicators to identify and assess changes in the coastal environment stems from a few distinct physiological and behavioral changes. They are superior in nutritional values such as protein, lipid quality, vital amino acids, and minerals. They are essential to achieve dietary needs and enhance human health. They are less common in Bangladesh, even though several species are consumed by the locals and Rohingya communities. They can satisfy the coastal population's need for protein and be a valuable part of the blue economy. Further investigation is required to determine the identity, species richness, diet, and toxicity of mudskippers. Additional research on the management, conservation, and seasonal fluctuations in the diversity of mudskippers in Bangladesh has been advocated. The findings of the present study will help a useful understanding of the morphological variability of the mudskipper species in the identification process as it aids the segregation of the species.

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