Journal of Threatened Taxa

Building evidence for conservation globally

www.threatenedtaxa.org

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

Review

A review about fish walking on land

Arumugam Kumaraguru, Rosette Celsiya Mary & Vijayaraghavalu Saisaraswathi

26 December 2020 | Vol. 12 | No. 17 | Pages: 17276–17286
DOI: 10.11609/jott.6243.12.17.17276-17286

Journal of Threatened Taxa | www.threatenedtaxa.org | 26 December 2020 | 12(17): 17276–17286
ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)
DOI: https://doi.org/10.11609/jott.6243.12.17.17276-17286
#6243 | Received 29 May 2020 | Final received 10 November 2020 | Finally accepted 02 December 2020
PLATINUM OPEN ACCESS

REVIEW

A review about fish walking on land

Arumugam Kumaraguru [1], Rosette Celsiya Mary [2] & Vijayaraghavalu Saisaraswathi [3]

[1] Honorary Wildlife Warden, Thiruvarur Forest Division, Tamil Nadu Forest Department, Tamil Nadu 620021, India.
[1] Biodiversity Conservation Foundation, #360, Indira Gandhi Street, KK.Nagar, Trichy, Tamil Nadu 620021, India.
[2] Nature Club, [2,3] School of Advanced Sciences, Vellore Institute of Technology University, Vellore, Tamil Nadu 632007, India.
[1] tiger.kguru@gmail.com, [2] rosetconserve@gmail.com, [3] sainaturevit@gmail.com (corresponding author)

Abstract: Mudskippers are amphibious species inhabiting semi-terrestrial ecosystems like mudflats, mangroves, marshy swamps, intertidal regions, and estuaries. Around 34 diversified species are found across the globe. Mudskipper belongs to the Oxudercidae family and the subfamily is Oxudercinae. The occurrence of species is vastly found across the Indo-West Pacific region, the tropical western coast of Africa and in the Indian Ocean. Mudskippers are known for being the biological indicator and also an indicator of estuarine safety monitoring. They are used by people for prey-catching baits. This review paper explains the ecological indicators, taxonomy, species diversity, habitat, behavioural pattern, respiration & kinematics, feeding ecology, reproduction, nutrition content & its medicinal value, and threats to mudskippers.

Keywords: Amphibious fish, distribution, ecological indicator, mudskippers, species diversity.

பரவெட்டிமீன்(மட்ஸ்கிப்பர்(கள்) (Mudskipper) நிலநீர் வாழிகள் வகுப்பைச்சார்ந்த, சேற்று திட்டுகள், சதுப்புநிலங்கள், அலைஏற்ற பகுதிகள், ஆற்று முகத்துவாரம் மற்றும் கழிநிலங்கள் போன்ற பகுதிகளை வாழ்விடமாக கொண்டவை. ஏறக்குறைய 34 பன்முகப்பட்ட பரவெட்டிமீன் இனங்கள் உலகில் காணப்படுகின்றன. பரவெட்டிமீன்/மட்ஸ்கிப்பர்கள் ஆக்ஸுடெர்சிடே கோபிடே (Oxudercidae Gobiidae) குடும்பத்தை சேர்ந்தவை. இந்தோ-மேற்கு பசிபிக் பகுதி, ஆப்பிரிக்காவின் வெப்பமண்டல மேற்கு கடற்கரை மற்றும் இந்தியப் பெருங்கடலில் இந்த உயிரினங்களின் நிகழ்வு பரவலாகக் காணப்படுகிறது. பரவெட்டிமீன் உயிரியல் குறிகாட்டியாகவும், ஆற்று முகத்துவாரம்களின் பாதுகாப்பு கண்காணிப்பின் குறிகாட்டியாகவும் அறியப்படுகின்றன. மனிதர்களின் பயன்பாட்டிற்கு பெரிதும் உபயோகபடாததால், இவை பெரும்பாலும் இரையை பிடிக்கும் தூண்டிலில் பயன்படுத்தப்படுகின்றன. இந்த ஆய்வுக் கட்டுரை, சுற்றுச்சூழல் குறிகாட்டிகள், வகைபிரித்தல், இனங்களின் பன்முகத்தன்மை, வாழ்விடம், நடத்தை முறை, சுவாசம் மற்றும் இயக்கவியல், உணவு சூழலியல், இனப்பெருக்கம், ஊட்டச்சத்து தரவுகள், அதன் மருத்துவ மதிப்பு மற்றும் அபாயங்கள் ஆகியவற்றை விளக்குகிறது.

Editor: A. Biju Kumar, University of Kerala, Thiruvananthapuram, India.

Date of publication: 26 December 2020 (online & print)

Citation: Kumaraguru, A., R.C. Mary & V. Saisaraswathi (2020). A review about fish walking on land. *Journal of Threatened Taxa* 12(17): 17276–17286. https://doi.org/10.11609/jott.6243.12.17.17276-17286

Funding: None.

Competing interests: The authors declare no competing interests.

Author details: Dr. A. Kumaraguru is working as conservation scientist specialized in wildlife biology and genetic studies on tiger. Ms. Rosette is currently doing her MSc in biotechnology and her research interests include marine biology, biodiversity and conservation, phytochemical studies, molecular docking. Dr. V. Sai Saraswathi is an expert in environmental sciences, working for the conservation of biodiversity, climate change, ethnobotany, pharmacognosy, and phytochemistry.

Author contribution: In this review paper, VS contributed in the literature review collection, paper editing, proof reading. ER collected literature review, paper drafting. AK prepared the review design, proof reading and editing. All authors were involved in the mansuscript revision.

INTRODUCTION

Osche (1962) suggested that mudskippers would be useful for interpreting the transition of species from water to land. There is some evidence about the transition of fishes to tetrapods, which occurred more than 360 million years ago (Ulrich & Elliott 2013). There are about 40 species classified under 10 genera. Mudskippers predominantly inhabit the mangrove forest and mudflats of the Indo-West Pacific region, the tropical western coast of Africa, and Indian Ocean coastlines. Mudskippers are known to be burrow dwellers preferring the swampy marshes, estuaries, and the intertidal regions for their living (Murdy 1989). The feeding ecology of the Mudskipper *Periophthalmus barbarous* was found to be 'opportunistic feeders' meant to be satisfying the food needs with the available resources (Chukwu & Deekae 2013). Generally, mudskippers feed on algae, detritus, diatoms, nematode, polychaetes and eggs of fishes, along with mud and sand particles (Ravi 2013).

Since long ago, researchers have explored mudskipper's distribution pattern, species diversity, behavioural patterns and their locomotory activities. In 1989, Murdy studied the morphological features of mudskippers, which paved the way for taxonomic classification of mudskippers. Also, he hypothesized the relationship of *Oxudericnae* gobies with other genera and groups. Mudskipper's early developmental age & growth, respiratory & circulatory adaptations, and feeding ecology were also studied by many researchers across the globe (Jaafar & Murdy 2017).

Due to the medicinal properties found in mudskippers, it gains commercial value either through food consumption or as traditional medicine by humans (Kanejiya et al. 2017a). Sometimes they are even used as bait for catching prey (Gadhavi et al. 2017). A few of the vernacular names used in different places for referring to mudskippers are *Periophthalmus darwini*, *Periophthalmus* sp., and *Periophthalmus novaeguineaensis* as sakomo, *Periophthalmus* as nebesokera, *Periophthalmus weberi* as paraguamo, *Periophthalmodon freycineti* as genora, *Boleophthalmus caeruleomaculatus* as ebanea, *Boleophthalmus* sp. as poti, *Scarpellos histophorus* as seekakowea, *Oxuderces wirzi* as canipo (Polgar & Lim 2011). Mudskippers are known as 'vaetti uluvai' in Tamil (Ragunathan 2010).

Ecological Indicator

Monitoring the intertidal and estuarine health depending on their abundance mudskippers have direct affection towards salinity and temperature variations (Kanejiya et al. 2017c). They also contribute towards the growth of mangrove trees, when the population of mudskippers is abundant, consequently providing appropriate nutrients supporting the growth of mangroves (Shenoy et al. 2012).

Polgar (2009) attempted the studies of Malayan mudskippers as a biomonitor in mangroves concerning species area relationship (SAR) and revealed that the destruction of habitats resulted from reduced species abundance. Mudskippers bioaccumulate pollutants through ingestion as they tend to be prey for many mudflat species. Mudskippers ensure the coastal, intertidal, and estuary's health (Polgar & Lim 2011). Studies have shown that mudskippers act as a biological indicator of addressing the severity of oil pollution in the coastal areas of the Persian Gulf. Biomarker responses of *Periophthalmus waltoni* were recorded and discovered that it acts as the ideal candidate for bioindicator in the coastal regions and mudflats. Correspondingly, it can be utilized for achieving sustainable development (Shirani et al. 2012).

Similarly, at Kuwait Bay, *Periophthalmus waltoni* acts as a bioindicator in identifying the bioaccumulation of metals (Bu-Olayan & Thomas 2008). It tends to be a feeble indicator at the Persian Gulf marine ecosystem, a biomonitor candidate-Boleophthalmus dussumieri used in the monitoring of polycyclic aromatic compounds (PAH). It might be various other environmental factors which are acting in that ecosystem leading *B. dussumieri* to be helpless (Sinaei & Mashinchian 2014). Metal toxicity and accumulation of metal toxicants like Zn, Cd, Pb, Cu have suggested that mudskippers are an ideal biomonitor. It was observed that their fins and liver are the biomonitors and accumulate metal toxins. Due to the contaminants of various metal pollutant, it is not recommended for human consumptions (Ikram et al. 2010).

Taxonomy

Mudskippers belong to the family Oxudercidae and the subfamily *Oxudercinae*. Some of the species are tabulated in Table 1 and Image 1.

Species Diversity

Globally, 34 diverse species of mudskippers were recognized, and among them, nine were found in Indian coastlines (Murdy et al. 1989). Nearly five diversified mudskipper species have been effectively documented from Gujarat coastlines (Devendra et al. 2016). In the southeastern coast of India, mudskippers were recorded

Table 1. Taxonomic rank, genus, and species of mudskippers around the world with reference to various authors belonging to different periods.

	Tribe (taxonomic rank)	Genus	Species	References
1	*Oxudercini*	Parapocryptes	*Parapocryptes rictuosus*, *Parapocryptes serperaster*	Valenciennes 1846
2	*Oxudercini*	Apocryptodon	*Apocryptodon madurensis*, *Apocryptodon punctatus*	Tomiyama 1934
4	*Oxudercini*	Oxuderces	*Oxuderces dentatus*, *Oxuderces wirzi*	Koumans 1938
5	*Periophthalmini*	Apocryptes	*Apocryptes bato*	Hamilton 1822
6	*Periophthalmini*	Pseudapocryptes	*Pseudapocryptes borneensis*, *Pseudapocryptes lanceolatus*	Bloch & Schneider 1801
7	*Periophthalmini*	Zappa	*Zappa confluentus*	Roberts 1978
8	*Periophthalmini*	Scartelaos	*Scartelaos cantoris*, *Scartelaos gigas*, *Scartelaos histophorus*, *Scartelaos tenuis*	Chu & Wu 1963
9	*Periophthalmini*	Boleophthalmus	*Boleophthalmus hirdsongi*, *Boleophthalmus boddarti*, *Boleophthalmus caeruleomaculatus*, *Boleophthalmus dussumieri*, *Boleophthalmus pectinirostris*,	Pallas 1772
10	*Periophthalmini*	Periophthalmodon	*Periophthalmodon freycineti*, *Periophthalmodon schlosseri*, *Periophthalmodon septemradiatus*,	Valenciennes 1846; Pallas 1772 Hamilton 1822
11	*Periophthalmini*	Periophthalmus	*Periophthalmus argentilineatus*, *Periophthalmus harbarus*, *Periophthalmus chrysospilos*, *Periophthalmus gracilis*, *Periophthalmus kalolo*, *Periophthalmus malaccensis*, *Periophthalmus minutus*, *Periophthalmus modestus*, *Periophthalmus novaeguineaensis*, *Periophthalmus novemradiatus*, *Periophthalmus waltoni*, *Periophthalmus weberi*	Valenciennes 1846 Hamilton 1822

most during the post-monsoon season, and their preferred habitats are estuarine lands and mangrove areas. A group of eight species from the Malay Peninsula and 12 species from Sumatra is present along the Straits of Malacca (Takita & Ali 1999). Earlier, there were nine species of mudskippers recorded in peninsular Malaysia (Polgar 2009). Recent studies have updated the total count to 17 in peninsular Malaysia (Khaironizam & Rashid 2005). Nineteen species have been recorded recently in the Ramsar site, Johor, Malaysia (Hui et al. 2019). Some of the mudskipper species found in Merauke District, Indonesia are *Boleophthalmus boddarti, B. pectinirostris, P. takita, P. argentilineatus, Scartelaos histophorus,* and *Oxuderces dentatus* (Elviana et al. 2019). *Periophthalmus waltoni* is maximally distributed along the Persian Gulf though there are many threats to its population density (Sharifian et al. 2018). Though there is a diverse population of *Periophthalmus barbarus* around southeastern Nigeria, it is affected by overexploitation (Abiaobo & Udo 2017). People do not consume *Periophthalmus novemradiatus* as a result of which their growth rate is rapidly increasing along the Bakkhali River Estuary, Bangladesh (Rahman et al. 2015). Complete phylogeographic studies of *Periophthalmus* distributed along Indo-Pacific region helped to understand its evolutionary history (Polgar et al. 2014). *Periophthalmus spilotus*, a new species of mudskipper, was identified from Sumatra, Indonesia (Murdy & Takita 1999). Similarly, a new species *Parapocryptes serperaster* has been recorded in peninsular Malaysia (Khaironizam & Rashid 2000). *Periophthalmus walailakae* has been recorded in southeastern India (Mahadevan et al. 2019a). There were about 24 newly recorded species during the recent studies in Indonesian waters (Pormansyah et al. 2019).

Living Habitat

Mudskippers inhabit riparian areas with soft and muddy plains. Also, they inhabit where the salinity level is found to be low and the place rich with benthic invertebrates (Baeck et al. 2008). Numerous species were living on the rocky coastline as much, as they occupy mudflats, mangroves, and sand flats (Gordon et al. 1968). Rehabilitating the coastal region with mangrove

Image 1. Blue-spotted Mudskipper *Boleophthalmus boddarti*. © A. Kumaraguru

saplings gives a better habitat for various species, and it was observed that large-sized mudskippers were found in the breakwater (sheltered area for mangroves) (Hashim et al. 2010). *Pseudapocryptes elongatus* is able to tolerate the salinity, and hence it survives in the open sea, coastal mangroves and inland habitat during different stages of their growth (Bucholtz et al. 2009). Mudskippers alter the environmental conditions improving the growth of young mangroves as they mix the soil with detritus (Ravi et al. 2013). Studies related to the microhabitat selection of Chinese mudskippers identified their preferences, such as salinity levels, land or water; water and air temperatures; light or dark; and various combinations among them were conveyed (Gordon et al. 1985). The major threats to the mudflats are soil erosion, macro algae, terrestrialization, and lack of estuarine water, human interference, and discharge of effluents (Ravi 2012). *Periophthalmodon septemradiatus* species is found to be the first species inhabiting and breeding from a saline environment to a completely fresh water region of the Mekong River (Mai et al. 2019). *Boleophthalmus pectinirostris* has shown behavioural preferences in choosing their microhabitat at their early juvenile stage (Chen et al. 2008). To determine the habitat selection, genomic studies were performed, and also the comparative analysis among different species were conducted (Cai 1996). Different mudskippers inhabit different microhabitats and have different burrow construction methods (Clayton 1993). Habitat selection is dependent on its ecological interactions (Polgar & Crosa 2009). Some species such as *Periophthalmodon septemradiatus* is found to survive in habitats with low salinity and far from the sea, whereas *B. boddarti* survives close to the sea with high salinity (Khaironiazam & Rashid 2003). Mudskippers preferred thick mudflat areas for carrying out their burrowing activity effortlessly (Kanejiya et al. 2017c). Burrows constructed by *Bolephthalmus boddartti* are classified as follows: burrows with single apertures represent newly constructed one, and the other single and double

openings ones currently exist. In contrast, the burrows with multiple apertures represent collapsed ones due to human interventions (Ravi et al. 2004).

Behavioral pattern of mudskipper

Population density is inversely proportional to the growth rate as the availability of food decreases due to an increased population. *Boleophthalmus pectinirostris* (Blue-spotted Mudskipper) is found to have the longest lifespan; seven and six years in males and females, respectively (Nanami & Takegaki 2005). A study on the terrestrial life of mudskippers with *Periophthalmus sobrinus* showed their survival capacity out of water is one and a half days. Surprisingly, there was no affection in metabolic and heart rates as well as the lactic acid concentration in blood during their living out of the water (Gordon et al. 1969). Whereas Chinese Mudskipper *Periophthalmus cantonensis* survives for two and a half days out of the water and observed medium sensitiveness of metabolism towards temperature. Starvation for 9.5 days did not affect the excretion of ammonia but affected excretion of urea (Gordon et al. 1978).

Boleophthalmus dussumieri has separate exit and entry for males and females. Juveniles pierce deep into mud during high tides. Adults neglect to build chimneys surrounding their holes as the consistency of the soil is between sand and clay (Rathod et al. 2019). Mudskippers growth rate is affected when being exposed to pollution at the embryonic stage (Kruitwagen et al. 2006). There is a significant role played by aquaporins (integral membrane proteins) for adapting themselves to the terrestrial lifestyle. The selective changes, like pore formation and substrate selection, have a substantial contribution to their adaptation to an amphibious lifestyle (Lorente-Martinez et al. 2018). The species *Periophthalmodon schlosseri* is found to be an ideal species for aquaculture and more mudskipper studies (Quang 2016). Mudskippers like *Boleophthalmus boddarti* constructs mud-walls, for territorial exclusion or spacing, territory, and reduces hostility. This is based on their abundance. These regional behavioural patterns give better knowledge about the elastic disc concept of territories (Clayton 1987). Mudflats are vital for the survival of mudskippers but global warming is a serious threat as the mudflats are greatly affected due to high temperature. Spawning season in *Scartelaos gigas* is from May to July. The growth rate is dependent on diet, water temperature, and mudflat exposure (Park et al. 2002).

Some mudskipper species tend to be more comfortable with a terrestrial lifestyle rather than an aquatic lifestyle. One among them is *Periophthalmodon schlosseri*, which has gill arrangements which are highly adaptable for air-breathing, and they spend less time in marine habitats (Takeda et al. 1999). *Boleophthalmus boddarti* builds mud walls for two significant reasons: to avoid hostility between neighbours and as assistance for feeding. Diatoms are the most preferred food for mudskippers. They prefer feeding on mud slopes as a measure of preventing intervention by their neighbours (Clayton & Wright 1989). *Periophthalmus sobrinus* prefers to live unaccompanied and rarely lives within closed groups. There were large spacings between nests and dark places were preferred for foraging (Gordon et al. 1968). The growth rates and life duration of both the sexes of *Pseudapocryptes elongatus* obtained from Sundarbans, India is four-plus years for both the sexes as the maximum age. Their growth index (Φ) is 4.394 (males) and 4.503 (females) possessing larger caudal fins (Mahadevan et al. 2019c).

The reason for aggressiveness in *Periophthalmus modestus* is the hypothalamic hormone, arginine-vasotocin (VT) (Nao et al. 2013). The foraging behaviours in *Periophthalmus waltoni* are not influenced by environmental factors. They hunt in the same area as their prey stays inside the burrow for a longer period of time (Clayton & Snowden 2000). The growth of *Bolepthalmus boddarti* has been recorded high during their juvenile period, decreasing in successive years because of maturation and spending their energy in spawning (Ravi & Rajagopal 2007).

Respiration and kinematics

Anatomical characteristics of mudskipper gills decide on adaptations of their habitat and *B. boddarti* is one that shows excellent adaptation to aquatic lifestyle. In comparison, terrestrial adaptations were favoured more at odds with their amphibious lifestyle (Low et al. 1988). Since mudskippers appear to change the way their skin breathes, their epidermis and skin layers have been studied in detail (Beon et al. 2012). They adapt towards terrestrial lifestyle by secreting mucus, and their head containing dense capillary network assists cutaneous respiration (Jie et al. 2003). Studies related to gaseous exchange and their demand for oxygen were done in the intertidal regions (Karen 1993). Ammonia excretion happens in mudskippers (*Periophthalmodon schlosseri*) through their head. Ammonia gets collected in their burrow through the acidification process, preventing them from reverse fluctuation (Randall et al. 2004). Mudskippers maintain the air phases according

to the tide. They can breathe both aquatically and aerially when there is a high tide, while at low tides they transfer air into their burrow for breathing (Lee et al. 2005). Comprehensive research was conducted in *Periophthalmus magnuspinnatus* on cutaneous respiration and its relationship with skin layers (Park 2002). Several mudskippers reported evaporative water loss along with their behavioural adaptations (Dabruzzi et al. 2011). Significant characteristics of gills found in *Periophthalmodon schlosseri*, contribute to their ability to live inland for a longer period of time (Wilson et al. 1999). The modifications and transformations that occur in the gill respiratory vasculatures and the mudskippers of the bucco-opercular cavities were examined using the technique of corrosion casting. This has helped to define their adaptation to an amphibious lifestyle (Gonzales et al. 2011). Histological studies using the paraffin method have studied the ambiguity in the structure of the gills and simultaneously compared their aquatic and terrestrial lifestyles (Supriyati et al. 2019). For their survival, condition-specific biochemical adaptations occurred during hypoxia, where the glycolysis process is modified to provide energy during muscle movements, and lactate is accumulated (Chew & Ip 1992).

Contradictory circumstances occur concerning their adaptations between *Periophthalmodon schlosseri* and *Boleophthalmus boddarti*. Around the same time, *P. schlosseri* tends to be adaptable to a terrestrial lifestyle and is an excellent candidate for aquaculture studies related to air-breathing fish. *B. boddarti*, however, appear as opposed to the earlier one (Kok et al. 1998). Mudskipper is an anomaly that stores pre-entry air inside their burrow and has no metabolism affection. They regularly maintain their air stages and adapt them to their amphibious lifestyle (Ishimatsu et al. 1998). The essential feature of their adaptation to terrestrial life is the presence of dermal bulges, thick middle cell layer and a vascularized epidermis (Zhang et al. 2000). In low tide conditions, the intertidal fishes, like mudskippers, tend to have many options to choose from. Mudskippers either agree to be an aquatic or temporary terrestrial living being (Karen 1995). Mudskipper's locomotion has been experimentally tested using water on gelatin and glass along with the assistance of a system for digital image processing. Wang et al. (2013) discovered through their study that mudskipper uses both body and pectoral fins for movement in the water and on gelatin, whereas they use only pectoral fins for land action. Escapism is a critical behaviour that is required for their survival. A few studies have shown that, during aquatic and terrestrial lifestyles, mudskippers alter their position as escapists (Swanson & Gibb 2004).

Feeding ecology

The mudskipper *Pseudapocryptes dentatus* follows herbivorous feeding patterns. Their main order is Diatoms-Bacillariophyceae, green algae and blue-green algae. Levels in size and metabolism are inversely proportional (Sarker et al. 1980). Both plants and animals were documented while studying the *Periophthalmus barbarous* stomach. This included mainly crabs, fish scales, and insects. We can recognize from this that mud-skippers are opportunistic feeders and are an ideal aquaculture choice (Chukwu & Deekae 2013). As described, their key food items include -diatoms, nematode, polychaetes, fish eggs, algae, detritus, along with particles of mud and sand (Ravi 2013). It has been shown, according to the study conducted with *Periophthalmodon schlosseri*, that there are differential preferences in the selection of food products between male and female. Females preferred small-scale fish, namely *Oryzias* sp., and males over small-scale fiddler crabs because they were highly involved in land activities (Zulkifli et al. 2012).

The *periophthalmus sobrinus* feeds on small animals. Their food sources are polychaetes, polydora, terebellid, nematodes, crustaceans, copepods, tanaids, prawns, schizopod larvae, alpheid shrimp juveniles, *Uca chlorophthalmus*, and tiny sand crab (Stebbins & Kalk 1961). The discerned food items of *Periophthalmus waltoni* are crustaceans (high occurrence), snails (slightly lower occurrence), 3.4% insects (lower appearance), and fishes (least) (Mhaisen & Al-maliki 2013). *Boleophthalmus pectinirostris* selects their meal based on the abundance, availability, size of the diatoms and temperature. The size of the species reflects over its feeding apparatus (Yang et al. 2003).

Boleophthalmus boddarti likewise feeds on Bacillariophyta (Quang 2015). The anatomical characteristics in *Periuphthalmus kuelreuteri* are examined by light and X-ray cinematography. It pushes forward with its pelvic fins when the prey gets near, and brings the jaws near to the target. Opercular bones, aid swallowing into the pharynx to position the prey. They found it easy to capture the prey in the land by biting and open mouth. It reaches the stomach via an esophagus after passing the pharyngeal jaws (Sponder & Launder 1981).

Reproduction

Studies were conducted in Nigeria's lagoon swamps, which concentrated primarily on sex ratios, egg

diameters, gonodosomatic index and levels of maturation (Lawson 2010). Reports on the growth of eggs with artificial fertilization and larval reports in the species *Periophthalmus cantonensis* were carried out (Tsuhako et al. 2003). The mudskipper's eggs were laid deep within the burrows where there is a hypoxic environment, and male mudskippers supply the oxygen by depositing oxygen through water. Once the development of the eggs is complete, they are released from the burrows and hatched by tides, making them prepare themselves during severity (Ishimatsu et al. 2007). A research on *Apocryptes bato*'s (Gobiidae) reproductive biology in the Payra River, southern Bangladesh, helped to understand the basics of reproduction in mudskippers (Ferdous et al. 2018). Studies related to reproductive biology, fertilization, maximum sizes achieved along with spawning will allow local fishermen to know the exact time of catching them, rather than disturb them during spawning seasons. The concept was prominent from the studies of sex maturation of *Boleophthalmus boddarti* (Quang et al. 2015). The species *Periophthalmodon septemradiatus* lays eggs year-round. Observing their complete duration during the maturation stages helped to understand reproductive biology and to learn about the methods of conservation (Dinh et al. 2018). Studies at intertidal swamps of the Imo River estuary dealt about the reproductive biology of *Periophthalmus barbarous* along with growth, mortality, recruitment pattern, gonadosomatic index, and spawning season (Etim et al. 2002).

Studies on nutrition content and medicinal value

Nutrient content of three species *Periophthalmus waltoni*, *Boleophthalmus dussumieri*, and *Scartelaos histophorus* were measured, such as starch, protein, and lipid. *Boleophthalmus dussumieri* is rich in nutrients and it comes from the liver. Because of this adventitious effect, people consume them in the Bhavnagar coast, Gujarat (Kanejiya et al. 2017a). Mudskippers are known to be very rich in proteins and other nutrients. They are either used in traditional medicines in countries like Malaysia or as bait and also utilized for consumption. During winter, mudskippers are caught and sold at the market by fishermen using net trap methods (Kanejiya et al. 2017b). Likewise, there are growing demands for mudskippers at Narmada estuary, Gujarat, and they are favoured by local people. As a result of this, the ecosystem can get highly exploited and can impact biodiversity (Bhakta et al. 2018). Though mudskipper meat possess nutritional benefits there are researchers stating about metal toxicity and bioaccumulation when consumed.

The research by Looi et al. (2016) concluded that the bioaccumulation of mercury in *Periophthalmodon schlosseri* did not cause any serious effects when consumed. From the evaluation of the nutrient content of *Pseudapocryptes elongatus*, it has been shown to contain sufficient protein, carbohydrate, lipid, important and non-essential amino acids, polyunsaturated fatty acid (PFA) with a greater amount than saturated fatty acid (SFA). For consumption it is highly recommended because of its nutritive value (Mahadevan et al. 2019b). Mudskippers are widely available in Nigeria and their prices are comparatively low, and they are consumed by the elderly (Edun et al. 2010). Exposure of mudskipper *Boleophthalmus boddarti* to natural radionuclides (^{238}U, ^{226}Ra and ^{210}Pb and ^{210}Po), the radionuclide concentration was found to be below the limit and therefore, did not have a profound impact in Bombay Harbour and coastal zone (Bangera & Patel 1984).

Threats to mudskippers

The effect on mudskipper density was recorded in the mudflats of Hathab coast, Gujarat, considering salinity and temperature as independent variables. Accordingly, mudskipper abundance and distribution have become a vital indicator for determining intertidal region health (Kanejiya et al. 2017c). Post-tsunami studies at Mudasolodai, Tamil Nadu, revealed that rapid changes in soil morphology led to changes that directly affected the mudskippers' livelihood. For construction, they usually prefer clay-rich soil, rather than sandy soil (Ravi 2005). Although metal uptakes were increasingly high during lower salinity, the levels of salinity in the intertidal mudskipper *Periophthalmus cantonensis* did not affect the metal (Cd, Se, & Zn) concentration factors (CF) (Ni et al. 2006). Mudskippers face other menaces due to metal toxicity. To illustrate, when exposed to Cr (Vl), *Boleophthalmus dentatus* causes affection in the activity of Na^+ , K^+ and ATPase, and further affects membrane activity, also causing metabolic stress (Kundu et al. 1995). Similarly, the same has also been deduced in other studies pertaining to *Boleophthalmus dentatus* obtained from the Gulf of Katch (Lakshmi et al. 1991). The shrimp effluents collected at the mudskipper habitat in the northern Persian Gulf have proved to support mudskipper enrichment, which helps them increase their species density and length. Despite severe changes and reduced dissolved oxygen, shrimp effluents create favourable physical conditions for their growth; it survived amid these adversities (Kohan et al. 2018). Mudskippers are known for their versatile

behaviour and amphibious character. They have less understanding of the public and have lost interest. The most striking characteristic of them is their survival ability and adaptation to different environmental changes. Surprisingly, mudskippers feed on the available foodstuffs, rather than relying on specific foods. Further research can be done with them as they define themselves as an ideal candidate for aquaculture. Gills' anatomical features are specifically built to suit both the terrestrial and aquatic lifestyles. They got adapted from the initial stages of egg production to adjust to severities such as high tide, and airflow maintenance.

CONCLUSION

Mudskippers are known for their significant behaviour of adapting themselves to different environment and amphibious nature. Mudskippers are less popular among people and aren't noticed much. Their most amazing feature is their capacity to survive and their adaptation to various changes in the environment. Surprisingly, mudskippers feed on the foodstuffs available, rather than rely on particular foodstuffs. Further research can be carried out as they may be an ideal candidate for aquaculture. The anatomical characteristics of gills are designed primarily to accommodate both the terrestrial and aquatic lifestyles. From the initial stages of egg production, they are taught to adjust themselves to severities such as high tide and maintenance of the airflow. The most striking aspect about them is their position in coastal areas as a biological indicator, pollution monitor, and estuarine health monitor.

REFERENCES

Abiaobo, N.O. & M.T. Udo (2017). The population dynamics of the Mudskipper, *Periophthalmus barbarous* (Linneaus, 1766) (Teleostei, Gobiidae) and the implication for conservation and management in the mangrove swamp of Iko River Estuary, southeastern Nigeria. *Journal of Applied Life Sciences International* 14(4): 1–19. https://doi.org/10.9734/JALSI/2017/37007

Baeck, G.W., T. Takita & Y.H. Yoon (2008). Lifestyle of Korean mudskipper *Periophthalmus magnuspinnatus* with reference to a congeneric species *Periophthalmus modestus*. *Ichthyological Research* 55: 43–52.

Bangera, V.S. & B. Patel (1984). Natural radionuclides in sediment and in arcid clam (*Anadara granosa L.*) and gobiid mudskipper (*Boleophthalmus boddaerti* Cuv. and Va.). *Indian Journal of Geo-Marine Sciences* 13(1): 5–9.

Beon, M.S., M.K. Oh, Y.J. Lee, C.H. Kim & J.Y. Park (2012). A comparative study on vascularization and the structure of the epidermis of an amphibious mudskipper fish, *Scartelaos gigas* (Gobiidae, Teleostei), on different parts of the body and the appendages. *Journal of Applied Ichthyology* 29(2): 410–415.

Bhakta, D., W.A. Meetei, G. Vaisakh, S. Kamble, T.N. Chanu & S.K. Das (2018). Mudskipper Fishery and Indigenous Fishing Devices in Narmada Estuary, Gujarat. *Journal of the Indian Society of Coastal Agricultural Research* 36(2): 74–78.

Bloch, M.E. & J.G. Schneider (1801). Systema Ichthyologiae Iconibus CX Illustratum. Post Obitum Auctoris Opus Inchoatum Absolvit, Correxit, Interpolavit Jo. Gottlob Schneider. Jo. Gottlob Schneider, Berlin, 584pp.

Bucholtz, R.H., A.S. Meilvang, T. Cedhagen, J.T. Christensen & D.J. Macintosh (2009). Biological Observations on the Mudskipper *Pseudapocryptes elongatus* in the Mekong Delta, Vietnam. *Journal of World Aquaculture Society* 40(6): 711–723.

Bu-Olayan, A.H. & B.V. Thomas (2008). Trace metals toxicity and bioaccumulation in Mudskipper *Periophthalmus waltoni* Koumans, 1941 (Gobiidae: Perciformes). *Turkish Journal of Fisheries and Aquatic Sciences* 8: 215–218.

Cai, Z. (1996). Population structure and reproductive characteristics of mudskipper *Boleophthalmus pectinirostris*, in Shenzhen Bay, China. *Acta Ecologica Sinica* 16 (1): 77–82.

Chen, S.X., W.S. Hong, Y.Q. Su & Q.Y. Zhang (2008). Microhabitat selection in the early juvenile mudskipper *Boleophthalmus pectinirostris* (L.). *Journal of Fish Biology* 72(3): 585–593. https://doi.org/10.1111/j.1095-8649.2007.01723.x

Chew, S.F. & Y.K. Ip (1992). Biochemical adaptations of the mudskipper *Boleophthalmus boddaerti* to a lack of oxygen. *Marine Biology* 112: 567–571.

Chu, Y.T. & H.L. Wu (1963). A study on the classification of the sciaenoid fishes of China. Shanghai Fisheries Institute, China, 1pp. https://www.google.com/books/edition/A_study_on_the_classification_of_the_sci/GN1gnAEACAAJ?hl=en

Chukwu, K.O. & S.N. Deekae (2013). Foods of the mudskipper (*Periophthalmus barbarus*) from New Calabar River, Nigeria. *Journal of Agriculture and Veterinary Science* 5(6): 45–48.

Clayton, D.A. (1987). Why Mudskippers build walls. *Behaviour* 102(3-4): 185–195. https://doi.org/10.1163/156853986X00117

Clayton, D.A. (1993). Mudskippers. *Oceanography Marine Biology: An Annual Review* 31: 507–577.

Clayton, D.A. & J.M. Wright (1989). Mud-walled territories and feeding behaviour of *Boleophthalmus boddarti* (Pisces: Gobiidae) on the Mudflats of Kuwait. *Journal of Ethology* 7(2): 91–95.

Clayton, D.A. & R. Snowden (2000). Surface activity in the mudskipper, *Periophthalmus waltoni* Koumans 1941 in relation to prey activity and environmental factors. *Journal of Tropical Zoology* 13(2): 239–249.

Dabruzzi, T.F., M.L. Wygoda, J.E. Wright, E. John & A.B. Wayne (2011). Direct evidence of cutaneous resistance to evaporative water loss in amphibious mudskipper (family Gobiidae) and rockskipper (family Blenniidae) fishes from Pulau Hoga, southeast Sulawesi, Indonesia. *Journal of Experimental Marine Biology and Ecology* 406(1–2): 125–129.

Devendra, S., J. Kanejiya, I. Beleem & G. Bharatsinh (2016). Checklist of intertidal marine fauna in mangrove ecosystem, Ghogha coast, Gulf of Khambhat, India. *Journal of Entomology and Zoology Studies* 4(4): 1281–1284.

Dinh, Q.M., L.T. Tran, N.C. Ngo, T.B. Pham & T.T.K. Nguyen (2018). Reproductive biology of the unique mudskipper *Periophthalmodon septemradiatus* living from estuary to upstream of the Hau River. *Acta Zoologica* 101(2): 206–217.

Edun, O.M., O.A. Akinrotimi, A. Uka & K.N. Owhonda (2010). Patterns of mudskipper consumption in selected communities of Rivers State, Nigeria. *Journal of Agriculture and Social Research* 10(2): 100–108. https://doi.org/10.4314/jasr.v10i2.67578

Elviana, S., S. Sunarni, M.R. Maturbongs, M.R. Sajriawati & S. Fakhriyyah (2019). Mudskipper diversity and its relationship to an environmental condition in estuary, pp. 1–5. In: IOP Conference Series: Earth and Environmental Science, The 1st International Conference of Interdisciplinary Research on Green Environmental Approach for Sustainable Development (ICROEST). Indonesia.

https://doi.org/10.1088/1755-1315/343/1/012191

Etim, L., R.P. King & M.T. Udo (2002). Breeding, growth, mortality and yield of the mudskipper *Periophthalmus barbarus* (Linneaus 1766) (Teleostei: Gobiidae) in the Imo River estuary, Nigeria. *Fisheries Research* 56(3): 227–238.

Ferdous, A., N. Saha, Z.F. Ahmed, M.Y. Hossain & J. Ohtomi (2018). Reproductive biology of *Apocryptes bato* (Gobiidae) in the Payra River, southern Bangladesh. *Journal of Applied Ichthyology* 34(5): 1169–1175.

Gadhavi, M.K., D. Kukadia, S. Dar, N. Gokulakkannan, G. Talukdar, K. Sivakumar & G.V. Gopi (2017). Indigenous techniques of catching mudskipper in Bhavnagar and Bharuch districts, Gujarat. *Indian Journal of Traditional Knowledge* 16(3): 533–538.

Gonzales, T.T., M. Katoh, A.G. Mazlan & A. Ishimatsu (2011). Gross and Fine Anatomy of the Respiratory Vasculature of the Mudskipper, *Periophthalmodon schlosseri* (Gobiidae: Oxudercinae). *Journal of Morphology* 272(5): 629–640.

Gordon, M.S., J. Boëtius, D.H. Evans & L.C. Oglesby (1968). Additional Observations on the Natural History of the Mudskipper, Periophthalmus sobrinus. *Copeia* 1968(4): 853–857.

Gordon, M.S., I. Boetius, D.H. Evans, M. Rosemary & L.C. Oglesby (1969). Aspects of the physiology of terrestrial life in amphibious fishes. *Journal of Experimental Biology* 50: 141–149.

Gordon, M.S., W.W. Ng & A.Y. Yip (1978). Aspects of the physiology of terrestrial life in amphibious fishes: III. The Chinese mudskipper Periophthalmus cantonensis. *Journal of Experimental Biology* 72: 57–75.

Gordon, M.S., D.J. Gabaldon & A.Y.W. Yip (1985). Exploratory observations on microhabitat selection within the intertidal zone by the Chinese mudskipper fish Periophthalmus cantonensis. *Marine Biology* 85(2): 209–215.

Hamilton, F. (1822). *An account of the Fishes in the River Ganges and its Branches*. Archibald Constable and Company, Edinburgh, 405pp.

Hashim, R., B. Kamali, N.M. Tamin & R. Zakaria (2010). An integrated approach to coastal rehabilitation: Mangrove restoration in Sungai Haji Dorani, Malaysia. *Estuarine, Coastal and Shelf Science* 86(1): 118–124.

Hui, N.Y., M. Mohamed, M.N.A. Othman & L. Tokiman (2019). *Diversity and Behaviour of Mudskippers of Tanjung Piai, Pontian, Johor*. IOP Conference Series: Earth and Environmental Science, 269pp.

Ikram, M.M., A. Ismail, C.K. Yap & A.A. Nor (2010). Levels of heavy metals (Zn, Cu, Cd, and Pb) in Mudskippers (*Periophthalmodon schlosseri*) and sediments collected from intertidal areas at Morib and Remis, Peninsular Malaysia. *Toxicological and Environmental Chemistry* 92(8): 1471–1486.

Ishimatsu, A., A. Hishida, T. Takita, T. Kanda, S. Oikawa, T. Takeda & K.H. Khoo (1998). Mudskippers store air in their burrows. *Nature* 391: 237–238.

Ishimatsu, A., Y. Yu, I. Naoko, T. Takeda, H.J. Lee & J.B. Graham (2007). Mudskippers brood their eggs in air but submerge them for hatching. *Journal of Experimental Biology* 210: 3946–3954.

Jaafar, Z. & E.O. Murdy (2017). *Fishes Out of Water: Biology and Ecology of Mudskippers*. CRC Press, Florida. 410pp.

Jie, Z., T. Taichi, T. Takita & A.B. Ali (2003). A study on the epidermal structure of *Periophthalmodon* and *Periophthalmus* mudskippers with reference to their terrestrial adaptation. *Ichthyological Research* 50: 310–317.

Kanejiya, J., D. Solanki & B. Gohil (2017a). Nutrient content of three species of Mudskipper (Gobiidae; Oxudercinae) in Bhavnagar coast, Gujarat, India. *The Journal of Zoology Studies* 4(3): 48–51.

Kanejiya, J., D. Solanki, I. Beleem & B. Gohil (2017b). Mudskipper fishing in the coast of Bhavnagar, Gulf of Khambhat, Gujarat, India. *Journal of Fisheries* 5(1): 461–464.

Kanejiya, J.R., D.A. Solanki & B.M. Gohil (2017c). Distribution of Mudskippers in the Mudflats of Hathab Coast, Gujarat, India. *Cibtech Journal of Zoology* 6(2): 1–9.

Karen, L.M.M. (1993). Aerial CO_2 release and respiratory exchange ratio in marine intertidal fishes. *Environmental Biology of Fishes*. 37: 189–196.

Karen, L.M.M. (1995). Time and tide wait for no fish: Air-breathing in intertidal fishes. *Environmental Biology of Fishes* 44: 165–181. https://doi.org/10.1007/BF00005914

Khaironizam, M.Z. & Y.N. Rashid (2000). A new record of the mudskipper *Parapocryptes serperaster* (Oxudercinae: Gobiidae) from Peninsular Malaysia. *Malaysian Journal of Science* 19(1): 101–104.

Khaironizam, M.Z. & N.Y. Rashid (2003). First record of the mudskipper, *Periophthalmodon septemradiatus* (Hamilton) (Teleostei: Gobiidae) from Peninsular Malaysia. *The Raffles Bulletin of Zoology* 51(1): 97–100.

Khaironizam, M.Z. & N.Y. Rashid (2005). Distribution of Mudskippers (Gobiidae: Oxudercinae) on the Selangor Coast. University of Malaya Press, Kuala Lumpur, 101–114pp.

Kohan, A., Z. Badbardast & A. Kohan (2018). Effects of shrimp effluents on Mudskippers (Gobiidae: Oxudercinae) in the northern Persian Gulf. *Marine Environmental Research*. 136: 174–178.

Kok, W.K., C.B. Lim, T.J. Lam & Y.K. Ip (1998). The Mudskipper *Periophthalmodon schlosseri* respires more efficiently on land than in water and vice versa for *Boleophthalmus boddaerti*. *Journal of Experimental Zoology* 280(1): 86–90. https://doi.org/10.1002/(SICI)1097-010X(19980101)280:1<86::AID-JEZ10>3.0.CO;2-U

Koumans, A.K.J. (1938). The development of atrial fibrillation and block states due to new views on stimulus formation in the heart muscle. *Archive for Cycle Research* 2(9-12): 327–348. https://doi.org/10.1007/bf02127310

Kruitwagen, G., T. Hecht, H.B. Pratap & S.E.W. Bonga (2006). Changes in morphology and growth of the mudskipper (*Periophthalmus argentilineatus*) associated with coastal pollution. *Marine Biology* 149: 201–211.

Kundu, R., R. Lakshmi & A.P. Mansuri (1995). Effects of Cr (VI) on ATPases in the brain and muscle of mudskipper, *Boleophthalmus dentatus*. *Bulletin of environmental contamination and toxicology* 55(5): 723–729. https://doi.org/10.1007/BF00203759

Lakshmi, R., R. Kundu, E. Thomas & A.P. Mansuri (1991). Mercuric chloride-induced inhibition of different ATPases in the intestine of mudskipper, *Boleophthalmus dentatus*. *Ecotoxicology and Environmental Safety* 21(1): 18–24. https://doi.org/10.1016/0147-6513(91)90003-8

Lawson, E.O. (2010). Aspects of Reproductive Biology in Mudskipper, *Periophthalmus papilio* from Mangrove Swamps of Lagos Lagoon, Lagos, Nigeria. *Journal of Fisheries International* 5(2): 36–43.

Lee, H.J., C.A. Martinez, K.J. Hertzberg, A.L. Hamilton & J.B. Graham (2005). Burrow air phase maintenance and respiration by the mudskipper *Scartelaos histophorus* (Gobiidae: Oxudercinae). *Journal of Experimental Biology* 208: 169–177.

Looi, L.J., A.J. Aris, H. Haris, F.M. Yusoff & Z. Hashim (2016). The levels of mercury, methylmercury and selenium and the selenium health benefit value in grey-eel catfish (*Plotosus canius*) and giant mudskipper (*Periophthalmodon schlosseri*) from the Strait of Malacca. *Chemosphere* 152: 265–273.

Lorente-Martínez, H., A. Agorreta, M. Torres-Sanchez & M.D. San (2018). Evidence of positive selection suggests possible role of aquaporins in the water-to-land transition of mudskippers. *Organisms, Diversity and Evolution* 18(4): 499–514.

Low, W.P., D.J.W. Lane & Y.K. Ip (1988). A comparative study of terrestrial adaptations of the gills in three Mudskippers: *Periophthalmus Chrysospilos, Boleophthalmus Boddaerti,* and *Periophthalmodon Schlosseri. Biological Bulletin* 174(3): 434–438.

Mahadevan, G., G. Polgar & P. Murugesan (2019a). First record of the mudskipper *Periophthalmus walailakae* (Gobiidae) from southeast India. *Cybium: International Journal of Ichthyology* 43: 373–375.

Mahadevan, G., M. Pouladi, A. Stara & C. Faggio (2019b). Nutritional evaluation of elongate mudskipper *Pseudapocryptes elongatus* (Cuvier, 1816) from Diamond Harbor, West Bengal, India. *Natural Product Research* Sep 16: 1–7. https://doi.org/10.1080/14786419.2019.1666388

Mahadevan, G., P. Bharathirajan, V. Ravi, M. Pouladi & M.V.K. Maryam (2019c). Short Communication: Age and growth of

elongated mudskipper, *Pseudapocryptes elongatus* (Cuvier, 1816) from Sundarbans, India. *Biodiversitas Journal of Biological Diversity* 20(1): 85–90. https://doi.org/10.13057/biodiv/d200111

Mai, H.V., X.T. Loi, Q.M. Dinh, D.D. Tran, M. Mizuri, H. Sagara, A. Yamada, K. Shirai & A. Ishimatsu (2019). Land Invasion by the Mudskipper, *Periophthalmodon septemradiatus*, in Fresh and Saline Waters of the Mekong River. *Scientific Reports* 9(1): 1–11. https://doi.org/10.1038/s41598-019-50799-5

Mhaisen, F.T & N.S. Al-Maliki (2013). Parasites Diseases and Food of the Dark-blotched Mudskipper *Periophthalmus waltoni* (perciformes: Gobiidae) in the Khor Al-Zubair estuary (Iraq). *Journal of Zoology in Middle East* 13(1): 85–88. https://doi.org/10.1080/09397140.1996.10637708.

Murdy, E.O. & T. Takita (1999). *Periophthalmus spilotus*, a new species of mudskipper from Sumatra (Gobiidae: Oxudercinae). *Ichthyological Research* 46(4): 367–370.

Murdy, E.O. (1989). Taxonomic Revision and Cladistic Analysis of the Oxudercine Gobies (Gobiidae: Oxudercinae). *Records of the Australian Museum* (Suppl. 11): 1–93. https://doi.org/10.3853/j.0812-7387.11.1989.93

Nanami, A. & T. Takegaki (2005). Age and growth of the mudskipper *Boleophthalmus pectinirostris* in Ariake Bay, Kyushu, Japan. *Fisheries Research* 74(1–3): 24–34.

Nao, K., N. Yudai, K. Kato, H. Takahashi, Y. Kobayashi, H. Sakamoto & T. Sakamoto, (2013). Potential roles of arginine-vasotocin in the regulation of aggressive behavior in the Mudskipper (*Periophthalmus modestus*). *General and Comparative Endocrinology* 194: 257–263.

Ni, I.H., S.M. Chan & W.X. Wang (2006). Influences of salinity on the biokinetics of Cd, Se, and Zn in the intertidal mudskipper *Periophthalmus cantonensis*. *Chemosphere* 61(11): 1539–1758.

Osche, G. (1962). The pre-adaptation phenomenon and its importance for the Evolution. *Zoological Scoreboard* 169: 14–49.

Pallas, P.S. (1772). Spicilegia Zoológica, which come new in the first place, and obscure, of animals, like icons, in the descriptions of the recorder, and the enlightened care of the PS Pallas 9: 1–86.

Park, J.Y. (2002). Structure of the skin of an air-breathing Mudskipper, *Periophthalmus magnuspinnatus. Journal of Fish Biology* 60(6): 1543–1550.

Park, K.D., J.K. Kim, D.S. Chang, J. Kim & W.O. Chul (2002). Age and growth of the Mudskipper, *Scartelaos gigas* (perciformes, gobiidae) from Korea. *Journal of Animal Cells and Systems* 12(4): 305–311. https://doi.org/10.1080/19768354.2008.9647186

Polgar, G. (2009). Species-area relationship and potential role as a biomonitor of mangrove communities of Malayan Mudskippers. *Wetland Ecology and Management* 17 (2): 157–164.

Polgar, G. & G. Crosa (2009). Multivariate characterisation of the habitats of seven species of Malayan Mudskippers (Gobiidae: Oxudercinae). *Marine Biology* 156(7): 1475–1486.

Polgar, G. & R. Lim (2011). Mudskippers: Human use, ecotoxicology and biomonitoring of mangrove and other soft bottom intertidal ecosystems. Open Publication of UTC Scholar, 51–86pp. https://opus.lib.uts.edu.au/handle/10453/117614

Polgar, G., L. Zane, M. Babbucci, F. Barbisan, T. Patarnello, R. Lukas & C. Papetti (2014). Phylogeography and demographic history of two widespread Indo-Pacific Mudskippers (Gobiidae: Periophthalmus). *Molecular Phylogenetics and Evolution* 73: 161-176.

Pormansyah, I.M., S. Arum, Y. Indra & Z. Hilda (2019). A review of recent status on Mudskippers (Oxudercine Gobies) in Indonesian Waters. *Oceanography and Fisheries* 9(4): 555769. https://doi.org/10.19080/OFOAJ.2019.09.555769

Quang, D.M. (2015). Preliminary study on dietary composition, feeding activity and fullness index of *Boleophthalmus boddarti* in Mekong Delta, Vietnam. *Academia Journal of Biology* 37(2): 252–257. https://doi.org/10.15625/0866-7160/v37n2.6599

Quang, D.M. (2016). Growth and body condition variation of the giant Mudskipper *Periophthalmodon schlosseri* in dry and wet seasons. *Academia Journal of Biology* 38(3): 352–358.

Quang, D.M., N.T.T. Giang & N.T.K. Tien (2015). Reproductive biology of the mudskipper Boleophthalmus boddarti in Soc Trang. *Academia Journal of Biology* 37(3): 362–369. https://doi.org/10.15625/0866-7160/v37n3.6720

Rahman, M.M., M.S. Parvez, N. Mallik & M.S.U. Nabi (2015). Population Dynamics of Mudskipper *Periophthalmus novemradiatus* from Bakkhali River Estuary, Cox's Bazar, Bangladesh. *Agricultural Science Research Journal* 5(8): 118–123.

Randall, D.J., Y.K. Ip, S.F. Chew & J.M. Wilson (2004). Air Breathing and Ammonia Excretion in the Giant Mudskipper, *Periophthalmodon schlosseri*. *Physiological and Biochemical Zoology* 77(5): 783–788.

Rathod, S., A.S. Morajkar & H.L. Pratipada (2019). Behavioural Studies of *Boleophthalmus dussumieri* (VAL., 1837) on the silted Intertidal Mudflats of Ulhas river Estuary. *International Journal of Advance and Innovative Research* 6(1): 137–140.

Ravi, V. (2005). Post-tsunami studies on the mudskipper *Boleophthalmus boddarti* (Pallas, 1770) from Mudasalodai, Tamil Nadu, southeast coast of India. *Journal of International Goby Society* 4: 9–17.

Ravi, V. (2012). Habitat Loss and Population Reduction of Mudskippers (Family: Gobiidae) from Tamil Nadu, S.E. Coast of India. *Marine Biodiversity: Present Status and Prospects* 37–49.

Ravi, V. (2013). Food and Feeding Habits of the Mudskipper, *Boleophthalmus boddarti* (Pallas, 1770) from Pichavaram Mangroves, Southeast Coast of India. *International Journal of Marine Science* 3(12): 98–104.

Ravi, V. & S. Rajagopal (2007). Age and Growth of the Mudskipper, *Boleophthalmus boddarti* (Pallas, 1770). *Journal of Aquatic Biology* 22(1): 123–128.

Ravi, V., S. Rajagopal, S.A. Khan & T. Balasubramanian (2004). On the Classification of Burrows of the Mudskipper, *Boleophthalmus boddarti* (Pallas) (Gobiidae: Oxudercinae) in the Pichavaram Mangroves, Southeast Coast of India. *Journal of Annamalai University, Science* September(2004): 235–239.

Ravi, V., G. Mahadevan & R. Bharathi (2013). Mudskipper Fishery at Namkhana Region – Sundarban Mangrove Forest, India. *Fishing Chimes* 33(4): 42–44.

Ragunathan, A.V. (2010, July 02). A Fish Species in Missing Evolutionary Link Traced, Cuddalore, The Hindu. http://www.thehindu.com/news/states/tamil-nadu/article495616.ece

Roberts, R.J. (1978). Fish Pathology. Bailliere Tindall, UK. https://www.google.com/books/edition/Fish_Pathology/8n-1T2mK0tIC?hl=en

Sarker, A.L., N.K. Al-Daham & M.N. Bhatti (1980). Food habits of the mudskipper, *Pseudapocryptes dentatus* (Val.). *Journal of Fish Biology* 17(6): 635–639.

Sharifian, S., M.R. Taherizadeh, A. Salarpouri & M. Dehghani (2018). Population dynamic of the Mudskipper *Periophthalmus waltoni* Koumans, 1941 from the Bay of Hormozgan Province, Persian Gulf. *Russian Journal of Marine Biology* 44: 149–158.

Shenoy, L., V.K. Patro & X. Ying (2012). Effects of Mudskippers On the soil composition and texture in mangrove forests, and hence the growth of Mangroves (*Avicennia alba*). Temasek Junior College, Singapore. https://nss.org.sg/documents/LGD%202012%20Project%20Mudskipper%20Temasek%20JC.pdf

Shirani, M., A. Mirvaghefi, H. Farahmand & M. Abdollahi (2012). Biomarker responses in Mudskipper (*Periophthalmus waltoni*) from the coastal areas of the Persian Gulf with oil pollution. *Environmental Toxicology and Pharmacology* 34(3): 705–713.

Sinaei, M. & A. Mashinchian (2014). Polycyclic aromatic hydrocarbons in the coastal sea water, the surface sediment and Mudskipper *Boleophthalmus dussumieri* from coastal areas of the Persian Gulf: source investigation, composition pattern and spatial distribution. *Journal of Environmental Health Science and Engineering* 12(1): 59.

Sponder, D.L. & G.V. Lauder (1981). Terrestrial feeding in the Mudskipper *Periophthalmus* (Pisces: Teleostei): A Cinerodiographic analysis. *Journal of Zoology* 193(4): 517–530. https://doi.org/10.1111/j.1469-7998.1981.tb01501.x

Stebbins, R.C. & M. Kalk (1961). Observations on the Natural History of the Mud-Skipper, Periophthalmus Sobrinus. *Copeia* (1961)1: 18–27. https://doi.org/10.2307/1440166

Supriyati, H., N.S. Apriliani & M.J. Luthfi (2019). Histological Study

of Mudskipper (*Periophthalmus gracilis*) Gills. In: Proceeding International Conference on Science and Engineering, Universitas Islam Negeri Sunan Kalijaga, Indonesia 2: 177–179.

Swanson, B.O. & A.C. Gibb (2004). Kinematics of aquatic and terrestrial escape responses in mudskippers. *Journal of Experimental Biology* 207: 4037–4044.

Takeda, T., A. Ishimatsu, S. Oikawa, T. Kanda, Y. Hishida & K.H. Khoo (1999). Mudskipper *Periophthalmodon schlosseri* can repay Oxygen debt in air but not in water. *Journal of Experimental Zoology* 284(3): 265–270.

Takita, T. & A.B. Ali (1999). Distribution and habitat requirements of oxudercine gobies (Gobiidae: Oxudercinae) along the Straits of Malacca. *Ichthyological Research* 46: 131–138.

Tomiyama, I. (1934). Four new species of gobies from Japan. *Journal of the Tokyo Imperial University* 3(3): 325–334.

Tsuhako, Y., A. Ishimatsu, T. Takeda, K.K. Huat & K. Tachihara (2003). The eggs and larvae of the giant mudskipper, *Periophthalmodon schlosseri*, collected from a mudflat in Penang, Malaysia. *Ichthyological Research* 50(2): 178–181.

Ulrich, K. & J.M. Elliott (2013). Do mudskippers and lungfishes elucidate the early evolution of four-limbed vertebrates?. *Evolution: Education and Outreach* 6(8). https://doi.org/10.1186/1936-6434-6-8.

Valenciennes, A. (1846). Natural History of Fish. France. 19. https://books.google.co.in/books?hl=en&lr=&id=4tBcAAAAcAAJ&oi=fnd&pg=PA1&dq=Histoire+Naturelle+des+Poissons&ots=75SD1EbV-3&sig=BGqsMA5Og4ze3gQrCbOykDNl-48&redir_esc=y#v=onepage&q=Histoire%20Naturelle%20des%20Poissons&f=false

Wang, L., M. Xu, B. Liu, T. Jiang, S. Zhang & J. Yang (2013). Experimental Study on Morphology and Kinematics of Mudskipper in Amphibious Environments. In: IEEE International Conference on Robotics and Biomimetics (ROBIO), Shenzhen, China. Date of conference 12–13 December 2013. https://doi.org/10.1109/ROBIO.2013.6739610

Wilson, J.M., T.W.K. Kok, D.J. Randall, W.A. Vogl & K.Y. Ip (1999). Fine structure of the gill epithelium of the terrestrial Mudskipper, *Periophthalmodon schlosseri. Cell and Tissue Research* 298(2): 345–356.

Yang, K.Y., S.Y. Lee & G.A. Williams (2003). Selective feeding by the mudskipper (*Boleophthalmus pectinirostris*) on the microalgal assemblage of a tropical mudflat. *Marine Biology* 143: 245–256. https://doi.org/10.1007/s00227-003-1067-y

Zhang, J., T. Taniguchi, T. Takita & A.B. Ali (2000). On the epidermal structure of *Boleophthalmus* and *Scartelaos* mudskippers with reference to their adaptation to terrestrial life. *Ichthyological Research* 47: 359–366. https://doi.org/10.1007/BF02674263

Zulkifli, S.Z., F.M. Yusuff, A. Ismail & N. Miyazaki (2012). Food preference of the giant mudskipper *Periophthalmodon schlosseri* (Teleostei: Gobiidae). *Knowledge and Management of Aquatic Ecosystem* 405: 10. https://doi.org/10.1051/kmae/2012013

Journal of Threatened Taxa

www.threatenedtaxa.org

PLATINUM OPEN ACCESS

ISSN 0974-7907 (Online) | ISSN 0974-7893 (Print)

December 2020 | Vol. 12 | No. 17 | Pages: 17263–17386
Date of Publication: 26 December 2020 (Online & Print)
DOI: 10.11609/jott.2020.12.17.17263-17386

Publisher & Host

WILD ZOOREACH Threatened Taxa

Member

FJN