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Abid A Ansari
Department of Biology, Faculty of Sciences, University of Tabuk, Tabuk, 71491, Saudi Arabia.

Subrata Trivedi
Department of Biology, Faculty of Sciences, University of Tabuk, Tabuk, 71491, Saudi Arabia.

Shalini Saggu
Department of Biology, Faculty of Sciences, University of Tabuk, Tabuk, 71491, Saudi Arabia.

Hasibur Rehman
Department of Biology, Faculty of Sciences, University of Tabuk, Tabuk, 71491, Saudi Arabia.

Correspondence:
Abid A Ansari
Department of Biology, Faculty of Sciences, University of Tabuk, Tabuk, 71491, Saudi Arabia.

Mudskipper: A biological indicator for environmental monitoring and assessment of coastal waters

Abid A Ansari, Subrata Trivedi, Shalini Saggu, Hasibur Rehman

Abstract
Mudskippers are important for their biological and eco-toxicological studies and recognized as potential bio-indicator in environmental monitoring and assessments of coastal waters and tropical or subtropical soft bottom intertidal systems. Mudskippers are very sensitive to ambient environment and this potential would be beneficial for new researches on this species especially its ecological importance in detecting pollution levels in coastal water ecosystems. Using these organisms as bio-indicator of pollution, environmental quality programme could be established. Regularly discharged pollutants have imminent detrimental effect on the flora and fauna of coastal ecosystems especially mangrove ecosystems and tropical mudflats. Abundance and distribution of mudskippers on land as well as in coastal waters could be considered as a direct indicator of habitat health. Protecting and improving the state of coastal waters and mangrove forests ecosystems which are the natural habitat for mudskippers, mudskipper populations can be protected. Controlling garbage, untreated waste waters, pollutants, nutrients directly into the coastal waters will definitely help in protecting mudskippers. The review contains an update on our knowledge of mudskipper species and its related research fields in special reference to their potential use as an ecological indicator in coastal waters. The contents of this review will leads to new researches, methodologies, discussions and efforts to overcome the global problem of coastal water pollution and degradation of coastal ecosystems.

Keywords: Mudskipper; Pollution; Bio-indicator; Ecotoxicology.

1. Introduction
With the exclusion of tetrapods, semi-terrestrial habitats over difficult conditions to vertebrates, and only a small number of species have truly amphibious behaviour. Mudskippers (Teleostei: Gobiidae: Oxudercinae: Periophthalmini) are gobies that are “fully terrestrial for some portion of the daily cycle” [1]. They are investigated for their biological and eco-toxicological studies, to determine its potential use as a bio-indicator in environmental assessments of coastal waters, tropical or subtropical soft bottom intertidal systems [2]. This potential would be beneficial for new researches on this species especially for its ecological importance in detecting pollution levels in coastal water ecosystems. Bio-ecological knowledge of this group is essentially required to evaluate its possible use as an ecological indicator for coastal pollution [3]. Mudskippers are entirely different from many other fishes as they can breathe comfortably, in water as well as in air [4].

The species is usually cultured and studied ecologically because of their considerable tolerance to environmental stressors, organic and inorganic contaminants [5]. If they are used as food source, it is highly recommended that they should be carefully and periodically monitored for contaminants to assess the health risk to consumers of this species. An urgent implementation to maintain the sustainability of natural resource is necessary and prompt environmental remediation measure and ecosystem rehabilitation is also urgently required [6]. Basic researches at all organism levels are also needed to understand the ecotoxicology and biology of different fishes especially of mudskipper and their use as ecological indicators of pollution in coastal waters. In particular the toxicodynamics in different fish species and their effects at the community level are needed [3].

A possible elucidation could be related to the mudskippers’ amphibious lifestyle, which may expose them more directly to various contaminants in coastal waters. Population dynamics of mudskippers, their easy and cost effective maintenance, and considerable tolerance to changes in water quality parameters have been frequently used both in aquaculture and in eco-toxicological studies [5].

In polluted coastal areas mudskippers are the potential bio-indicators and bio-accumulators of pollutants and directly or indirectly related with human health issues, as they are consumed in different regions [2]. Mudskippers absorb and accumulate many different pollutants released into the coastal environment by industrial, agricultural, domestic and transportation activities [3].
The physiological, histological, and embryological changes in mudskippers are considered as strong indicators of water quality parameters. Mudskippers can accumulate very high concentrations of toxic compounds in their tissues [3]. Their robustness to environmental stressors and tolerance against many contaminants give them the capacity to be exposed to toxicants without significant effects, and to biomagnifying toxicants in their body tissues [3]. Air breathing fishes like mudskippers could be considered as a keystone species in tropical mangrove habitats. They play an important role in benthic ecology as they prey small crustaceans and graze diatoms and algae from mudflats [5].

2. Habit and Habitat

Mudskipper is an amphibious fish, uses their pectoral fins to walk on land. The fish adapted to intertidal habitats (both high and low tide) and are very active when out of water for feeding, interaction and another and for defense they dig his own deep burrow to keep away them from any disturbances in their habitats. Some common mudskipper adopted most terrestrial habits and remains emerged for about 90% of the time [2]. Some species emerges only at night and graze on algae, to escape from predators, to avoid hypoxic conditions that develop in pools when there is very low tide. The mudskippers inhabited in mangrove swamps have a direct influence of tidal fluctuations, and at the time of any danger, they can jump into the open sea or can move rapidly onto muddy land using their strong pectoral fins [7, 8].
The common mudskipper (*Periophthalmus kalolo*) and barred *mudskipper (Periophthalmus argentilineatus*) are found exclusively in mangrove habitats, ambon rock skipper (*Paralticus amboinensis*), lined rock skipper (*Istiblennius lineatus*), and streaky rock skipper (*Istiblennius dussumieri*) are more widespread in rock pools along the coastal margins and mangrove zones. The adults inhabits from the upper sub-tidal to the high intertidal zone, including tidal reaches of rivers, supratidal ecotones to freshwater swamps and diverse sympatric assemblages [9, 10, 11]. Mudskippers usually live in mixed colonies with digging crabs [12]. The fishes prefer to live in polygonal territories of about one meter, defend against enemies and search for phyto and zooplanktons [13].
They can borrow up to one and a half meters deep anywhere in their territory, sometimes right beside the walls [14]. Different species of mudskippers live in brackish to normal seawater, in swamps and estuaries, on mud flats, in intertidal habitat and in mangrove ecosystems [15]. Mudskippers are also fascinating pets due to their entertaining behavior, funny antics. All known species of mudskippers are burrowers and reasonably sedentary. Among the different species *Boleophthalmus, Periophthalmodon* and *Periophthalmus* showed territorial behavior [16]. The habit and habitat of mudskippers has a direct influence of synodic and tidal cycles and environmental factors such as temperature, relative humidity and light [17].

3. Species Distribution

The mudskippers are globally distributed in mangrove ecosystems and mudflats of Africa, Madagascar, Bengal (India), Southeast Asia, Northern Australia, Southeast China, Southern Japan, Samoa and Tonga Islands, Saudi Arabia, Bay of Kuwait in the Arabian Gulf area, Polynesia and Hoga Island in Indonesia. The highest species richness reported from coastal areas of South-East Asia, Australia and New Guinea. The distribution pattern has a wide biogeographical range, from the west coast of Africa to the whole Indo-west Pacific region where *Periophthalmus argentilineatus* is common and widespread [18]. *Periophthalmus barbarous* and *Periophthalmus koelreuteri* is specifically distributed in Western Africa, *Periophthalmus waltoni* in Kuwait and northern part of Hormuz Strait (Persian Gulf) and *P. cantonensis* is often in southern China and south-eastern Asia [19-23].

4. Taxonomy

The group presently includes 34 species in seven genera *Periophthalmus, Periophthalmodon, Boleophthalmus, Scartelaos, Pseudapocryptes, Zappa, Apocryptes* [24, 25]. The genus *Periophthalmus* is the most diverse and widespread genus of mudskipper. Previously it was reported that the mudskippers constitute a group of 25 air-breathing species in four genera (*Periophthalmodon, Periophthalmus, Boleophthalmus and Scartelaos,* Table 1) [26].

Table 1: Scientific classification of mudskipper

Kingdom	Animalia
Phylum	Chordata
Superclass	Osteichthyes
Class	Actinopterygii
Superorder	Acanthopterygii
Order	Perciformes
Suborder	Gobiodei
Family	Gobiidae
Subfamily	Oxudercinae

5. Evolution

In general the aquatic hypoxia, owing to metabolic oxygen consumption and organic decay are considered as the most important selective force in the evolution of air-breathing vertebrates. To determine more details on evolution patterns in amphibious fishes, the role of environmental and biotic factors on their behavior could be tested. Unlike the other fishes mudskipper can walk that is a question of interest that how the mudskipper evolved to have fins like the other fishes but the fins became too strong which made them able to walk on land [2]. Several species of air-breathing gobies (mudskippers) and blennies (rock skippers) are especially adapted to life in two worlds, being able to live on land and in the sea. Air-breathing mudskippers and rock skippers have many morphological and physiological modifications allowing them to adopt an amphibious behavior and life style [27].

6. Adaptations

The anatomical and behavioral adaptations of mudskippers allow them to live effectively on land as well as in the water. Most of the time they spent is usually out of water, so they have numerous physiological, morphological and behavioral specializations for an amphibious life [28, 29].

6.1. Behavioral Adaptations

Mudskipper used to live in territories' build by their own. They maintain polygonal mud-walled territories provide which is considered an excellent example of the elastic disc concept of territories. They also construct mud walls around their territories to reduce an aggression between neighbor animals. The mud walls are considered to play a secondary, indirect role in maintaining populations within the territories by maintaining diatom population which a primary food source for mudskippers [12]. The territorial behavior helps them to maintain high population densities within a confined habitat full of all amenities for their survival (Fig.1). The environmental factors also have a direct impact on mudskipper population and diversity [12].

Fig 1: Natural habitat and territorial behavior of mudskippers (photograph taken at Red Sea coast of Duba, Tabuk, Saudi Arabia).

Mudskipper population also showed a correlation with mangrove ecosystems which is the primary habitat of mudskippers. Organic and inorganic pollutants, expansion of urban areas, degradation of coastal ecosystems have a significant impact on mudskipper population [2]. Mudskippers are the prey for many predators as they are abundant and important prey items for many intertidal transient species marine visitors and are predated by many intertidal transient fishes, reptiles and shorebirds [9]. To avoid marine predators the fish dig deep burrows. They live in polygonal territories of a size of about one meter to defend them against predators. Some species of mudskippers are primary consumers (herbivores) and some are secondary consumers (carnivores) but some are also reported as omnivores [30, 31]. *Periophthalmus* is a carnivorous mudskipper feeds on little crabs and other arthropods. *Boleophthalmus* is an herbivore which feed by a side-to-side head movement to collect the fine surface film of diatoms and algae. The biofilms are composed of a matrix of extracellular polymeric secretions (EPS), and are able to chelate metals effectively and other contaminants mediating their trophic transfer into benthic food webs [32].

In a study, the food and feeding habits and feeding intensities of the mudskipper, *B. boddarti* from the Pichavaram mangroves were determined following points and volumetric methods. The results revealed that diatoms are the major food items in their gut and which is about 55% of its total diet in a year. Some small nematodes, polychaetes, algae and fish eggs constitute rest of their food items. Their feeding becomes poor when there is any flood in the mudflats especially during monsoon season [33].

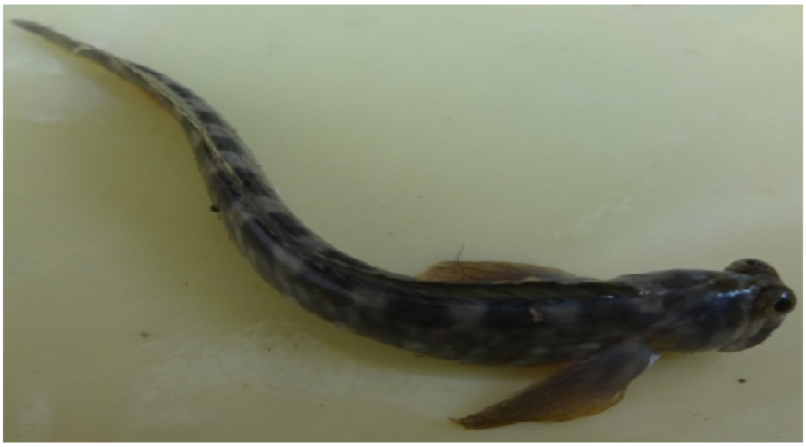

Fig 2: Morphology of mudskipper (photograph of a mudskipper collected from Red Sea coast of Duba, Tabuk, Saudi Arabia).

6.2. Morphological Adaptations

Mudskipper uses its pectoral fins to move around by skips. They can flip their muscular body to catapult themselves up to 2 feet into the air. The mudskipper can have a size ranges from

10-30 cm. The Atlantic mudskipper grows 20-25 cm. *Periophthalmus argentilineatus* grows to a length of about 9.5 cm and some other species of *Periophthalmus* mudskipper gain a size of 15 cm. Among the different species of mudskippers *Boleophthalmus* is the largest, measuring 25-30 cm. The heads are blunt having large, movable, close-set, and protuberant eyes on the top for an all-round view and mouth faces downwards as they feed on the mud surface (Fig.2). Eyes are well-adapted to vision in air, and when they are laying waiting for their prey only eyes stick up out of the muddy water. In order to keep eyes wet, little cups underneath the eyes and when blinks, the eyes roll down into the skull and get remoistened by the water held in these little cups [34]. The mudskipper, *Periophthalmus walailakae* have only one row of teeth on the upper jaw, scales on the isthmus, and a different upper lip and jaw morphology. Different species can also be distinguished by size, external morphology, and number of rays in each fin, body color patterns and scattered black dots on their skin. The scales are present on the snout, intertidal, and isthmus [35].

6.3. Physiological Adaptations

Mudskippers have multiple modes of breathing. They can respire through their skin, mucosal lining in their mouth and throat (the pharynx). But they need their body always wet since they can take oxygen by diffusion process only. Due to this habit the mudskipper population is limited to humid environment only which is exactly a similar habit adopted by amphibians, known as cutaneous air breathers. An important adaptation to respiratory system is their enlarged gill chambers, where they are able to retain a bubble of air. The large gill chambers closes tightly when the fish is to keep the gills moist which can allow them to function and supply oxygen for respiration when they are on land. When mudskippers burrow submerged, can also maintain an air pocket inside, which make them able to breathe even in very low oxygen condition. The anatomical and physiological adaptation of mudskippers to aerial respiration varies species to species. They are poorly adapted to respire aquatically in hypoxic conditions, but respire aerially to avoid low oxygen stress [36-39]. Mudskippers are essentially ammoniotelic, excrete mainly through their gills and are highly tolerant of ammonia concentrations in their environment. They are very much capable of active excretion of ammonia, even at pH 9.0 [40, 41]. When mudskippers are on land, they detoxify ammonia through partial amino acid catabolism [42, 43]. The mudskippers are euryhaline and can withstand rapid and drastic changes in salinity [44].

Osmoregulation in hypersaline waters is done by accumulation of free amino acids (FAA) and ammonia in their muscles and through the rapid activation of gills [45-47]. In many species of mudskipper regulation in hyposmotic conditions is partially behavioral evapotranspiration through their skin. Hot and humid is the most suitable environment for the survival of mudskippers as they need their body moist in order to breathe through their skin. In very hot summers, mudskipper can remain active for several minutes when they are out of water. For thermoregulation they dig in deep burrows in soft sediments. The annual ranges of body temperatures of emergent mudskippers is 14-35 °C and that of air temperatures is 10-42 °C [48].

Mudskippers swim by side to side movements in water. But on land they have two main ways for their movement. First is to walk on their pectoral fins, and other is to skip or jump, hence their name mudskipper. They are much capable to climb, walk and skip out of water. They use their pectoral fins to "walk" on land [49] and use to move around in a series of skips; even they can flip their muscular body to catapult themselves up to 2 feet (60 cm) into the air. The pelvic fins move forward and fused together to form a little cup which they use as a sort of crutch to balance. Their very strong and well-muscled pectoral fins move down the body and allow them to swing, inhabiting them between the tides and the rear fin acts as a stabilizer [50].

7. Reproduction and life cycle

Different observations have been made by various workers on reproduction and life cycle of mudskippers [51-54]. Most remarkable of the reproduction in mudskippers are the storage and maintenance of air within egg chambers by egg-guarding parental fish, embryonic development therein, and the mechanism for the induction of embryonic hatching by actively flooding the chambers by the parental fish, even though these are described unambiguously only for a single species of mudskippers [55].

The mudskippers are sexually monomorphic (males and females are morphologically similar). During breeding season only, the male display and advertises their sexual behavior. To raise their young the mudskippers dig deep burrows. The male fertilizes and oxygenate the eggs, and take care and guarded the eggs [36]. After hatching, the larvae swim off and float around with other types of planktons. Then the new small mudskippers hide themselves into the soft mud areas and remain there until they reach maturity and manage to build a new territory. Out of thousands of eggs, only few larvae of mudskipper survive as they are the favorite food for many predators such as crabs. The larvae have 30-50 days of pelagic life, they settle in the intertidal zone. The mudskipper may have a life span of about 5 years [56].

8. Anthropogenic impacts

The population dynamics (growth, mortality, recruitment) are the basic and important parameters to evaluate the intensity of exploitation of the mudskipper population. Some species of mudskipper like common in China are now considered as endangered due to degradation in their natural habitat, pollution, overconsumption and uncontrolled fishing [57]. Humans and mudskippers interactions are frequent and intense due to their tolerance to organic pollution, easy availability of mudskipper habitats to human beings as it is close to coastal urban settlements. Mudskippers are also consumed as food and in preparation of traditional medicines. In many countries like Bangladesh, China, Japan, Korea, Philippines, Taiwan, Thailand and Viet Nam several species are considered a delicacy, thus are extensively farmed. Mudskipper’s flesh can have high nutritive value but their consumption is only limited. In a preliminary test by their taste scores were higher than that of widely consumed species like mullets [58-60].

9. Species protection

Protecting and improving the state of mangrove forests ecosystems which are the natural habitat for mudskippers mudskipper populations can be protected. Controlling garbage, untreated waste waters, pollutants, nutrients directly into the coastal waters will definitely help in protecting mangrove forests and thus mudskippers [2].

10. Ecological Indicator-Coastal Pollution

Coastal pollution is increasing significantly over the last few years and expanding environmental problems in many developing as well as some developed countries. Untreated industrial and urban wastes are directing discharging in the local marine environment, resulting in high concentrations of contaminants in the coastal sediments [61]. Most of the heavy metals and metalloids are discharged from power, thermal, desalination and water treatment plants. A leakage from oil wells is also a significant cause of pollution in marine environment. Mudskippers inhabited in the coastal ecosystems faces a direct exposure to such contaminants in dissolved as well as dietary phases. Most of the metals are essential for the normal physiological functioning but above the tolerable limits may affect the metals biokinetics which may lead to mortality and sub-lethal concentrations may results in behavioral, biochemical and histological changes in mudskippers [62].

Mudskipper, *Periophthalmus waltoni* is reported as a strong bio-indicator of marine pollution and could be use to investigate the stressed ecosystem, contaminated with various inorganic pollutants [63]. Coastal marine environments can easily exposed to the pollutants such as polycyclic aromatic hydrocarbon (PAH) compounds, formed as result of incomplete combustion of coal, fossil fuel, wood and also produces after forest fires, volcanic activities and petroleum seeps [64]. Bombay harbor, India is contaminated with various anthropogenic pollutants including heavy metals, radionuclides, hydrocarbons and sewage discharges. Morphological and growth parameters of mudskipper were found associated with coastal pollution in this area. Dynamics in natural populations of mudskippers indicates the effects of pollution on coastal areas [65].

11. Ecological Indicator-Inorganic pollution

Coastal waters receive large inputs of anthropogenic heavy metals and metalloids. To determine the effects of heavy metals concentration the mudskippers are investigated for regular monitoring of coastal marine pollution. A positive and significant correlation between heavy metal concentrations in sediment and tissue samples of mudskippers was observed. The plasma enzyme levels in mudskippers were higher in polluted location causing a change in protein metabolism [66]. Accumulation of different heavy metals in the mudskipper *Boleophthalmus boddaerti* have been reported from Nayachara Island, which is located opposite to the Haldia Port-cum-Industrial Complex in West Bengal, India [67]. In this study, the levels of nine metals (Zn, Ni, Mn, Co, Fe, Cu, Pb, Cr and Cd) were analyzed in the pre-monsoon, monsoon and post-monsoon seasons in the liver, muscles and skeletal parts of the mud skipper. A unique seasonal pattern was revealed with high levels of metals in the monsoon season. Use of mudskippers has been reported to investigate the heavy metal pollution (Fe, Cu, Zn, Cd and Pb) in Sundarbans mangrove forest [68].

The mudskippers accumulate heavy metals in their gills, skin and also in digestive system [69]. Trace metals such as Copper (Cu), Zinc (Zn), Cadmium (Cd) and Iron (Fe) were found to bioaccumulate in liver followed by gills and muscles which support the use of mudskippers as a bioindicator to metal pollution. Some possible impacts of heavy metals (Zn, Mn, Cu, Fe, Co, Ni, Cd, Cr, Pb and Sr) on mudskippers inhabited in coastal waters were studied. All metals were found in very high concentrations which can affect adversely the life pattern of these coastal organisms [70]. Mercury concentrations were determined fishes in order to identify possible indicator species that can be used to monitor pollution in an ecosystem. The mudskippers were also investigated for its use as a bioindicator of trace metals toxicity and bioaccumulation [71].

In soft muscle tissue of Niger Delta mudskipper, *Periophthalmus barbarus* (L) Barium levels were determined using Buck Scientific Atomic Absorption and Emission Spectrophotometer 200A (AAS) to determine the possible use of the fish as a bioindicator of Barium pollution in coastal waters [72]. Hg concentrations in sediments, bivalves, benthic fishes (*Boleophthalmus boddarti*), crabs, prawns, gastropods and pelagic fishes and found high Hg concentration in their body tissues. *Boleophthalmus dentatus* is utilized in various ecotoxicological studies in India, especially to biomonitor the heavy metal pollution in coastal waters. Chronic dose and duration-dependent effects of $HgCl_2$ on ATPases and acid and alkaline phosphatases in gills tissues of mudskippers showed approximately linear inhibition of enzymes concentration with increasing sublethal concentrations and durations of exposure of Hg [73].

A cellular damage was found related to the apparent blockage of transport mechanisms across the cell membrane. The physiological and histopathological effects of sublethal doses of Hg++ (0.50, 1.00, 1.25, 1.50 ppm $HgCl_2$; LC50 = 1.65 ppm) on kidneys, gills, intestine, liver, brain and muscle of mudskipper, *Boleophthalmus dentatus* (= *B. dussumieri*) was investigated and found that there was a dose and duration-dependent inhibition of ATPase enzymes in all the studied tissues [74]. Also measured significant dose and duration dependent changes in the activity of 5 types of ATPases of the brain and muscle as influence by the exposure of Cr (VI) (30-60 mg/l for 1-3 days). As a response to the toxicant a significant stimulation of the enzymatic activities and a general dose dependent inhibition of the enzymes' activity were observed. The Cr causes metabolic changes in gills, then the kidneys, and finally the intestine of mudskippers [75]. In a preliminary study conducted in Indonesia by [76] Ni, Pb and Cd were found in high concentration in the liver and muscle of mudskipper, *Periophthalmus sp.* Mercury, copper and cadmium changes the total protein content of the muscles of *Boleophthalmus dussumieri*. Assimilation efficiency (AEs) of mudskipper to heavy metals (Cd, Cr, and Zn) was determined to quantify its relative importance in bioconcentration and biomagnifications processes [77]. Cu, Zn, Pb, Hg, As, Cr and Ca level in the muscle, gills and liver tissues of mudskipper, *Periophthalmus koelreuteri* were measured [78].

Enzymetic activities in the liver of *Boleophthalmus pectinirostris* exposed to different levels of Cd^{2+} were measured and found mudskippers very sensitive to Cd^{2+} stress [79]. Thereafter Liu and Zhou [80] also observed the chronic effects of sublethal doses of Cd on the hepatic cells of *Periophthalmus modestus* and found dose-dependent influences on mitochondria, endoplasmic reticulum, and nucleolus. Bu-Olayan and Thomas [62] measured the acute and chronic effects of aqueous uptake of Zn, Cu, Cd and Fe in *Periophthalmus waltoni* under lab conditions. Cd was found to be the most toxic metal among all. A progressive degeneration and necrosis in various tissues of *Boleophthalmus dussumieri* was observed when treated with fluoride. Fluoride treatment also decreased the activities of acid and alkaline phosphatases and total proteins in the liver and muscles of mudskipper [81]. Bioaccumulation of perfluorinated contaminants (PFCs) in mudskippers was measured at higher trophic levels [82].

12. Ecological Indicator-Organic pollution

Mudskippers are not able to resist the oil pollution unlike the other fish as they spent most of the time out of water and are in direct contact with water polluted with oil [83]. Hydrocarbon levels can be detected in Mudskipper which indicating a polluted environment. Mudskippers can accumulate and are very sensitive for PAHs in the coastal environments and widely used as monitoring tool for the marine pollution. Their tissues may give an indication of the bioavailable portion of environmental PAHs contamination [84]. Toxic effect of petroleum hydrocarbons on aquatic organisms have been determined by various workers [85]. Acute toxicity test of water soluble fraction (WSF) of diesel fuel on the mudskipper, *Periophthalmus koelreuteri* showed that the mudskipper was found highly sensitive to very low concentrations of water-soluble fractions of diesel fuel. *Periophthalmus waltoni* has the great potential to be used as a bioindicator in ecosystems polluted with PAHs [86].

A significant decrease in the glycogen and protein content in was recorded when *Boleophthalmus dentatus* (= *B. dussumieri*) was exposed to lethal and sub-lethal doses of the organochlorine pesticide endosulfan. PCBs are well known as endocrine disrupters and inhibitors of antioxidants in various fishes. They are associated with oxidative stress, impairment of protein metabolism, and hyperglycemia through glycogenolysis in fishes. Hyperglycemia induced by cortisol or catecholamines is observed as a general response to environmental stressors in fishes [87]. Mudskippers (*Boleophthalmus pectinirostris, Periophthalmus modestus*) and worm-eel gobies (*Odontamblyopus rubicundus*; Gobiidae: Amblyopinae) are found very capable to accumulate PCBs in their tissues. Further monitored the environmental levels of dichlorodiphenyltrichloroethane and its isomers (DDTs), dichlorodiphenyldichloroethylene and dichlorodiphenyldichloroethane (DDD and DDE, respectively), hexachlorocyclohexane isomers (HCHs), chlordane compounds (CHLs), hexachlorobenzene (HCB) and PCBs in *Boleophthalmus pectinirostris*) [82]. Wong *et al.* [88] found mudskippers highly contaminated with DDTs and HCB and PAHs. Further Wong *et al.* [89] measured the concentrations of several organochlorine *et al* insecticides (DDTs, HCHs, HCB and 11 cyclodiene insecticides) in *Boleophthalmus boddaerti*. A significant correlation was reported between mudskippers and enzotriazole UV stabilizers in the sediments [90]. Concentrations of PAHs, alkylphenols, and organotin compounds were measured in mudskipper *Periophthalmus modestus* and *Acanthogobius flavimanus* [91, 92].

13. Ecological Indicator-Urban and industrial effluents

Studies on growth and morphology of barred mudskippers (*Periophthalmus argentilineatus*) suggest its possible use bioindicator of coastal pollution due to urban and industrial wastes. Habitat, growth and developmental parameters of mudskippers have a direct correlation with coastal pollution [93].

14. Ecological indicator-Mutagens

Mitomycin-C (MMC) and heavy metals like Hg, Se, Cr causes mutagenesis in mitotic chromosomes in gill cells of *Boleophthalmus dussumieri* [94]. Gadhia *et al*. [95] extended the same observations by investigating the effects of antineoplastic antibiotics Bleomycin and Doxorubicin on the gills of *Boleophthalmus dussumieri*. DNA breaks when mudskipper exposed to benzo[a]pyrene [BaP], which is polycyclic aromatic hydrocarbon (PAH) and reported as strong carcinogenic compound [96].

15. Discussion

The mudskippers are very sensitive to coastal environmental factors and always in direct contact with various pollutants directly discharged untreated into coastal waters produced as result of industrial, agricultural and domestic activities. Due to their natural abundance, considerable resistance to highly polluted habitats and benthic habits, mudskippers are used to study the coastal pollution [97]. The mudskippers showed a very high potential for bioaccumulation of different types of pollutants from coastal waters and are very important for biomonitoring the coastal ecosystems. The mudskippers are frequently used to develop new scientific methodologies in the field of ecotoxicology [98], Fig. 3).

Studies consisted of dose- and duration-dependent experiments on mudskippers at the organismal and sub-organismal levels have been done especially on the ecotoxicology of heavy metals in coastal waters (Table 2). But recent studies are conducted on stress responses and propagation through food webs at the supra-organismal level, with special reference to ecotoxicology of hydrophobic organic compounds [98]. The pioneer work on ecotoxicology of mudskippers was conducted in the 1970s by [99], when they determined heavy metal concentration in *Boleophthalmus pectinirostris* and some other organisms in the Ariake Sea (Japan). Then only, the ecotoxicological investigation has been started on mudskippers by various workers to use them in biomonitoring the coastal pollution as a result of anthropogenic activities [55].

The mudskippers are very sensitive to coastal environmental factors and always in direct contact with various pollutants directly discharged untreated into coastal waters produced as result of industrial, agricultural and domestic activities. Due to their natural abundance, considerable resistance to highly polluted habitats and benthic habits, mudskippers are used to study the coastal pollution [100]. The mudskippers showed a very high potential for bioaccumulation of different types of pollutants from coastal waters and are very important for biomonitoring the coastal ecosystems. The mudskippers are frequently used to develop new scientific methodologies in the field of ecotoxicology. Studies consisted of dose- and duration-dependent experiments on mudskippers at the organismal and sub-organismal levels have been done especially on the ecotoxicology of heavy metals in coastal waters (Table 2). But recent studies are conducted on stress responses and propagation through food webs at the supra-organismal level, with special reference to ecotoxicology of hydrophobic organic compounds [98].

Table 2: A summative assessment of mudskipper's importance as biological indicator in coastal waters.

Mudskipper species	Parameters	Comments	Reference
Boleophthalmus boddaerti	Heavy metals (Zn, Ni, Mn, Co, Fe, Cu, Pb, Cr and Cd)	Metal level in liver, muscle and skeletal parts in different seasons.	Trivedi *et al*. 1995
Periophthalmus koelreuteri	Heavy metals (Cu, Zn, Pb, Hg, As, Cr and Ca)	level in the muscle, gills and liver	Eboh *et al*. (2006).
Boleophthalmus	heavy metal concentration in	pioneer work on ecotoxicology of	Uchida *et al*. (1971)

pectinirostris	the Ariake Sea (Japan)	mudskippers	
	Heavy metals (Fe, Cu, Zn, Cd and Pb)	Metal accumulation in mudskippers.	Ahmed *et al*. 2010
	Heavy metals	Accumulation of heavy metals in gills, skin and digestive system	Hein *et al*. 1993; Ni *et al*. 2005
	Heavy metals	mudskippers as a bio indicator of metal pollution	Taylor *et al*. 1985; Chan 1995; Wong *et al*. 1999; Somer 2003; Ni *et al*. 2005; Bu-olayan *et al*. 2008
Periophthalmus barbarus	Barium level in soft muscle tissue	bioindicator of Barium pollution	Nwakanma and Hart 2013
Boleophthalmus boddarti	Hg concentration in body tissues		Mahajan and Srinivasan 1988
Boleophthalmus dentatus	Heavy metal pollution in coastal waters.	ecotoxicological studies in India	Valenciénnes 1837 sensu; Murdy 1989
		chronic dose and duration-dependent effects of $HgCl_2$ on ATPases and acid and alkaline phosphatases in gills, intestine and kidney of mudskippers	Lakshmi *et al*. (1990); Lakshmi *et al*. 1991a, b, c
Boleophthalmus dentatus	physiological and histopathological effects of sublethal doses of Hg++	Effect on kidneys, gills, intestine, liver, brain and muscle	Kundu *et al*. (1992a, b)
Periophthalmus sp	Ni, Pb and Cd	high concentration in the liver and muscle	Amin and Nurrachmi (1999)
Boleophthalmus dussumieri.	Hg, Cu, Cd	changes the total protein content of the muscles	Amin and Nurrachmi (1999)
Periophthalmus modestus	effects of sublethal doses of Cd on the hepatic cells	dose-dependent influences on mitochondria, endoplasmic reticulum, and nucleolus	Liu and Zhou (2007)
Periophthalmus waltoni	acute and chronic effects of aqueous uptake of Zn, Cu, Cd and Fe	Cd most toxic	Bu-Olayan and Thomas (2008)
Periophthalmus koelreuteri	Acute toxicity test of water soluble fraction (WSF) of diesel fuel	highly sensitive to very low concentrations of water-soluble fractions of diesel fuel	Manuel 2012
Boleophthalmus boddaerti	effect of ^{238}U, ^{226}Ra, ^{210}Pb and ^{210}Po	high degree of bioaccumulation of these natural radionuclides in tissues	Bangera and Patel (1984)
Periophthalmus waltoni	variations in biomarker responses	great potential to be used as a bioindicator in ecosystems polluted with PAHs	Shirani *et al* 2012
Boleophthalmus dentatus	lethal and sub-lethal doses of endosulfan (organochlorine pesticide)	significant decrease in the glycogen and protein content	Patel and Parmar, 1993
Boleophthalmus dussumieri	Fluoride treatment	progressive degeneration and necrosis in various tissues	Shaikh and Hiradar (1987).
	Fluoride treatment	decreased activities of acid and alkaline phosphatases and total proteins in liver and muscles	Shaikh and Hiradar 1988
Periophthalmus argentilineatus	Habitat, growth and developmental parameters	direct correlation with coastal pollution	Gruitwagen *et al*. 2006
Periophthalmus dipes	Textile dyeing and printing Industry effluents	affects ATPases in Liver, Brain, and Muscle	Chhaya *et al*. 1997
	Abundance and distribution of mudskippers on land as well as in coastal waters	direct indicator of habitat health	Kruitwagen 2006
Boleophthalmus dussumieri	Mitomycin-C (MMC) and heavy metals like Hg, Se, Cr	causes mutagenesis in mitotic chromosomes in gill cells	Krishnaja and Rege 1982
Boleophthalmus dussumieri	effects of antineoplastic antibiotics Bleomycin and Doxorubicin	causes mutagenesis in mitotic chromosomes in gill cells	Gadhia *et al*. (2008)
	Exposure to a polycyclic aromatic hydrocarbon (PAH) benzo[a]pyrene [BaP]	Causes DNA breaks	Feng *et al*. (2003)
Various species of mudskippers	could be used as a cytogenetic model	*in vivo* detection of potential mutagens, dose and time dependent affects of pollutants.	Krishnaja and Rege (1982)
Boleophthalmus pectinirostris, Periophthalmus modestus	Accumulation of PCBs	very capable to accumulate PCBs	Nakata *et al*. 2002, Nakata *et al*. 2003

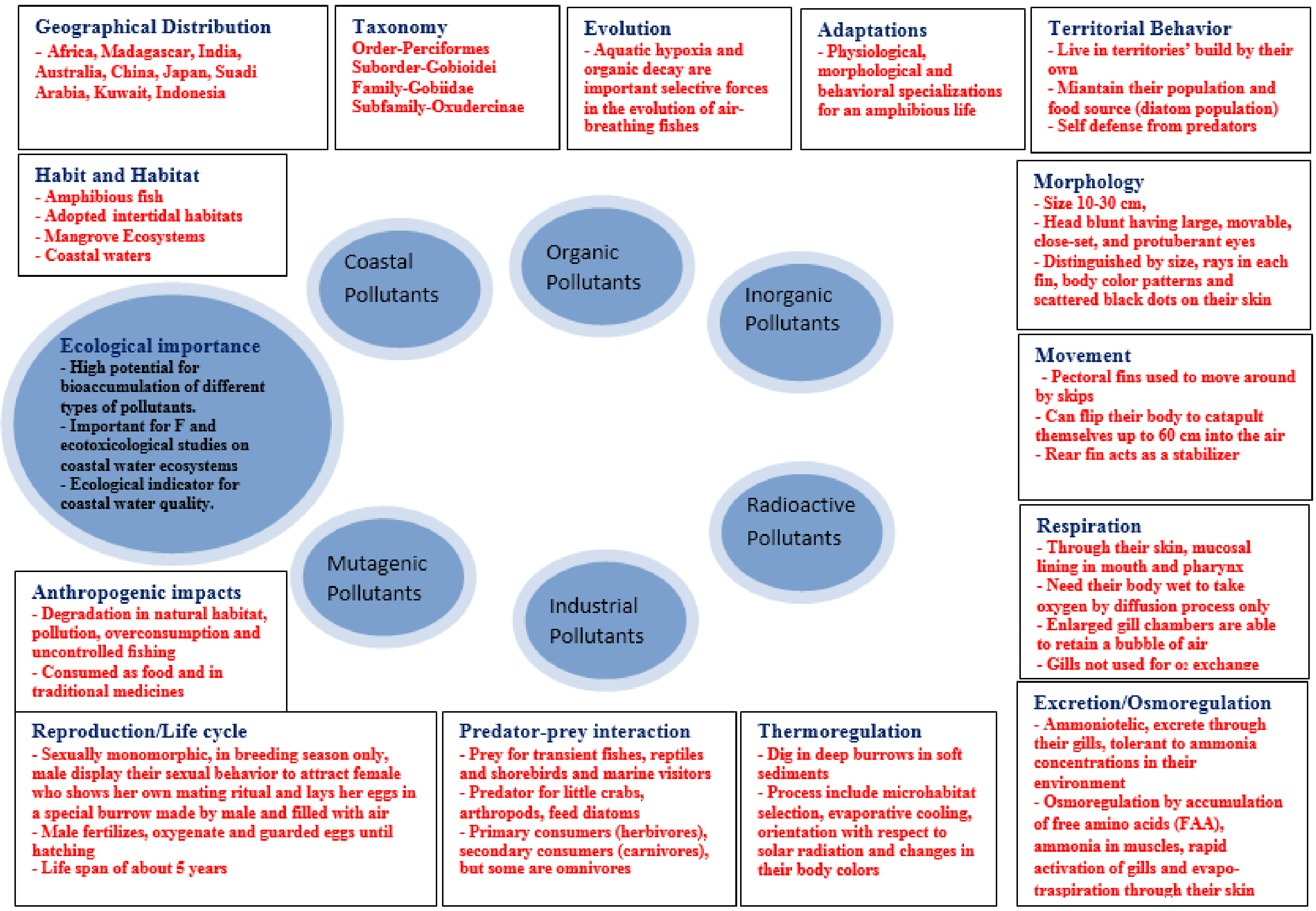

Fig 3: A summary on mudskipper and its importance as a biological indicator in coastal waters.

Mudskippers are very sensitive to ambient environment and are frequently used as bioindicators in monitoring pollution especially in coastal ecosystems. Using these organisms as bioindicator of pollution, environmental quality programme could be established [101]. Coastal organisms are considered as the most efficient bioaccumulator and bioindicator to monitor different types of pollutant in coastal waters. A regularly discharged industrial effluent may have imminent detrimental effect on the flora and fauna of coastal ecosystems [102]. Mudskippers are not widely accepted as food fishes but they have both ecological and economic importance as it occupies a unique niche in its habitat and ecosystem. Mudskippers are consumed as a food in China, Taiwan, and in some parts of India. In some countries the fishes used to culture for its raw flesh [19] and utilized by some Nigerian artisanal fishermen as baits in exploiting other commercially important species. Biomarkers are widely applied to monitoring environmental quality and the fish health inhabited in the polluted ecosystems [103].

Coastal fish species have been widely used in toxicological studies as models to investigate aquatic ecosystem health, function and energy flow. It is necessary to investigate bioaccumulation process in these fish species for the indication of any perturbation in the ecosystem and health of organisms inhabited [104]. Biochemical parameters of mudskippers can be used to evaluate the impact of contamination as they respond specifically level and type of contaminant in aquatic ecosystems [105].

Amazing behaviour and an importance as indicator in mangrove ecosystems makes mudskipper biology and ecology a topic of interest of researchers from this field. Range of adaptation and capacity to tolerate extreme environmental conditions are the important characteristics of mudskippers made them fit for their use as ecological indicators. Research projects to examine life pattern of this fish could provide important information which can help to exploit them in ecotoxicological studies of coastal environments. Air-breathing fish like mudskippers can significantly resist the water loss. Their habit and habitat, morphological and physiological adaptations, thermoregulation, excretion, life and reproductive behavior to environmental changes are needed to be investigated at all areas and levels of research [106].

Mudskippers are very strongly associated with mangrove ecosystems and tropical mudflats. The mangrove forests are favorite habitat of mudskipper. If the mangrove forests are destroyed the mudskippers do not have habitat and food that would make extremely difficult for mudskipper to maintain their population in these ecosystems [106]. Abundance and distribution of mudskippers on land as well as in coastal waters could be considered as a direct indicator of habitat health. Different trophic levels of mudskipper species as carnivores, omnivores and herbivores and their habitat differentiation and ecological partition allow them contaminant assessments in their body tissues [107, 108]. Pollutants released into coastal waters may show early effects on these fishes which can be used in environmental monitoring and impact assessment at an early stage before establishment of the problem completely. The rapid and extensive destruction of mangrove forests and adjacent peritidal ecosystems requires the development of efficient management for the conservation of different genera and species of mudskippers [109].

16. Conclusions

Mudskipper has very less economic importance but they play a significant role as bio-indicator in coastal water ecosystems. Level of pollution in coastal ecosystems can be determined by measuring the density, size, deformities and some other morphological, anatomical, physiological and genetic parameters of mudskippers. Some specific physiological and behavioral changes made them important as bio-indicators to detect and determine the changes in coastal environment.

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