# Species-area relationship and potential role as a biomonitor of mangrove communities of Malayan mudskippers

**Gianluca Polgar**
Dipartimento di Biologia Animale e dell'Uomo, University of Rome ''La Sapienza'', Rome, Italy e-mail: polgar@alfanet.it; gianluca.polgar@uniroma1.it URL: www.themudskipper.org;

The original publication (Wetlands Ecology and Management 2008, 17(2): 157-164 - doi: 10.1007/s11273-008-9090-x) is available at springerlink.com (http://www.springerlink.com/content/n2437r660327505n/) to authorized users.

## Abstract
The rapid and extensive destruction of mangrove forests and adjacent peritidal ecosystems in the Indo-Pacific region requires the development of efficient management and conservation actions. Mudskippers (Gobiidae: Oxudercinae) are amphibious gobies that are strictly linked to mangrove forests and tropical mudflats. I recorded the presence and habitat distribution of mudskipper species in four mangrove ecosystems along the west coast of Peninsular Malaysia. Different localities host different mudskipper communities, while in each locality species are differentially distributed along the intertidal gradient. At the ecosystem level, I found a significant exponential correlation between sampled area and the species richness of these communities, consistent with the SAR hypothesis. At the habitat level, the presence of a vertical zonation along the intertidal gradient suggests the possibility of using the species living exclusively in higher or lower levels as bioindicators for habitat anthropogenic impact, respectively from the land and from the sea.

**Keywords** Habitat destruction - Biodiversity loss - Mangals - Tropical intertidal zones - *Boleophthalmus* - *Periophthalmodon – Periophthalmus*

## Introduction

As recently as 40–50 years ago, mangrove forests, or mangals (Macnae 1968), occupied about 60–75% of low-energy tropical shorelines around the world (Por and Dor 1984). Trend analyses show that the world has lost approx. 5 million ha of mangrove forests in the years 1980–2000, that is 20%of the total extent (Wilkie and Fortuna 2003). In South-East Asia, some of the most diverse mangrove formations in the world suffer from the highest loss rates of vegetation coverage (up to 2% per year: Wilkie and Fortuna 2003), mainly as a result of habitat destruction (Hogarth 1999; Menasveta 1996; Sasekumar 1980, 1991; Tomlinson 1986). The economic value of these ecosystems should be considered from a holistic perspective, since coastal reclamation and mangrove deforestation have far-reaching effects (Duke and Wolanski 2001). Rational management is being attempted; nevertheless, with the exception of ecotourism, the majority of these initiatives turned out to be largely unsustainable (Ellison 2000). At the same time, a firm political decision to reduce deforestation and the concrete instrumentation of management plans are largely lacking.

Oxudercine gobies (Teleostei, Gobiidae, Oxudercinae), also known as 'mudskippers', include abundant and typical resident species of mangrove and mudflat ecosystems throughout the Indo-Pacific region and along the Atlantic African coasts (Murdy 1989). These fishes present different degrees of adaptation to the amphibious lifestyle, and have colonised the entire intertidal gradient, from the subtidal to the supratidal zone (Nursall 1981; Murdy 1989; Takita et al. 1999; King and Udo 1997).

Data from a preliminary survey of the distribution of Malayan mudskipper species are here presented and discussed, to support the use of mudskippers as biomonitors of the health of mudflats and mangrove forests.

## Materials and methods

A sampling survey was made in August 1996 in four localities distributed along coast in western Peninsular Malaysia: Tanjung Tuan (Lat 2°24'52" N, Long 101°51'15" E), Morib (Lat 02°45'33" N, Long 101°26'16" E), Sungai Sementa Besar (Lat 03°04'51" N, Long 101°21'35" E), and Kuala Selangor (Lat 03°19'32" N, Long 101°14'20" E). These localities are distributed within approximately 130 km (**Fig. 1**).

In each locality the horizontal extent of the intertidal zone was measured at spring low tide by use of GPS, tape meter and compass, moving from land to water. The distance was measured from the highest reaches of the mangrove forest (reclamation bund), to a point 10 m beyond the pneumatophore zone, at the edge of the low forest's marine fringe. In each locality I recorded the presence of mudskipper species in several plots along the intertidal gradient, within strip transects 25 m wide. The transects' total area was calculated by means of satellite images (Google Earth Plus, v. 4.2). I made a qualitative classification of mudskipper habitats based on plant zonation and on the presence of different water bodies and sedimentary deposits (Sasekumar 1980; Macnae 1968; Ricci Lucchi and Mutti 1980). In particular, 'estuarine tidal mudflats' are extended tidal mudflats associated with estuaries; and 'creek mud banks' are unvegetated mud banks of permanent tidal creeks. 'Low forests' are pioneer arboreal plant associations colonising the lower levels of the intertidal zone (*Avicennia* spp. and *Sonneratia* spp. zone: Sasekumar 1980); while 'high forests', are more terrestrial arboreal mangrove associations, found at higher levels (*Rhizophora* spp. and *Bruguiera* spp. zone: Sasekumar 1980). 'High inlet networks' are here defined as typical braided networks of ephemeral tidal waterways (inlets, gullies), which are flooded only by spring tides (Macnae 1968, pers. obs.). These networks are found in the higher portion of the high forest zone, where the empty beds are characterised by wetter and softer sediments at low tide. Typically in Malayan systems, this zone is also characterised by the mud mounds built by *Thalassina anomala* (Decapoda: Thalassinidae), and colonized by *Achrostichum* spp. halophytic ferns.

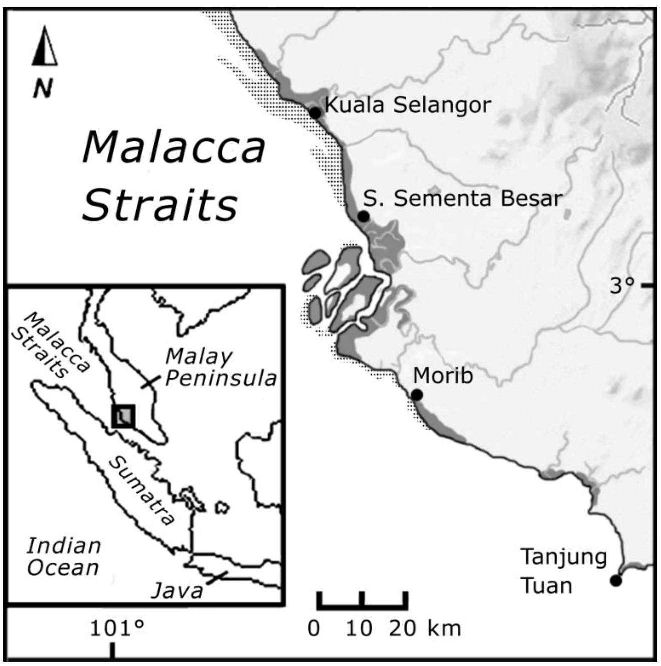


**Fig. 1** Coastal areas of Western Peninsular Malaysia. Shaded areas: mangrove forests; stippled areas: tidal flats exposed at low tide (modified from Coleman et al. 1970); large dots: study localities

The presence of mudskipper species was determined during about 40 h of direct observation by naked eye or binoculars (Pentax 8 x 40), at distances of 2–10 m, at low tide (LT ± 2 h), and between 9 am and 7 pm hours. All sites were surveyed during spring tides; in Kuala Selangor, forested areas were also visited during neap tides. A reference collection was made by using hand nets, bait and line, stake nets and cast nets. Collected specimens were morphologically examined in the laboratory to verify the efficiency of visual discrimination in the field (Murdy 1989; Murdy and Takita 1999; Takita et al. 1999; Darumas and Tantichodok 2002). A sample was fixed in 10% formalin, preserved in 70% ethanol, and deposited to the Genoa Natural History Civic Museum (MSNG).
More material was subsequently collected in the same areas by Dr. M.Z. Khaironizam in Sementa and in Kuala Selangor (Khaironizam and Norma-Rashid 2002; Polgar and Khaironizam 2008, in press).

To minimize the effects of ecological partitions between different age classes (Nursall 1981; Clayton and Vaughan 1988; Clayton 1993), only the presence of larger individuals was recorded (SL C 50% of the maximum recorded standard length: Murdy 1989; Murdy and Takita 1999; Takita et al. 1999; Darumas and Tantichodok 2002; Swennen and Ruttanadakul 1995; Khaironizam and Norma-Rashid 2002). This also increased the reliability of discrimination, since diagnostic morphological characters and colouration traits of smaller individuals are often not discernible in the field.

In order to record the habitat distribution of mudskipper species, each strip transect was divided into two zones along the intertidal gradient: (1) high forest and (when present) high inlets' network (HF); and (2) low forest and (when present) unvegetated mudflat (LF). At low tide, mudskippers are differentially distributed, and three species assemblies are observed: (1) species found only in low forests and/or on mudflats and creek mud banks (SLF: found in the LF zone); (2) species found only in high forests (SHF: found in the HF zone); and (3) species found in both zones (SIF) (Fig. 2).

## Results and discussion

The surveyed ecosystems presented wider intertidal zones and higher habitat diversities moving from south to north, from Tanjung Tuan to Kuala Selangor. Therefore, strip transects had proportionally larger areas (Fig. 1, Table 1).

Nine species of mudskippers and their habitat distribution were recorded (Table 2): *Boleophthalmus boddarti* (Pallas, 1770); *Boleophthalmus* sp.; *Periophthalmodon schlosseri* (Pallas, 1770); *Periophthalmus argentilineatus* Valenciennes, 1837; *P. chrysospilos* Bleeker, 1852; *P. gracilis* Eggert, 1935; *P. novemradiatus* (Hamilton, 1822); *P. spilotus* Murdy and Takita 1999; and *P. walailakae* Darumas and Tantichodok 2002.

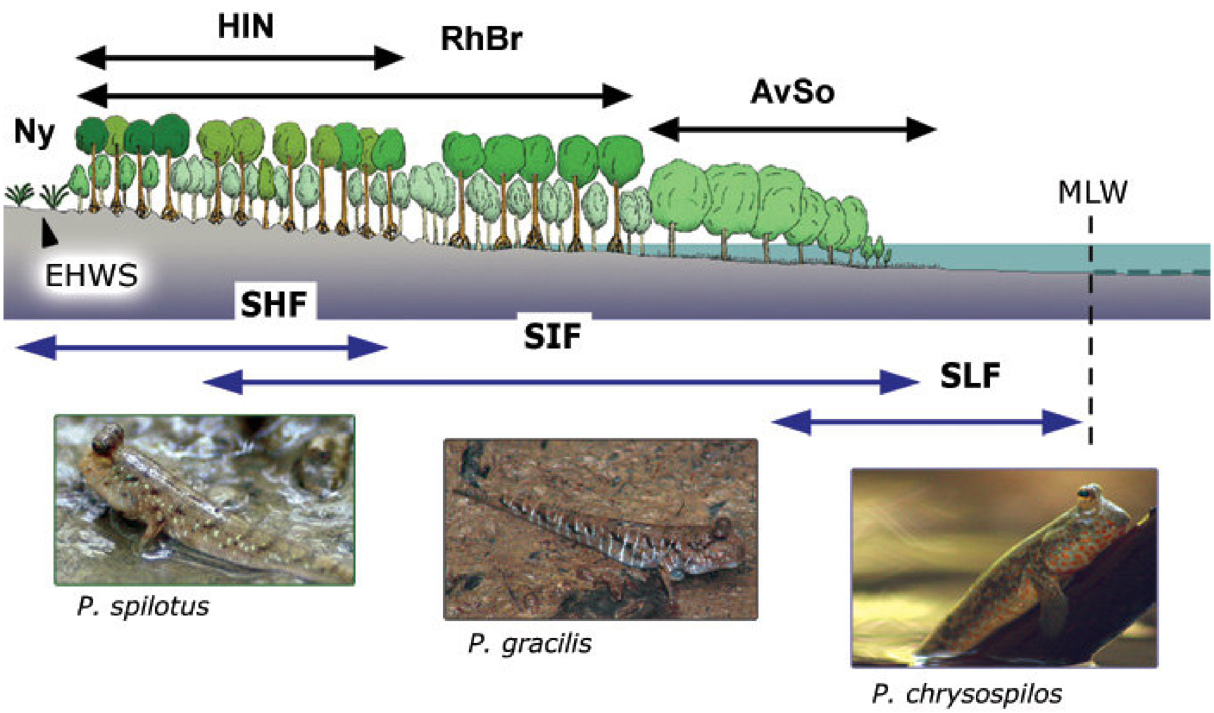


**Fig. 2** Distribution of oxudercine species along the intertidal zone. Mangrove ecosystems and mudflats are the natural habitat of amphibious oxudercine gobies, or 'mudskippers' (Gobiidae: Oxudercinae). Adults have species-specific habitat distributions along the intertidal gradient at low tide. There are species which are found only in high forests and high inlet networks (SHF); species found in low forests and/or on unvegetated mud areas (SLF); and species found in both zones (SIF). As an example, three species of the genus *Periophthalmus* (= *P.*) are illustrated (photos by G. Polgar: *P. spilotus*: Malaysia, Kuala Selangor, 1996; *Periophthalmus gracilis* and *Periophthalmus chrysospilos*: Malaysia, Pulau Kukup, 2007). EHWS = Extreme High Water Springs; MLW = Mean Low Waters. Mangrove zonation modified from Macnae (1968): AvSo = *Avicennia* and *Sonneratia* zone; RhBr = *Rhizophora* and *Bruguiera* zone; HIN = high inlet network; mounds of *Thalassina anomala* are illustrated in this area; Ny = belt of *Nypa fruticans* at the landward edge (this zone is usually lacking due to land reclamation)

**Table 1** Extent of the intertidal zone, area of strip transects and habitat diversity in the surveyed localities

| Locality | Ext. (m)[a] | Area of strip transects ($m^2$) | Number of plots | Estuarine tidal mudflats | Creek mud banks | Low forests | High forests | High inlet networks |
|---|---|---|---|---|---|---|---|---|
| Tanjung Tuan | 30 | 750 | 2 | | | X | (X)[b] | |
| Morib | 120 | 3,000 | 3 | | X | X | (X) | |
| Sungai Sementa Besar | 200 | 5,000 | 2 | | X | X | X | X |
| Kuala Selangor | 450 | 11,250 | 4 | X | | X | X | X |

Systems with wider intertidal zones have higher habitat diversities.

[a] Average linear horizontal extent of the intertidal zone

[b] In parentheses, relatively small stands of *Rhizophora* spp., behind the pioneer zone. See text for other definitions. "X" indicates presence.

**Table 2** Presence-absence matrix and habitat distribution of the mudskipper species in the surveyed plots

| Plots[a] | zone[b] | arg[c] | bod | chr | gra | nov | sch | spi | wal | *Boleophthalmus* sp. |
|---|---|---|---|---|---|---|---|---|---|---|
| T1 | LF | **1** | 0 | 0 | **1** | **1** | 0 | 0 | 0 | 0 |
| T2 | (HF)[d] | 0 | 0 | 0 | **1** | 0 | 0 | 0 | 0 | 0 |
| M1 | LF | 0 | **1** | **1** | 0 | 0 | **1** | 0 | 0 | 0 |
| M2 | LF | **1** | 0 | 0 | **1** | 0 | 0 | 0 | **1** | 0 |
| M3 | (HF) | 0 | 0 | 0 | **1** | 0 | 0 | 0 | **1** | 0 |
| S1 | LF | 0 | **1** | **1** | 0 | 0 | **1** | 0 | 0 | 0 |
| S2 | HF | 0 | 0 | 0 | **1** | **1** | 0 | **1** | **1** | 0 |
| K1 | LF | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **1** |
| K2 | LF | 0 | **1** | **1** | 0 | 0 | **1** | 0 | 0 | 0 |
| K3 | HF | 0 | 0 | 0 | **1** | **1** | 0 | **1** | 0 | 0 |
| K4 | HF | 0 | 0 | 0 | 0 | **1** | **1** | 0 | **1** | 0 |

[a] T: Tanjung Tuan; M: Morib; S: Sungai Sementa Besar; K: Kuala Selangor

[b] LF: low forests, mudflats and creek mud banks; HF: high forests and high inlet networks

[c] Mudskipper species are indicated by the first three letters of their specific scientific name; *Boleophthalmus* sp. indicates the unidentified species of *Boleophthalmus*; 1= presence; 0= absence

[d] In parentheses, relatively small stands of *Rhizophora* spp., behind the pioneer zone

All the observed and collected species are consistent with the available keys (Murdy 1989; Larson and Takita 2004) and with field identification notes by Takita et al. (1999). In particular, the behavioural and colouration traits of *B.* sp. (found only in Kuala Selangor), are consistent with the species identified by Takita et al. (1999) as *Boleophthalmus dussumieri* Valenciennes, 1837 from the same locality. Nonetheless, subsequent surveys and collections made in Johor, Malaysia and examination of additional material obtained from Kuwait, Iran, Taiwan and Southern China, suggest that this Malayan species is not *B. dussumieri*, but *Boleophthalmus pectinirostris* (Linnaeus, 1758). No specimen of this species was collected in Kuala Selangor, and further taxonomic studies are being made to confirm this record.

Four species were exclusively found in more aquatic habitats (SLF); one species was only found in more terrestrial ones (SHF); and four species were found in both habitats (SIF: Table 3). Among SIF species, *P. novemradiatus* was found in LF habitats only once (Tanjung Tuan), while *Pn. schlosseri* was found in HF habitats only in one locality (Kuala Selangor) (Table 2).

The number of species (n) is positively correlated to the total surveyed area (A) in each locality (Tables 1, 3). In particular, the scatter plot of n against A fits an exponential curve (on a log-log plot, consistent with the SAR hypothesis (Species-Area-Relationship: Rosenzweig 1995).

**Table 3** Mudskipper species assemblies in the surveyed localities

| Species | Species assembly | Tanjung Tuan | Morib | Sungai Sementa Besar | Kuala Selangor |
|---|---|---|---|---|---|
| *P. spilotus* | SHF[a] | | | X | X |
| *P. novemradiatus* | SIF[b] | X | | X | X |
| *P. gracilis* | SIF | X | X | X | X |
| *P. walailakae* | SIF | | X | X | X |
| *Pn .schlosseri* | SIF | | X | X | X |
| *P. argentilineatus* | SLF[c] | X | X | | |
| *P. chrysospilos* | SLF | | X | X | X |
| *B. boddarti* | SLF | | X | X | X |
| *Boleophthalmus* sp. | SLF | | | | X |
| Totals[d]**:** | | 3 (0, 2, 1) | 6 (0, 3, 3) | 7 (1, 4, 2) | 8 (1, 4, 3) |

[a] Species found only in high forests and high inlet networks

[b] Species found in both zones

[c] Species found only in low forests and on unvegetated mud

[d] Total number of species found in each locality (in parentheses, number of species in each assembly: high forest, both zones, low forest)

The SAR is a classical ecological concept and a general descriptor at ecosystem level. In this case, mangrove forested areas are considered as ‘‘islands’’ separated by distance along coast. SAR’s ecological interpretation is often controversial (Rosenzweig 1995; Gotelli and Ellison 2004). In very general terms, z exponents of 0.2–0.4 can derive from differently clustered distributions of conspecific individuals, which is in accordance with the observed vertical zonation, and from abundance distributions similar to lognormal ones with extra rarity, widespread among very different organisms (Martín and Goldenfeld 2006).

Under constant tidal conditions and within a given mangrove ecosystem, the composition of the mudskipper community (i.e. the number of species) drastically changes along the intertidal gradient, while compositional changes in a perpendicular direction seem negligible. If future studies will confirm and generalise this pattern, and if a SAR exists between different systems, the species numbers will be in an exponential relationship not only with areas, but also with the linear extent of the respective intertidal zones.

At the ecosystem level, the decreasing number of species from north to south seems to be related to the distribution of available habitats along coast. In the Straits of Malacca the formation of mudflats is determined by the high sediment loads discharged by fluvial systems (e.g. Klang-Langat and Selangor rivers) and by the pattern of currents along coast, which are predominantly directed from SE to NW (Coleman et al. 1970, Fig. 1). The distribution of mudskipper species suggests both an interaction between habitat availability and larval dispersal processes, influenced by the pattern of currents, and the existence of specific mechanisms of habitat selection (Begon et al. 1986).

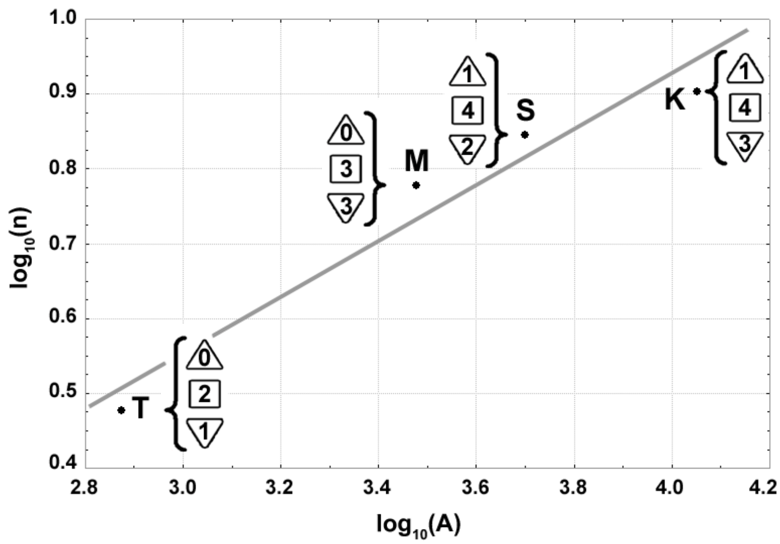


**Fig. 3** The number of species (n) plotted against the explored areas at low tide (**a**), on a log-log plot (slope = 0.37; ***r*** = 0.97; P (uncorr) < 0.05). T = Tanjung Tuan; M = Morib; S = Sungai Sementa Besar; K = Kuala Selangor. Numbers in triangles pointing upward = number of species found only in high forests and high inlet networks; numbers in triangles pointing downward = number of species found only in low forests and on unvegetated mudflats; numbers in squares = number of species found in both zones

On the other hand, these results also imply that an anthropogenic reduction of available habitats by deforestation and land reclamation would result in a decrease of the number of mudskipper species.

At the habitat level, the zonation of mudskipper species suggests a species-specific selection of environmental conditions along the intertidal gradient, even if the role of synecological factors, such as direct and indirect intra- and interspecific competition, is almost completely unknown (Nursall 1974, 1981; Milward 1974). As a general rule, only a minority of aquatic intertidal species is able to cope with the harsh conditions found in the supratidal zone (Raffaelli and Hawkins 1999). Supratidal mangrove zones host fewer and evolutionarily peculiar species, such as *P. spilotus* and *P. novemradiatus*. Since higher zones are also more impacted by anthropogenic habitat destruction, such species can be used as key-indicators of the effects of habitat destruction of mangrove ecosystems from land. Unfortunately, no such study is currently available. In peninsular Malaysia, the freshwater species *Periophthalmodon septemradiatus* (Hamilton, 1822), presently known only from a village nearby Kuala Selangor (Khaironizam and Norma-Rashid 2003), is maybe the most terrestrial and one of the most endangered Malayan mudskipper species.
Instead, species living exclusively at lower levels can be key-indicators of disturbing factors acting primarily from the sea, such as pollution (e.g. Nakata et al. 2002; Kruitwagen et al. 2006).

Narrower intertidal zones have also lower habitat diversity (Table 1). The decreased species richness may thus be a consequence of reduced habitat availability. Nevertheless, not only do species living exclusively at higher or lower levels (SHF and SLF) generally decrease in number in systems with narrower intertidal zones, but so do ubiquitous species (SIF). Almost all species assemblies contain the same or a higher amount of species in localities with wider intertidal zones (Table 3, Fig. 3).

This suggests that some factor correlated to the total available area is acting at ecosystem level, affecting whole mudskipper communities-

Further investigations may quantify whether the observed SAR is mainly caused either by a simplification of ecosystem structure and a reduction of habitat availability in areas with narrower intertidal zones, or by the influence of coastal currents and physiography on larval dispersal patterns.

Species' reference collection

*Boleophthalmus boddarti* (Pallas, 1770): 1 specimen from 1 locality, Selangor, MALAYSIA: Sementa, Sungai Sementa Besar; MSNG 54124 (108 mm SL), exposed creek's mud banks, 30 August, 1996.
*Periophthalmodon schlosseri* (Pallas, 1770): 1 specimen from 1 locality, Selangor, MALAYSIA: Kuala Selangor; MSNG 54125 (159 mm SL), mangal high forest (*Bruguiera* and *Rhizophora* spp. zone), 09 August, 1996. *Periophthalmus argentilineatus* Valenciennes, 1837: 1 specimen from 1 locality, Negeri Sembilan, MALAYSIA: Tanjung Tuan; MSNG 54126 (46 mm SL), *Sonneratia* spp. pioneer shore, 15 August, 1996. *Periophthalmus chrysospilos* Bleeker, 1852: 3 specimens from two localities, Selangor, MALAYSIA: Morib and Pulau Kelang; size range 65.2–74.3 mmSL:MSNG54128, 2 (65, 74 mmSL), *Sonneratia* spp. pioneer shore, Morib, ibid., 17 August, 1996; MSNG 52024, 1 (74 mm SL), lower mud flat, northern coast of Pulau Kelang, ibid., 30 August, 1996. *Periophthalmus gracilis* Eggert, 1935: 6 specimens from 4 localities, MALAYSIA, Selangor and Negeri Sembilan: Kuala Selangor, Pulau Kelang, Morib, and Tanjung Tuan; size range 27–40 mm SL: MSNG 54129, 2 (27, 30 mmSL), mixed mangrove forest, high inlet network, Kuala Selangor, ibid., 27 August, 1996; MSNG 54130, 1 (27 mm SL), mixed mangrove forest, Pulau Kelang, ibid., 30 August, 1996; MSNG 54131, 1 (33 mmSL), *Rhizophora* spp. forest, Morib, ibid., 17 August, 1996; MSNG 54132, 2 (31, 40 mm SL), *Sonneratia* spp. pioneer shore and *Rhizophora* spp. forest, Tanjung Tuan, ibid., 15 August, 1996. *Periophthalmus novemradiatus* (Hamilton, 1822): 6 specimens from 3 localities, MALAYSIA, Selangor and Negeri Sembilan: Kuala Selangor, Pulau Kelang, and Tanjung Tuan; size range 40–57 mm SL: MSNG 54133, 1 (44 mm SL), Bruguiera spp. high forest, nearby the reclamation bund, Kuala Selangor, ibid., 08 August, 1996; MSNG 54134, 2 (40, 57 mm SL), mangrove mixed forest, high inlet network, Kuala Selangor, ibid., 27 August, 1996; MSNG 54135, 2 (40, 49 mm SL), inside and in front of a *Rhizophora* spp. stand, Pulau Kelang, ibid., 30 August, 1996; MSNG 54136, 1 (52 mm SL), *Sonneratia* spp. pioneer shore, Tanjung Tuan, ibid., 15 August, 1996. *Periophthalmus walailakae* Darumas & Tantichodok, 2002: 1 specimen from 1 locality, Selangor, MALAYSIA: Kuala Selangor; MSNG 51393, (109 mm SL), *Bruguiera* spp. high forest, 8 August, 1996.

## Acknowledgements

A special thanks goes to Dr. A. Sasekumar, Institute of Postgraduate Studies, University of Malaya, Kuala Lumpur,Malaysia, for his extensive contribution to the specimens' field collection, supervision of this preliminary survey, and museum facilities during a visit at the university's zoological collection. For manuscript's revision, thanks to two anonimous referees, and to Prof. G. Crosa, Dipartimento di Biotecnologie e Scienze Molecolari, Universita` dell'Insubria, Varese, Italy.

## References

Begon M, Harper JL, Townsend CR (1986) Ecology. Individuals, populations and communities. Blackwell, London

Clayton DA (1993) Mudskippers. In: Ansell AD, Gibson RN, Barnes M (eds) Oceanography and marine biology. An annual review, vol 31. UCL Press, London, pp 507–577

Clayton DA, Vaughan TC (1988) Ethogram of *Boleophthalmus boddarti* (Pallas), a mudskipper found on the mudflats of Kuwait. J Univ Kuwait (Sciences) 15(1):115–138

Coleman JM, Gagliano SM, Smith WG (1970) Sedimentation in a Malaysian high tide tropical delta. In: Morgan JP (ed) Deltaic sedimentation, modern and ancient. Special Publ. No 15, S.E.P.M., pp 185–197

Darumas U, Tantichodok P (2002) A new species of mudskipper (Gobiidae: Oxudercinae) from southern Thailand. Phuket Mar Biol Cent Res Bull 64:101–107

Duke NC, Wolanski E (2001) Muddy coastal waters and depleted mangrove coastlines—depleted seagrass and coral reefs. In: Wolanski E (ed) Oceanographic processes of coral reefs. Physical and biological links in the Great Barrier Reef. CRC Press LLC, Boca Raton

Ellison A (2000) Mangrove restoration: do we know enough? Restoration Ecol 8(3):219–229

Gotelli NJ, Ellison AM (2004) A primer of ecological statistics. Sinauer Associates Inc. Publishers, Sunderland

Hogarth PJ (1999) The biology of mangroves. Oxford University Press, Oxford

Khaironizam MZ, Norma-Rashid Y (2002) A new record of mudskipper *Periophthalmus spilotus* (Gobiidae: Oxudercinae) from Selangor coast, Peninsular Malaysia. Nat Hist Bull Siam Soc 50(2):245–250

Khaironizam MZ, Norma-Rashid Y (2003) First record of the mudskipper, *Periophthalmodon septemradiatus* (Hamilton) (Teleostei: Gobiidae) from Peninsular Malaysia. Raff Bull Zool 51(1):97–100

King RP, Udo MT (1997) Some aspects of the reproductive biology of the endangered mudskipper, *Periophthalmus barbarus* (Gobiidae) in Imo River estuary, Nigeria. Trans Nig Soc Biol Conserv 5:50–58

Kruitwagen G, Hecht T, Pratap HB et al (2006) Changes in morphology and growth of the mudskipper (*Periophthalmus argentilineatus*) associated with coastal pollution. Mar Biol 149(2):201–211
Larson HK, Takita T (2004) Two new species of *Periophthalmus* (Teleostei: Gobiidae: Oxudercinae) from northern Australia, and a re-diagnosis of *Periophthalmus novaeguineaensis*. The Beagle, Rec Mus Art Galleries N Terr 20:175–185
Macnae W (1968) A general account of the fauna and flora of mangrove swamps and forests in the Indo-West-Pacific Region. Adv Mar Biol 6:73–270
Martín HG, Goldenfeld N (2006) On the origin and robustness of power-law species-area relationships in ecology. PNAS 103(27):10310–10315
Menasveta P (1996) Mangrove destruction and shrimp culture systems. Thai J Aquatic Sci 2(2):72–82
Milward NE (1974) Studies on the taxonomy, ecology and physiology of Queensland mudskippers. Ph.D. dissertation, University of Queensland, Brisbane
Murdy EO (1989) A taxonomic revision and cladistic analysis of the oxudercine gobies (Gobiidae: Oxudercinae). Rec Aust Mus Suppl No 11:1–93
Murdy EO, Takita T (1999) *Periophthalmus spilotus*, a new species of mudskipper from Sumatra (Gobiidae: Oxudercinae). Ichthyol Res 46(4):367–370
Nakata H, Sakai Y, Miyawaki T (2002) Growth-dependent and species-specific accumulation of polychlorinated biphenyls (PCBs) in tidal flat organisms collected from the Ariake Sea, Japan. Arch Environ Contam Toxicol 42:222–228
Nursall JR (1974) Character displacement and fish behaviour, especially in coral reef communities. Am Zool 14:1099–1118
Nursall JR (1981) Behaviour and habitat affecting the distribution of five species of sympatric mudskippers in Queensland. Bull Mar Sci 31(3):730–735
Polgar G, Khaironizam MZ (2008) First record of *Periophthalmus walailakae* (Gobiidae: Oxudercinae) from Peninsular Malaysia. Cybium (in press)
Por FD, Dor I (1984) Hydrobiology of the mangal. Dr Junk W. Publ., The Hague, pp 1–14
Raffaelli D, Hawkins S (1999) Intertidal ecology. Kluwer Academic Publishers, Dordrecht
Ricci Lucchi F, Mutti E (1980) Sedimentologia, vol I–III. CLUEB, Bologna
Rosenzweig ML (1995) Species diversity in space and time. Cambridge University Press, New York
Sasekumar A (1980) The present state of mangrove ecosystems in South-East Asia and the impact of pollution. In: FAO/UNEP project: impact of pollution on the mangrove ecosystem and its productivity in Southeast Asia (SCS/80/WP/94b), Manila, 4–8 February 1980. South China Sea Fisheries Development and Coordinating Programme
Sasekumar A (1991) A review of mangrove–fisheries connections. In: Sasekumar A (ed) Proceedings of a workshop on mangrove fisheries and connections, Ipoh
Swennen C, Ruttanadakul N et al (1995) The five sympatric mudskippers (Teleostei: Gobioidea) of Pattani area, Southern Thailand. Nat Hist Bull Siam Soc 42:109–129
Takita T, Agusnimar, Ali AB (1999) Distribution and habitat requirements of oxudercine gobies (Gobiidae: Oxudercinae) along the Straits of Malacca. Ichthyol Res 46(2):131–138
Tomlinson PB (1986) The botany of mangroves. Cambridge University Press, Cambridge
Wilkie ML, Fortuna S (2003) Part 1: global overview. In: Status and trends in mangrove area extent worldwide. Forest Resources Assessment Working Paper No. 63. Forest Resources Division. FAO, Rome. Available via DIALOG. http://www.fao.org/docrep/007/j1533e/J1533E02.htm# P199_6397. Cited 4 Mar 2008