

# Mangrove-associated bivalves in Southeast Asia: A review

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## ABSTRACT

Mangroves are plants with high tolerance to salinity, tidal variation, temperature and moisture which grow in the intertidal zone. The high productivity of mangroves creates a suitable living habitat for aquatic and terrestrial organisms, including bivalves. Several bivalve species are collected as food for humans. Despite the insufficient information regarding the interaction between mangroves and bivalves, this aspect is essential for resource and habitat management. Furthermore, the total number of identified bivalve species living in mangroves is still unknown. Therefore, this article presents a review of the diversity and interaction between bivalves and mangroves in the Southeast Asia region. Published data on distribution of bivalve species in mangroves were listed and checked using online databases and datasets from international organisations. This review will serve as baseline information on the biodiversity of bivalves in Southeast Asia for future studies, although some of the species listed require further validation from taxonomists. A total of 175 species from 34 families, 87 genera and 4 unidentified species of bivalves were recorded in Southeast Asia. The highest number of species was found in Indonesia, Thailand, Malaysia and the Philippines, which surround the South China Sea, whereas no data for Laos could be obtained. Six species were listed as invasive alien species by the Global Register of Introduced and Invasive Species (GRIIS) and the Global Invasive Species Database (GISD) but not recorded as invasive in Southeast Asia. Meanwhile, six species were classified as Least Concern, 71 were categorised as Not Evaluated, and the remaining 98 were not included in the International Union for Conservation of Nature's Red List of Threatened Species. These statuses indicate that the current use of bivalves in the Southeast Asia region is still sustainable. Nevertheless, continuous monitoring should be conducted to provide appropriate data for proper management.

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## 1. Introduction

The intertidal zone in tropical and subtropical regions in 124 countries between the latitudes of 30°N and 30°S is where the distribution of mangroves is reported (FAO, 2007b; Giri et al.,

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2010; Kathiresan and Bingham, 2001). Various methods of classifying mangroves have been presented; the earliest was by Lugo and Snedaker (1974), who classified mangroves into over-washed, fringe, riverine, basin, scrub and hammock based on topography and hydrology. Then, Thom (1984) classified mangroves as carbonate settings, drowned bedrock valley, river- and wave-dominated, tide-dominated and river-dominated. More recently, FAO (2007a) classified mangroves in Southeast Asia into deltaic, fringing, estuarine and basin mangroves. In addition, 'mangrove wetland' is a term used to describe a mangrove forest and associated water bodies that are flooded by low saline water. Occasionally, freshwater floods occur during the monsoon seasons and brackish water or seawater floods in other periods (Selvam and Karunakaran, 2004).

A mangrove habitat is shaped by its characteristics. It is dominated by highly tolerant trees and shrubs which can survive under anaerobic and muddy soils, high temperature, strong tides and winds and unstable water salinity (Kathiresan and Bingham, 2001). Nevertheless, mangrove species possess particular morphological and ecophysiological adaptations to survive under extreme conditions, including aerial roots, viviparous water-dispersed propagules, high effectiveness of salt-excreting leaves and nutrient retention properties, and significant canopy production (Kathiresan and Bingham, 2001; Alongi, 2002). These unique adaptations allow gases exchange and transpiration in mangroves and further increase the dispersal rate of mangrove propagules.

Mangroves are characterised by high productivity and are rich in organic matter and nutrients, which support high biodiversity and provide a nursery ground for marine organisms (Prabhakar, 2012; Kabir et al., 2014). These attributes are closely linked to insufficient structural complexity, tannin capacity, sediment loads, mangrove litter decomposition, level of exploitation of natural sources and tidal inundation (Kabir et al., 2014). Furthermore, mangroves provide nutrients and spaces which contribute to a habitat that is conducive to flora and fauna. Notably, some species have commercial values as protein sources or building material which could be used for personal use or commercial activities (Aksornkoae, 2012).

Some bivalves from the phylum Mollusca are exclusively found in mangrove ecosystems. Notably, bivalves are among the commercial mangrove species. The earliest records on the diversity of bivalves in mangroves in Southeast Asia were published by Purchon and Purchon (1981) and Morris and Purchon (1981) in West Malaysia and Singapore, respectively. Specifically, 186 species were identified in West Malaysia and Singapore from various habitats, while 14 species were collected from the mangrove ecosystem. Most early studies on bivalves in mangrove ecosystems focused on bivalve diversity. Subsequently, more studies were conducted, including the studies by Ashton et al. (2003), Tan and Kastoro (2004), and Printrakoon et al. (2008). Investigations on the ecology of bivalves in the mangrove ecosystem were also conducted, such as feeding habits (Supriyantini et al., 2007; Tue et al., 2012), population structure (Prezant et al., 2008; Dolorosa and Dangan-galon, 2014; Yahya et al., 2017) and heavy metals (Edward et al., 2009; Yap et al., 2014; Ong et al., 2017).

This review focuses solely on bivalves identified in mangrove wetland ecosystems in Southeast Asia based on published data in scientific publications and reports. All identified bivalves were checked in online databases and datasets from international organisations, including the Global Worldwide Mollusc Species Data Base (Galli, 2016), Global Biodiversity Information Facility (GBIF, 2020), Invasive Species Compendium (CABI, 2019a), International Union for Conservation of Nature (IUCN)'s Red List of Threatened Species (2019), SeaLifeBase (Palomares and Pauly, 2019), and World Register of Marine Species' Editorial Board (2019), to determine their distribution which was not highlighted in

previous articles and current accepted scientific names. To specify the species' recent status in the environment, an inspection was conducted through the Global Invasive Species Database (GISD) and the Global Register of Introduced and Invasive Species (GRIIS, 2019), which were managed by the Invasive Species Specialist Group of the IUCN Species Survival Commission. The interaction between bivalves and mangrove ecosystems was also discussed. All information obtained from the online databases and datasets are classified country-wise and according to systematic classification. Possible factors affecting the population of identified bivalves and other issues are also discussed.

## 2. Mangroves in Southeast Asia

Mangroves in Southeast Asia constitute approximately 34%–42% of the 6.8 million ha of mangroves worldwide (Fig. 1). Specifically, Indonesia has the most extensive coverage of mangroves (60%), followed by Malaysia (11.7%), Myanmar (8.8%) and Thailand (5%) (Giesen et al., 2006). Notably, the development and diversity of mangroves have been reported to be the highest in Southeast Asia, and 268 species have been recorded. The diversity of mangroves included 52 true mangrove species which were available in mangroves (Giesen et al., 2006). Furthermore, mangroves were found in the intertidal zone, at the interface of land and sea (Hutchison et al., 2014). Moreover, mangroves are important for small-scale and commercial fisheries (Hutchison et al., 2014). However, there has been a marginal reduction in the area under mangrove cover due to human activities, including timber harvest and forest clearing for the construction of prawn and fish ponds (Sasekumar and Chong, 1998; Chong, 2006; Giesen et al., 2006; FAO, 2007b; Kabir et al., 2014).

Giesen et al. (2006) stated that 268 flora species were recorded in mangroves in Southeast Asia, including 129 trees and shrubs, 50 terrestrial herbs consisting of 27 types of grass and grass-like plants, 28 climbers, 28 epiphytes, 24 ferns, 7 palms, 1 screw pine (pandan) and 1 cycad. However, only 52 species, known as true mangrove species, were found exclusively in mangrove ecosystems, including 42 trees and shrubs (Giesen et al., 2006). Overall, the countries with a high diversity of mangroves are Indonesia with 45 species, Malaysia with 40 species, Thailand with 34 species and Singapore with 31 species (Kathiresan and Rajendran, 2005).

The mangrove ecosystem provides food and a complex root system, thereby contributing to a suitable feeding, reproduction, and nursery ground for commercial species, including crabs, fish, shellfish and prawns (Sasekumar and Chong, 1998; Rönnbäck, 1999; Kumar, 2000; Sze and Ahmad, 2000; Sydenham and Thomas, 2003; Selvam and Karunakaran, 2004; Kathiresan and Rajendran, 2005; FAO, 2007b; Aksornkoae, 2012; Nasution and Zulkifli, 2014; Ziaullah et al., 2015). The presence of mangroves in the intertidal zone results in low food supply from algae and phytoplankton compared with the food supply obtained from the subtidal zone (Selvam and Karunakaran, 2004). In this case, decomposition will take place to transform litter from shed leaves, broken twigs and branches, fallen fruits and other parts of mangroves into food. Moreover, mangrove litter will spread to the nearby water bodies during high tides, followed by the secretion of chemicals from the litter. These chemicals attract fungi to be attached to the decomposing litter before they are separated into small pieces (Selvam and Karunakaran, 2004). Fungal invasion results in the growth of bacteria on decomposing and finely decomposed matter. Overall, the decomposed matter, fungi, and bacteria are defined as detritus (Selvam and Karunakaran, 2004). The organisms which feed on detritus, including annelids, crabs, fish, molluscs, nematodes and shrimps, are known as detritivores or detritus consumers.

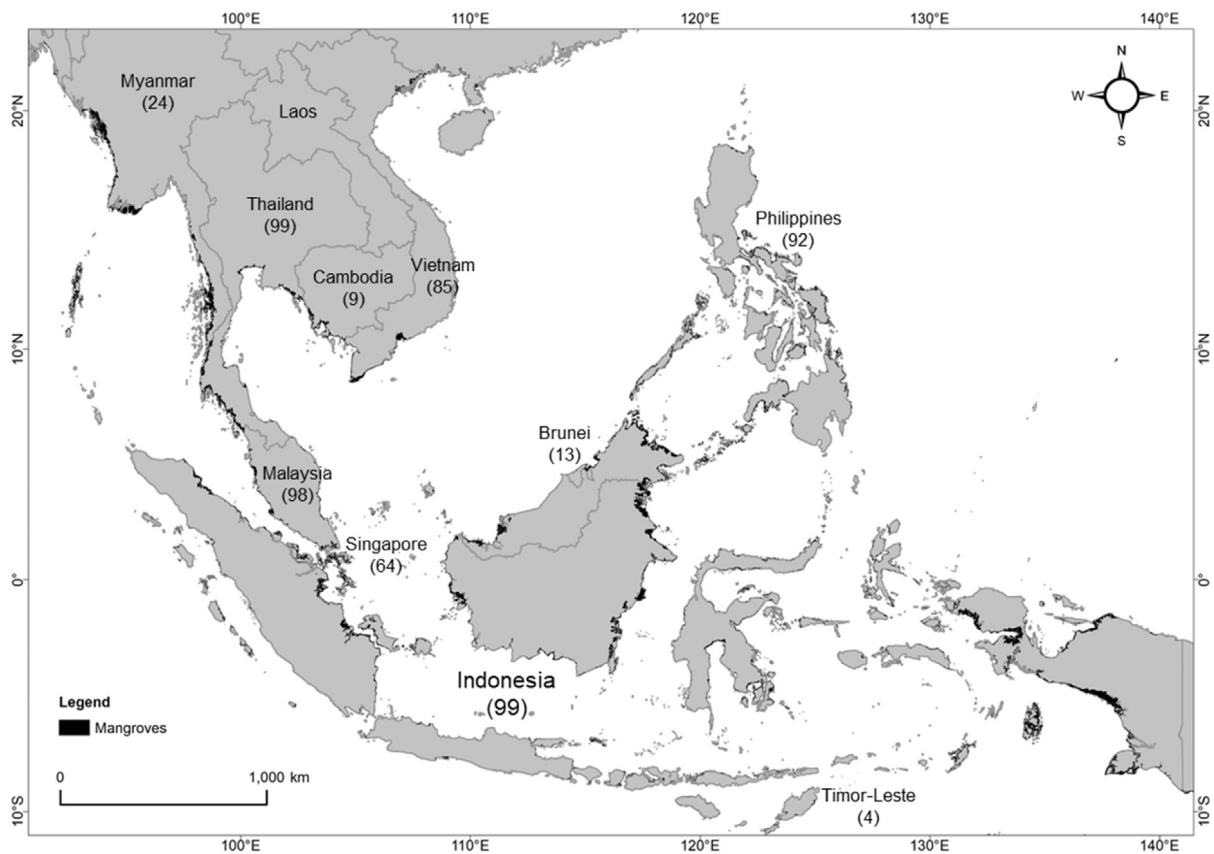


**Fig. 1.** Mangrove distribution in Southeast Asia in 2016. The numbers in brackets indicate the number of bivalve species recorded in the mangroves and listed in the review.

Source: Modified from Bunting et al. (2018).

### 3. Mangroves as a habitat for bivalves

The high productivity in mangroves from leaves, detritus and plankton contributes to the high diversity of macrofauna in mangroves. Macrofauna species are capable of preventing predation, tolerating extreme environmental changes, including desiccation of mangrove and fluctuation in temperature and water salinity levels, and surviving in mangroves (Nasution and Zulkifli, 2014; Tokan et al., 2018). Furthermore, upon horizontal or vertical distribution, molluscs in mangroves may be categorised into non-arboreal when living on a substrate's surface, infaunal when they are burrowed in the substrate, and arboreal when they are attached to the roots, stems and mangrove leaves (Mujiono, 2016). Compared with un-vegetated channel zones and mudflats, previous studies found that mangrove vegetation such as *Avicennia* spp. and *Rhizophora* spp. possessed a higher diversity of bivalves than other mangrove habitats (Sasekumar, 1974; Sheriden, 1997; Sasekumar and Chong, 1998; Printrakoon et al., 2008). Additionally, Printrakoon et al. (2008) highlighted that mollusc diversity in the *Rhizophora* spp. zonation was lower than that in the *Avicennia* spp. zonation in the upper Gulf of Thailand.

Also known as *Saccostrea* spp. and *Magallana* spp., oysters are sessile bivalves that live as attachments on substrates. They are commonly found in the low intertidal zone due to their ability to constantly acquire food through filtration (Khade and Mane, 2012). As a result, they have a dominant presence in the seaward fringe, where the pneumatophores of *Avicennia* spp. and *Sonneratia* spp. are usually found in high densities (Aksornkoae, 2012). Furthermore, the surface area of substrates for the settlement of transient organisms is extended in a complex three-dimensional structure due to the presence of pneumatophores

and roots of mangroves (Alfaro, 2006). Notably, pneumatophores reduce the water current velocity near the bottom of the mangroves, leading to food deposition for deposit feeders (Skilleter and Warren, 2000). Other bivalves such as *Isognomon ehippium* and *Brachidontes pharaonis* are attached to mangrove roots by their byssus, restricted to microhabitats located below the mean water depth, and are usually abundant in areas near open water (Macintosh, 1982; Menzel, 1991). All sessile bivalves in mangroves are broadcast spawners. This reproductive strategy is imperative to the survival of the population, allows the species to have wider distribution, and avoids overcrowding at one site of the mangroves.

The structure and elasticity of mangrove root masses make it impossible for bivalves with soft fleshy feet to penetrate (Nagelkerken et al., 2008). A possible and rational solution for these bivalves, such as the blood clam *Tegillarca granosa* and other cockles, is to shallowly burrow in the sediment (Macintosh, 1982). Most bivalve species are incapable of burrowing deeper in the mangrove sediments because of the presence of submerged roots and plant matter that decay at a slow rate compared with that in other ecosystems (Alongi, 2018). Generally, bivalves are incapable of tolerance if exposed to a wide range of water salinity and air for an extended period (Sasekumar, 1974). However, *Geloina expansa*, which was previously identified as *Polymesoda expansa* or *P. erosa*, is adjusted for a semi-terrestrial existence where it resides in the high shore. In this case, occasional high-tide inundation occurs in the habitat (Nagelkerken et al., 2008), and *G. expansa* could survive without water for up to 14 days (Morton, 1976). However, significantly low organic matter and pH in the high shore sediment may result in lower diversity and abundance of infauna bivalves in mangroves (Kabir et al., 2014). Moreover,

the shells of bivalves are sensitive as the calcium carbonate of the shell erodes at a low pH (Ashton et al., 2003).

#### 4. The functional role of bivalves in mangroves

The feeding modes of bivalves are essential in mangrove ecosystems. Bivalves in mangrove play either of the following roles: (1) filter feeding the suspended particles in the water column or (2) deposit feeding the food particles on the sediment surface. These feeding guilds are important for the continuous productivity and function of mangroves (Boominathan et al., 2008). The burrowing activities of bivalves facilitate the flushing of toxic substances and improve the water flow through the porosity of the sediment (Nagelkerken et al., 2008). Overall, filter and deposit feeding activities by bivalves contribute to nutrient recycling in mangroves (Kristensen et al., 2008). In addition, removal of suspended particles through filtering activities helps reduce turbidity, subsequently increasing the water quality in mangroves.

Other bivalves such as *Teredo* spp. function as ecosystem engineers which can create, significantly modify and maintain the habitat. Teredinid bivalves burrow in the woods (teredinid tunnels) and feed on rotten stems and dead mangroves (Hendy et al., 2014). Vacant teredinid tunnels create new habitats for other organisms such as gastropods, isopods and juvenile crabs (Hendy et al., 2014). These tunnels allow organisms to survive higher temperatures, external environments, desiccation and predators (Selvam and Karunakaran, 2004; Hendy et al., 2014). In contrast, teredinids are considered pests because they damage the hulls of wooden ships and wharf pilings due to their burrowing activities.

Bivalves could also be used as bio-indicators of the local mangrove biodiversity and ecosystem health (Macintosh et al., 2002; Amin et al., 2009). Ong et al. (2017) used *G. expansa* as a bio-indicator of metal contamination in Sungai (River) Kelantan, Malaysia. The bivalves' feeding guilds resulted in the accumulation of various nutrients and possible pollutants from the water column and surface sediments. Further, their limited mobility and sensitivity make them an ideal biological indicator in an environment.

Although humans usually collect bivalves for food, bivalves have also been exploited as sources of minerals, protein and glycogen (Suryavanshi et al., 2012). For example, *G. expansa* and *Crassostrea* spp. are known as food sources; in addition, they are currently being tested as potential antiviral drugs (Chatterji et al., 2002). These applications increase the demand for certain species. However, some of the commercial mangrove bivalves can only be harvested naturally in their habitat. For example, the mud clam *Geloina* spp. can only be harvested naturally in mangroves. *Geloina* spp. are highly exploited in the artisanal fisheries of India (Clemente and Ingole, 2009), Malaysia (Hamli et al., 2012), Indonesia (Sarong et al., 2015), Northern Australia (Gimin et al., 2004) and the Philippines (Dolorosa and Dangan-galon, 2014). Nevertheless, other commercial bivalves can be cultured, with the spat being produced in hatcheries, such as oysters from the genus *Magallana* (previously *Crassostrea*). The mariculture of oysters is a lucrative industry because oysters are highly sought after and demands are continuously increasing (Mizuta and Wikfors, 2019). Nevertheless, not all mangrove bivalves have commercial value. As an example, despite the high abundance and edibility of *Potamocorbula* spp., these species do not possess commercial value possibly due to its small size and absence of other applications.

#### 5. Biodiversity of bivalves in the mangroves of Southeast Asia

A total of 175 species of bivalves from 34 families, 87 genera and four unidentified species were recorded in mangrove areas from 10 Southeast Asian countries: Brunei, Cambodia, Indonesia, Malaysia, Myanmar, the Philippines, Singapore, Thailand, Timor-Leste and Vietnam (Fig. 1 and Table 1). The highest number of species was recorded in Indonesia, followed by Thailand, Malaysia and the Philippines (99, 99, 98 and 92 species, respectively). Meanwhile, lower numbers of species were recorded in Brunei, Cambodia and Timor-Leste (13, 9 and 4 species, respectively) due to the small area under mangrove cover and lack of research on bivalves in these countries. Although Singapore has the smallest area under mangrove cover, its bivalve diversity is high, with 37% of species recorded. In addition, no mangrove bivalve was recorded in Laos; this country is the only landlocked country in Southeast Asia. Moreover, a number of bivalves could not be identified up to the species level, including Veneridae, Teredinidae 1, Teredinidae 2 and Galeommatoidea gen. sp. (Paphavasit et al., 1996; Ashton et al., 2003; Hendy et al., 2014; Zvonareva et al., 2019).

Among the bivalve species, *Anadara antiquata*, *Corbicula fluminea*, *Donax faba*, *Enigmonia aenigmatica*, *Gafrarium pectinatum*, *Geloina bengalensis*, *G. expansa*, *I. ephippium*, *Meretrix meretrix*, *Planostrea pestigris* and *T. granosa* were found to be the most widely distributed in the mangrove wetlands of Southeast Asia (Fig. 2). Specifically, *E. aenigmatica* and *T. granosa* are present in nine countries and *A. antiquata*, *C. fluminea*, *D. faba*, *G. pectinatum*, *G. bengalensis*, *G. expansa*, *I. ephippium*, *M. meretrix* and *P. pestigris* are present in eight countries from the total of 11 countries representing Southeast Asia. Data from Brunei, Cambodia, Myanmar and Timor-Leste are limited but can be obtained from the online databases including Worldwide Mollusc Species Data Base (Galli, 2016) and Global Biodiversity Information Facility (GBIF, 2020), reflecting the lack of research in these countries. Indonesia, Malaysia, the Philippines and Thailand contribute more than 50% of the species listed in Table 1. At a glance, this may indicate the high diversity and endemism within these countries. However, it is believed that parataxonomists identified most of the bivalve species and relied on published descriptions; thus, the accuracy of the identification of certain species can be challenged. Moreover, identification by parataxonomists mostly depends on the morphology of the shells, without verification from bivalve taxonomists or confirmation via molecular techniques (e.g., DNA barcoding). In addition, a majority of publications involving bivalves in this region are without images or illustrations that can be used to determine whether the bivalve species in one country are similar to those in other countries. Hence, the species were treated as different species by labelling with numbers. For example, *Solen* sp. 1 and *Solen* sp. 2, recorded in Malaysia and Indonesia, respectively, cannot be categorised as similar species without strong evidence.

Despite being in the same region, the bivalves' richness in the mangroves in each country in Southeast Asia is slightly different. Various location and environmental parameters play significant roles in the species distribution of bivalves in mangroves. The distribution of bivalves can be divided by zonation patterns of tidal elevation, vegetation type and sediment properties in mangrove ecosystems (Dittmann, 2001) as well as physico-chemical properties of the environment, including salinity, temperature, depth, organic matter and sediment characteristics (Kathiresan and Bingham, 2001; Lee, 2008; Tokan et al., 2018). For example, oysters such as *Saccostrea cucullata* and *Magallana* spp., which attach to mangrove roots, are present in high abundance at the mangrove fringe, an area that is inundated most of the time. At the same time, mangrove clams such as *G. bengalensis* and

**Table 1**

Identified bivalves in the mangrove areas in Southeast Asia (/: present, -: not available, LC: Least Concern, and NE: Not Evaluated). Laos is the only Southeast Asia country with no mangrove.

Source: Frith et al. (1976), Frith (1977), Morris and Purchon (1981), Purchon and Purchon (1981), Toral-Barza and Gomez (1985), Chan (1986), Choy and Booth (1994), Paphavasit et al. (1996), Poutiers (1998), Ashton et al. (2003), Tan and Kastoro (2004), Printrakoon et al. (2008), Printrakoon and Tëmkin (2008), Nordhaus et al. (2009), Tan and Yeo (2010), Dewiyanthi and Karina (2012), Budiarsa and Rizal (2014), Dechruksa et al. (2014), Dolorosa and Dangan-galon (2014), Shokita (2014), Hendy et al. (2014), Hong (2014), Syafruddin and Zulkifli (2014), Aunurohlim Sujatmiko et al. (2015), Libres (2015), Zakaria and Rajpar (2015), Galli (2016), Premcharoen et al. (2016), Straffella et al. (2018), Suhendra et al. (2017), Yahya et al. (2017), Basyuni et al. (2018), Invasive Alien Species in Malaysia (2018), Octavina et al. (2018), Tokan et al. (2018), Baderan et al. (2019), Htwe and Oo (2019), Lee et al. (2019), Palomares and Pauly (2019) and Zvonareva et al. (2019).

| No. | Family         | Genus                | Species                         | Commercial values | IUCN | Brunei | Cambodia | Indonesia | Malaysia | Myanmar | Philippines | Singapore | Timor-Leste | Thailand | Vietnam |
|-----|----------------|----------------------|---------------------------------|-------------------|------|--------|----------|-----------|----------|---------|-------------|-----------|-------------|----------|---------|
| 1   | Anomiidae      | <i>Enigmonia</i>     | <i>Enigmonia aenigmatica</i>    | -                 | NE   | /      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 2   | Arcidae        | <i>Anadara</i>       | <i>Anadara antiquata</i>        | /                 | NE   | /      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 3   | Arcidae        | <i>Anadara</i>       | <i>Anadara cf. antiquata</i>    | /                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 4   | Arcidae        | <i>Anadara</i>       | <i>Anadara cornea</i>           | /                 | -    | -      | -        | /         | -        | -       | /           | /         | -           | /        | /       |
| 5   | Arcidae        | <i>Anadara</i>       | <i>Anadara gubernaculum</i>     | -                 | -    | -      | -        | /         | /        | -       | /           | /         | -           | -        | /       |
| 6   | Arcidae        | <i>Anadara</i>       | <i>Anadara kagoshimensis</i>    | /                 | -    | -      | -        | /         | /        | -       | /           | -         | -           | -        | /       |
| 7   | Arcidae        | <i>Anadara</i>       | <i>Anadara uropigimelana</i>    | /                 | NE   | -      | -        | /         | -        | -       | /           | -         | -           | /        | -       |
| 8   | Arcidae        | <i>Anadara</i>       | <i>Anadara sp.</i>              | -                 | -    | -      | -        | -         | -        | -       | /           | -         | -           | -        | -       |
| 9   | Arcidae        | <i>Arca</i>          | <i>Arca avellana</i>            | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 10  | Arcidae        | <i>Arca</i>          | <i>Arca ventricosa</i>          | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | /           | /        | /       |
| 11  | Arcidae        | <i>Barbatia</i>      | <i>Barbatia amygdalumtostum</i> | /                 | -    | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 12  | Arcidae        | <i>Barbatia</i>      | <i>Barbatia virescens</i>       | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 13  | Arcidae        | <i>Barbatia</i>      | <i>Barbatia sp. 1</i>           | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 14  | Arcidae        | <i>Barbatia</i>      | <i>Barbatia sp. 2</i>           | -                 | -    | /      | -        | -         | -        | -       | -           | -         | -           | -        | -       |
| 15  | Arcidae        | <i>Tegillarca</i>    | <i>Tegillarca granosa</i>       | /                 | NE   | /      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 16  | Arcidae        | <i>Tegillarca</i>    | <i>Tegillarca nodifera</i>      | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 17  | Cardiidae      | <i>Cerastoderma</i>  | <i>Cerastoderma glaucum</i>     | -                 | NE   | -      | -        | -         | -        | -       | /           | -         | -           | -        | -       |
| 18  | Cardiidae      | <i>Fragum</i>        | <i>Fragum mundum</i>            | -                 | NE   | -      | -        | /         | -        | -       | /           | -         | -           | -        | /       |
| 19  | Cardiidae      | <i>Fragum</i>        | <i>Fragum unedo</i>             | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 20  | Cardiidae      | <i>Vasticardium</i>  | <i>Vasticardium angulatum</i>   | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 21  | Cardiidae      | <i>Vasticardium</i>  | <i>Vasticardium flavum</i>      | -                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | -       |
| 22  | Corbulidae     | <i>Corbula</i>       | <i>Corbula fortisulcata</i>     | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | /       |
| 23  | Corbulidae     | <i>Corbula</i>       | <i>Corbula sp.</i>              | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 24  | Corbulidae     | <i>Potamocorbula</i> | <i>Potamocorbula fasciata</i>   | -                 | -    | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 25  | Cyrenidae      | <i>Corbicula</i>     | <i>Corbicula fluminea</i>       | /                 | LC   | -      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 26  | Cyrenidae      | <i>Corbicula</i>     | <i>Corbicula sp.</i>            | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 27  | Cyrenidae      | <i>Geloina</i>       | <i>Geloina bengalensis</i>      | /                 | LC   | -      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 28  | Cyrenidae      | <i>Geloina</i>       | <i>Geloina coxans</i>           | /                 | NE   | /      | -        | /         | -        | -       | /           | -         | -           | /        | /       |
| 29  | Cyrenidae      | <i>Geloina</i>       | <i>Geloina expansa</i>          | /                 | LC   | -      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 30  | Cyrenidae      | <i>Geloina</i>       | <i>Geloina sp.</i>              | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 31  | -              | -                    | <i>Galeommatoidea gen. sp.</i>  | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 32  | Donacidae      | <i>Donax</i>         | <i>Donax faba</i>               | -                 | NE   | -      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 33  | Glaucanoidae   | <i>Glaucanome</i>    | <i>Glaucanome angulata</i>      | -                 | -    | -      | -        | -         | -        | -       | -           | /         | -           | -        | /       |
| 34  | Glaucanoidae   | <i>Glaucanome</i>    | <i>Glaucanome curta</i>         | -                 | NE   | -      | -        | /         | -        | -       | /           | -         | -           | -        | -       |
| 35  | Glaucanoidae   | <i>Glaucanome</i>    | <i>Glaucanome vires</i>         | -                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | -       |
| 36  | Glaucanoidae   | <i>Glaucanome</i>    | <i>Glaucanome sp.</i>           | -                 | -    | /      | -        | -         | -        | -       | -           | -         | -           | -        | -       |
| 37  | Lasaeidae      | <i>Lasaea</i>        | <i>Lasaea sp.</i>               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 38  | Lasaeidae      | <i>Mysella</i>       | <i>Mysella sp.</i>              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 39  | Laternulidae   | <i>Laternula</i>     | <i>Laternula anatina</i>        | -                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 40  | Laternulidae   | <i>Laternula</i>     | <i>Laternula navicula</i>       | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 41  | Lucinidae      | <i>Anodontia</i>     | <i>Anodontia edentula</i>       | -                 | -    | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 42  | Lucinidae      | <i>Austriella</i>    | <i>Austriella corrugata</i>     | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 43  | Lucinidae      | <i>Austriella</i>    | <i>Austriella sp.</i>           | -                 | -    | -      | -        | -         | -        | -       | -           | /         | -           | /        | -       |
| 44  | Lucinidae      | <i>Liralucina</i>    | <i>Liralucina lyngei</i>        | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 45  | Lucinidae      | <i>Lucinoma</i>      | <i>Lucinoma sp.</i>             | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | -       |
| 46  | Lucinidae      | <i>Lucina</i>        | <i>Lucina sp.</i>               | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 47  | Lucinidae      | <i>Notomyrtea</i>    | <i>Notomyrtea fabula</i>        | -                 | NE   | -      | -        | -         | -        | -       | /           | -         | -           | -        | /       |
| 48  | Lucinidae      | <i>Pegophysema</i>   | <i>Pegophysema philippiana</i>  | -                 | NE   | -      | -        | /         | -        | -       | /           | /         | -           | -        | /       |
| 49  | Lucinidae      | <i>Pillucina</i>     | <i>Pillucina profusa</i>        | -                 | -    | -      | -        | -         | -        | -       | /           | -         | -           | -        | /       |
| 50  | Lucinidae      | <i>Pillucina</i>     | <i>Pillucina vietnamica</i>     | -                 | NE   | -      | -        | -         | -        | -       | -           | -         | -           | /        | /       |
| 51  | Mactridae      | <i>Heterocardia</i>  | <i>Heterocardia gibbosa</i>     | -                 | -    | -      | -        | -         | -        | -       | /           | /         | -           | /        | -       |
| 52  | Mactridae      | <i>Mactra</i>        | <i>Mactra chinensis</i>         | -                 | NE   | /      | -        | -         | /        | -       | /           | -         | -           | /        | /       |
| 53  | Mactridae      | <i>Mactra</i>        | <i>Mactra cumingii</i>          | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | /        | -       |
| 54  | Mactridae      | <i>Mactra</i>        | <i>Mactra cygnus</i>            | -                 | -    | -      | -        | /         | -        | -       | /           | -         | -           | /        | /       |
| 55  | Mactridae      | <i>Mactra</i>        | <i>Mactra iridescens</i>        | -                 | NE   | -      | -        | -         | -        | -       | /           | -         | -           | /        | -       |
| 56  | Mesodesmatidae | <i>Coecella</i>      | <i>Coecella horsfieldii</i>     | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 57  | Myidae         | <i>Sphenia</i>       | <i>Sphenia sp.</i>              | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 58  | Myochamidae    | <i>Myadora</i>       | <i>Myadora sp.</i>              | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 59  | Mytilidae      | <i>Arcuatula</i>     | <i>Arcuatula senhousia</i>      | -                 | NE   | -      | -        | /         | -        | -       | /           | /         | -           | /        | -       |
| 60  | Mytilidae      | <i>Brachidontes</i>  | <i>Brachidontes pharaonis</i>   | -                 | NE   | -      | -        | /         | /        | -       | -           | -         | -           | /        | -       |
| 61  | Mytilidae      | <i>Brachidontes</i>  | <i>Brachidontes mutabilis</i>   | -                 | NE   | -      | -        | /         | -        | -       | /           | /         | -           | /        | /       |
| 62  | Mytilidae      | <i>Brachidontes</i>  | <i>Brachidontes rostratus</i>   | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 63  | Mytilidae      | <i>Brachidontes</i>  | <i>Brachidontes striatulus</i>  | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |

(continued on next page)

Table 1 (continued).

| No. | Family         | Genus                | Species                            | Commercial values | IUCN | Brunei | Cambodia | Indonesia | Malaysia | Myanmar | Philippines | Singapore | Timor-Leste | Thailand | Vietnam |
|-----|----------------|----------------------|------------------------------------|-------------------|------|--------|----------|-----------|----------|---------|-------------|-----------|-------------|----------|---------|
| 64  | Mytilidae      | <i>Brachidontes</i>  | <i>Brachidontes</i> sp.            | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 65  | Mytilidae      | <i>Modiolatus</i>    | <i>Modiolatus flavidus</i>         | -                 | -    | -      | -        | /         | /        | -       | /           | -         | /           | -        | -       |
| 66  | Mytilidae      | <i>Modiolatus</i>    | <i>Modiolatus</i> sp.              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 67  | Mytilidae      | <i>Modiolus</i>      | <i>Modiolus auriculatus</i>        | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 68  | Mytilidae      | <i>Modiolus</i>      | <i>Modiolus modulaides</i>         | -                 | -    | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 69  | Mytilidae      | <i>Modiolus</i>      | <i>Modiolus</i> sp. 1              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 70  | Mytilidae      | <i>Modiolus</i>      | <i>Modiolus</i> sp. 2              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 71  | Mytilidae      | <i>Modiolus</i>      | <i>Modiolus</i> sp. 3              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 72  | Mytilidae      | <i>Perna</i>         | <i>Perna viridis</i>               | /                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 73  | Mytilidae      | <i>Xenostrobus</i>   | <i>Xenostrobus</i> sp.             | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 74  | Noetiidae      | <i>Estellacar</i>    | <i>Estellacar olivacea</i>         | -                 | NE   | -      | -        | -         | -        | -       | /           | -         | -           | /        | /       |
| 75  | Ostreidae      | <i>Crassostrea</i>   | <i>Crassostrea</i> sp.             | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 76  | Ostreidae      | <i>Dendostrea</i>    | <i>Dendostrea folium</i>           | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 77  | Ostreidae      | <i>Ostrea</i>        | <i>Ostrea edulis</i>               | /                 | -    | -      | -        | /         | /        | -       | -           | -         | -           | -        | -       |
| 78  | Ostreidae      | <i>Ostrea</i>        | <i>Ostrea</i> sp. 1                | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 79  | Ostreidae      | <i>Ostrea</i>        | <i>Ostrea</i> sp. 2                | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 80  | Ostreidae      | <i>Magallana</i>     | <i>Magallana bilineata</i>         | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | -        | /       |
| 81  | Ostreidae      | <i>Magallana</i>     | <i>Magallana gigas</i>             | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 82  | Ostreidae      | <i>Magallana</i>     | <i>Magallana rivularis</i>         | /                 | -    | -      | -        | /         | -        | -       | /           | -         | -           | /        | /       |
| 83  | Ostreidae      | <i>Planostrea</i>    | <i>Planostrea pestigris</i>        | /                 | LC   | -      | /        | /         | /        | /       | /           | -         | /           | /        | /       |
| 84  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea cucullata</i>        | /                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 85  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea cf. cucullata</i>    | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | /       |
| 86  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea echinata</i>         | /                 | NE   | /      | -        | /         | -        | -       | /           | -         | -           | -        | -       |
| 87  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea kegaki</i>           | -                 | LC   | -      | -        | /         | -        | -       | -           | /         | -           | -        | /       |
| 88  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea scyphophilla</i>     | -                 | LC   | -      | -        | /         | /        | -       | /           | /         | -           | -        | /       |
| 89  | Ostreidae      | <i>Saccostrea</i>    | <i>Saccostrea spathulata</i>       | -                 | -    | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 90  | Periplomatidae | <i>Cochlodesma</i>   | <i>Cochlodesma praetenue</i>       | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 91  | Pharidae       | <i>Pharella</i>      | <i>Pharella acutidens</i>          | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 92  | Pharidae       | <i>Sinonovacula</i>  | <i>Sinonovacula constricta</i>     | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 93  | Pharidae       | <i>Siliqua</i>       | <i>Siliqua</i> sp.                 | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 94  | Pinnidae       | <i>Atrina</i>        | <i>Atrina exusta</i>               | -                 | -    | -      | -        | /         | /        | -       | /           | -         | -           | -        | /       |
| 95  | Pinnidae       | <i>Pinna</i>         | <i>Pinna muricata</i>              | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | -        | /       |
| 96  | Placunidae     | <i>Placuna</i>       | <i>Placuna ephippium</i>           | /                 | NE   | -      | /        | /         | /        | -       | /           | /         | -           | /        | /       |
| 97  | Placunidae     | <i>Placuna</i>       | <i>Placuna placenta</i>            | /                 | NE   | /      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 98  | Psammobiidae   | <i>Gari</i>          | <i>Gari</i> sp.                    | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 99  | Psammobiidae   | <i>Hiatula</i>       | <i>Hiatula chinensis</i>           | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | /       |
| 100 | Psammobiidae   | <i>Hiatula</i>       | <i>Hiatula</i> sp.                 | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 101 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon australica</i>        | -                 | -    | /      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 102 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon ephippium</i>         | -                 | NE   | -      | /        | /         | /        | /       | /           | /         | -           | /        | /       |
| 103 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon cf. ephippium</i>     | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 104 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon isognomonum</i>       | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 105 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon nucleus</i>           | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 106 | Pteriidae      | <i>Isognomon</i>     | <i>Isognomon</i> sp.               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 107 | Samelidae      | <i>Theora</i>        | <i>Theora cadabra</i>              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 108 | Solecurtidae   | <i>Azorinus</i>      | <i>Azorinus</i> sp. (?)            | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 109 | Solenidae      | <i>Solen</i>         | <i>Solen cf. vagina</i>            | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 110 | Solenidae      | <i>Solen</i>         | <i>Solen delesserti</i>            | -                 | NE   | -      | -        | -         | -        | /       | /           | /         | -           | /        | -       |
| 111 | Solenidae      | <i>Solen</i>         | <i>Solen strictus</i>              | /                 | NE   | -      | -        | -         | /        | -       | /           | -         | -           | -        | /       |
| 112 | Solenidae      | <i>Solen</i>         | <i>Solen tchangii</i>              | -                 | -    | -      | -        | -         | -        | -       | /           | -         | -           | -        | /       |
| 113 | Solenidae      | <i>Solen</i>         | <i>Solen thachi</i>                | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 114 | Solenidae      | <i>Solen</i>         | <i>Solen</i> sp. 1                 | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 115 | Solenidae      | <i>Solen</i>         | <i>Solen</i> sp. 2                 | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 116 | Solenidae      | <i>Solen</i>         | <i>Solen</i> sp. 3                 | -                 | -    | /      | -        | -         | -        | -       | -           | -         | -           | -        | -       |
| 117 | Solenidae      | <i>Solen</i>         | <i>Solen</i> sp. 4                 | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 118 | Solenidae      | <i>Solen</i>         | <i>Solen</i> sp. 5                 | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 119 | Spondylidae    | <i>Spondylus</i>     | <i>Spondylus virgineus</i>         | -                 | -    | -      | -        | /         | -        | -       | /           | -         | -           | /        | -       |
| 120 | Tellinidae     | <i>Angulinides</i>   | <i>Angulinides opalinus</i>        | -                 | -    | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 121 | Tellinidae     | <i>Macalia</i>       | <i>Macalia bruguieri</i>           | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 122 | Tellinidae     | <i>Macoma</i>        | <i>Macoma</i> sp.                  | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 123 | Tellinidae     | <i>Moerella</i>      | <i>Moerella donacina</i>           | -                 | NE   | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 124 | Tellinidae     | <i>Exotica</i>       | <i>Exotica</i> sp.                 | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 125 | Tellinidae     | <i>Jactellina</i>    | <i>Jactellina clathrata</i>        | -                 | NE   | -      | -        | /         | -        | -       | /           | /         | -           | -        | /       |
| 126 | Tellinidae     | <i>Nitidotellina</i> | <i>Nitidotellina</i> sp.           | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 127 | Tellinidae     | <i>Pinguitellina</i> | <i>Pinguitellina cycladiformis</i> | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 128 | Tellinidae     | <i>Quidnupagu</i>    | <i>Quidnupagus palatam</i>         | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | -        | /       |
| 129 | Tellinidae     | <i>Serratina</i>     | <i>Serratina capsoides</i>         | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 130 | Tellinidae     | <i>Tellina</i>       | <i>Tellina</i> sp. 1               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 131 | Tellinidae     | <i>Tellina</i>       | <i>Tellina</i> sp. 2               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 132 | Tellinidae     | <i>Tellina</i>       | <i>Tellina</i> sp. 3               | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 133 | Tellinidae     | <i>Tellina</i>       | <i>Tellina</i> sp. 4               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 134 | Tellinidae     | <i>Tellina</i>       | <i>Tellina</i> sp. 5               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |

(continued on next page)

Table 1 (continued).

| No.   | Family       | Genus                 | Species                           | Commercial values | IUCN | Brunei | Cambodia | Indonesia | Malaysia | Myanmar | Philippines | Singapore | Timor-Leste | Thailand | Vietnam |
|-------|--------------|-----------------------|-----------------------------------|-------------------|------|--------|----------|-----------|----------|---------|-------------|-----------|-------------|----------|---------|
| 135   | Tellinidae   | <i>Tellinella</i>     | <i>Tellinella cruciata</i>        | /                 | -    | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 136   | Tellinidae   | <i>Tellinella</i>     | <i>Tellinella virgata</i>         | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | -       |
| 137   | Teredinidae  | <i>Bactronophorus</i> | <i>Bactronophorus thoracites</i>  | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 138   | Teredinidae  | <i>Nausitora</i>      | <i>Nausitora saulii</i>           | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 139   | Teredinidae  | <i>Teredo</i>         | <i>Teredo navalis</i>             | -                 | NE   | -      | -        | /         | -        | /       | -           | -         | -           | -        | /       |
| 140   | Teredinidae  | <i>Teredo</i>         | <i>Teredo</i> sp. 1               | -                 | -    | -      | -        | -         | -        | /       | -           | /         | -           | -        | -       |
| 141   | Teredinidae  | <i>Teredo</i>         | <i>Teredo</i> sp. 2               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 142   | Teredinidae  | <i>Teredo</i>         | <i>Teredo</i> sp. 3               | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 143   | Teredinidae  | -                     | Teredinidae 1                     | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 144   | Teredinidae  | -                     | Teredinidae 2                     | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | -        | -       |
| 145   | Trapezidae   | <i>Neotrapezium</i>   | <i>Neotrapezium sublaevigatum</i> | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 146   | Ungulinidae  | <i>Transkeia</i>      | <i>Transkeia globosa</i>          | -                 | -    | -      | -        | /         | -        | -       | -           | -         | -           | /        | -       |
| 147   | Trapezidae   | <i>Trapezium</i>      | <i>Trapezium bicarinatum</i>      | -                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | -       |
| 148   | Veneridae    | <i>Anomalodiscu</i>   | <i>Anomalodiscus squamosus</i>    | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 149   | Veneridae    | <i>Dosinia</i>        | <i>Dosinia anus</i>               | -                 | NE   | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 150   | Veneridae    | <i>Gafrarium</i>      | <i>Gafrarium dispar</i>           | -                 | NE   | -      | -        | /         | /        | /       | /           | -         | /           | /        | -       |
| 151   | Veneridae    | <i>Gafrarium</i>      | <i>Gafrarium pectinatum</i>       | -                 | NE   | /      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 152   | Veneridae    | <i>Marcia</i>         | <i>Marcia hiantina</i>            | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 153   | Veneridae    | <i>Marcia</i>         | <i>Marcia japonica</i>            | -                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 154   | Veneridae    | <i>Marcia</i>         | <i>Marcia recens</i>              | -                 | -    | -      | -        | /         | /        | -       | -           | /         | -           | /        | /       |
| 155   | Veneridae    | <i>Marcia</i>         | <i>Marcia</i> sp. 1               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 156   | Veneridae    | <i>Marcia</i>         | <i>Marcia</i> sp. 2               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 157   | Veneridae    | <i>Marcia</i>         | <i>Marcia</i> sp. 3               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 158   | Veneridae    | <i>Meretrix</i>       | <i>Meretrix casta</i>             | /                 | NE   | -      | -        | /         | /        | /       | /           | -         | -           | /        | /       |
| 159   | Veneridae    | <i>Meretrix</i>       | <i>Meretrix lusoria</i>           | /                 | NE   | -      | -        | /         | /        | -       | /           | -         | -           | /        | /       |
| 160   | Veneridae    | <i>Meretrix</i>       | <i>Meretrix lyrata</i>            | /                 | NE   | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 161   | Veneridae    | <i>Meretrix</i>       | <i>Meretrix meretrix</i>          | /                 | NE   | /      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 162   | Veneridae    | <i>Paphia</i>         | <i>Paphia</i> sp. 1               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 163   | Veneridae    | <i>Paphia</i>         | <i>Paphia</i> sp. 2               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 164   | Veneridae    | <i>Paphia</i>         | <i>Paphia</i> sp. 3               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 165   | Veneridae    | <i>Paphia</i>         | <i>Paphia</i> sp. 4               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 166   | Veneridae    | <i>Paphia</i>         | <i>Paphia</i> sp. 5               | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 167   | Veneridae    | <i>Pelecypora</i>     | <i>Pelecypora exilium</i>         | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | /        | -       |
| 168   | Veneridae    | <i>Pitar</i>          | <i>Pitar</i> cf. <i>striatus</i>  | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 169   | Veneridae    | <i>Pitar</i>          | <i>Pitar</i> sp.                  | -                 | -    | -      | -        | -         | /        | -       | -           | -         | -           | -        | -       |
| 170   | Veneridae    | <i>Placamen</i>       | <i>Placamen isabellina</i>        | -                 | -    | -      | -        | /         | /        | -       | /           | /         | -           | /        | /       |
| 171   | Veneridae    | <i>Ruditapes</i>      | <i>Ruditapes philippinarum</i>    | -                 | NE   | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 172   | Veneridae    | <i>Ruditapes</i>      | <i>Ruditapes</i> sp.              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | -        | /       |
| 173   | Veneridae    | <i>Tapes</i>          | <i>Tapes literatus</i>            | -                 | -    | -      | -        | /         | /        | /       | /           | /         | -           | /        | /       |
| 174   | Veneridae    | -                     | Unidentified Veneridae            | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| 175   | Xylophagidae | <i>Xylophaga</i>      | <i>Xylophaga</i> sp.              | -                 | -    | -      | -        | -         | -        | -       | -           | -         | -           | /        | -       |
| TOTAL |              |                       |                                   | 34                | -    | 13     | 9        | 99        | 98       | 24      | 92          | 64        | 4           | 99       | 85      |

*G. expansa* live in sediments adjacent to or within the mangrove roots area.

Commercial species of bivalves such as oysters, clams, mussels and cockles are collected by local communities to be consumed or sold at markets and restaurants. Although bivalves are edible, only 35 identified species possess commercial values. Some commercial bivalves possess high production and high market value and are easy to culture, such as *Magallana bilineata*, *T. granosa* and *S. cucullata*. Indonesia, Malaysia, the Philippines and Singapore are among the Southeast Asian countries with a high production of bivalves in the shellfish culture sector. The shellfish culture sector offers great potential for Southeast Asian countries to increase domestic consumption and foreign exchange earnings from export (Lovatelli, 1988).

Among the bivalve species listed in Table 1, six species are classified as Least Concern, 71 species are classified as Not Evaluated, and the remaining 98 are not recorded in the IUCN Red List of Threatened Species. The IUCN Red List of Threatened Species defines species under Least Concern as those which have been assessed following the Red List criteria. Besides, these species do not possess the qualifications to be listed as Critically Endangered, Endangered, Vulnerable or Near Threatened categories. Not Evaluated refers to species which are yet to be assessed under the IUCN Red List of Threatened Species. Overall, these conservation

statuses may illustrate that sustainable use of these resources is applied. However, continuous monitoring should be conducted to update the conservation status of these species.

Interestingly, *B. pharaonis*, *B. striatulus*, *C. fluminea*, *Magallana gigas*, *Ostrea edulis* and *Teredo navalis* are among the invasive alien species listed in GRIIS and GISD (Fig. 2). However, *C. fluminea* is a native species of Southeast Asia, while *B. pharaonis*, *B. striatulus*, *M. gigas*, *O. edulis* and *T. navalis* are non-native species. *B. pharaonis* is native to the Red Sea and the Indian Ocean, *B. striatulus* is native to India, *M. gigas* is native to the coast of east Asia, *O. edulis* is native to Europe and the Mediterranean, and the origin of *T. navalis* is still unknown (CABI, 2019a; CABI, 2019b; CABI, 2019c; CABI, 2019d; GISD, 2019a; GISD, 2019b; Ho, 2013; Morton and Tan, 2006). CBD (2019) and IUCN (2019) have defined native species as species restricted to a particular geographical region and non-native or alien species as species introduced outside its natural past or present distributional range. The non-native or alien species can be an invasive species as its population increases in size, and its invasion has a negative impact on the ecosystem it has been introduced in IUCN (2019). Non-native species have been introduced in Southeast Asia either by aquaculture, discharge from ballast water, ship hulls, or other human activities. Nonetheless, all alien bivalve species are not categorised as invasive in this region. Interestingly, the infamous



**Fig. 2.** The most widely distributed species of bivalves in the mangrove wetlands of Southeast Asia. Images retrieved from catalogues and collections from the Natural History Museum Rotterdam, Netherlands (Donax faba), Rijksmuseum van Natuurlijke Historie, Netherlands (Planostrea pestigris) and the South China Sea Repository and Reference Centre, Universiti Malaysia Terengganu, Malaysia (Anadara antiquata, Corbicula fluminea, Enigmonia aenigmatica, Gafrarium pectinatum, Geloina bengalensis, Geloina expansa, Isognomon ephippium, Meretrix meretrix and Tegillarca granosa).

invasive bivalve Caribbean mussel (*Mytilopsis sallei*) has not been found in the mangrove area, although this species was found at a high density in the river and monsoon drain in Singapore and Malaysia with a salinity range of 2 to 22 ppt (Tan and Morton, 2006).

*Corbicula fluminea* is one of the commercial bivalve species in Southeast Asia. It is highly invasive in its introduced range, but the size of its population has not been recorded. This species has been introduced in several parts of Africa, North America and throughout Europe and the Mediterranean (Aldridge et al., 2012). Rapid growth, early sexual maturity, short life span and high fecundity (*r* life strategy) are the major factors for colonisation of *C. fluminea* of new environments (Sousa et al., 2008). The introduction of *C. fluminea* to the United States has caused

clogging of water intake pipes, subsequently affecting power and water treatment plants as well as other industries that require raw water (GISD, 2019a).

Ballast water and ship hulls are the main vectors of the introduction of *B. pharaonis* and *B. striatulus* in other regions (CABI, 2019a; Morton and Tan, 2006). *B. pharaonis* is among the early non-native species recorded in the eastern Mediterranean, and it is invasive in Turkey and Sicily (CABI, 2019a; Doğan et al., 2007; Sarà et al., 2000). The invasiveness of *B. pharaonis* caused many problems to the economy and ecosystems, such as damage to ecosystem services, reduction of the native biodiversity and infrastructure damage and transportation disruption. The fouling activities of *B. pharaonis* caused economic problems to ship owners in Turkey, and it invaded the coral reefs near the Suez



**Fig. 3.** Bivalve species found in Southeast Asia that are listed as alien and/or invasive species. Images of *Magallana gigas*, *Ostrea edulis* and *Teredo navalis* were retrieved from catalogues and collections from the Natural History Museum Rotterdam, Netherlands; *Brachidontes pharaonis* and *Corbicula fluminea* from the South China Sea Repository and Reference Centre, Universiti Malaysia Terengganu, Malaysia; and *Brachidontes striatulus* from the Zoölogisch Museum Amsterdam, Netherlands.

Canal (CABI, 2019a; Çinar, 2006). *Brachidontes striatulus* is present abundantly in India but did not significantly affect countries in which it was introduced, such as Singapore and Malaysia (Morton and Tan, 2006).

The Pacific oyster (*M. gigas*), which originated in Japan, has been introduced as an aquaculture species in Malaysia, the Philippines, Singapore, Thailand and Vietnam due to its rapid development and tolerance to various environmental conditions (FAO, 2019; GISD, 2019b). At present, this species is not suppressing the native oyster species. Unfortunately, *M. gigas* became an invasive species in New Zealand and Australia, replacing native species by competing for food and space by building large oyster beds through its natural spat settlement and recruitment (CABI, 2019b). The high tolerance to salinity changes of the European oyster *O. edulis* has been exploited commercially. The successful cultivation of *O. edulis* resulted in high oyster production and initiated the introduction of this species to other regions (CABI,

2019c). Nonetheless, there is no documented study on the impact of the introduction of *O. edulis* to this region.

Often mistakenly identified as annelids, shipworms such as *T. navalis* are bivalves with unknown origin; thus, their current status is listed as cryptogenic in many repositories (CABI, 2019d; Ho, 2013). Accidental introduction by ballast water and ship hulls are the main vectors of dispersal of *T. navalis* other than via floating woods, which depends on water currents (CABI, 2019d). *T. navalis* has been recorded in Indonesia, Myanmar and Vietnam. However, no study has recorded the severity of its invasiveness in Southeast Asia. The burrowing activity of *T. navalis* in any unprotected and untreated wooden constructions submerged in marine waters such as wooden ships and harbour buildings is very destructive (CABI, 2019d). *T. navalis* is widely distributed in Japanese waters and has affected the seawater logs stored in the country (Tsunoda, 1979).

The species listed in Table 1 give a general overview of the current biodiversity of bivalves in the mangroves of Southeast Asia. The high number of species shows that mangrove ecosystems are important to conserve the biodiversity of bivalves. Species categorised as critical should be paid close attention as they have the capacity to be invasive in this region. All the data provided here are important for the development of policies and decision-making regarding the conservation and sustainable management of bivalves in the mangroves of Southeast Asia.

## 6. Conclusion

Mangroves are an essential habitat for bivalves. Some bivalves are found exclusively in mangrove ecosystems. The biodiversity of bivalves in the mangroves of Southeast Asia varies across countries owing to the different environments and various depths of research conducted in each country. Hence, additional studies on Southeast Asia's bivalves in mangrove ecosystems are necessary to cover various aspects, including proper taxonomic works using both morphological and molecular identification methods, ecological function and requirement by selected species, identification of potential applications of alternative species to reduce exploitation of certain species, and identification of key bivalve species in mangrove ecosystems. The compilation of data on the biodiversity, ecology and ecosystem services of bivalves in mangroves in Southeast Asia is important for the development of policies and decision-making regarding conservation and sustainable management of this resource, including alien and invasive species management, and improving the community livelihood that lives and depends on mangroves.

## CRedit authorship contribution statement

**Nurulafifah Yahya:** Conceptualization, Methodology, Visualization, Investigation, Writing - original draft. **Izwandy Idris:** Funding acquisition, Conceptualization, Investigation, Methodology, Writing - review & editing. **Noor Shahida Rosli:** Investigation, Writing - review & editing. **Zainudin Bachok:** Funding acquisition, Supervision, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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