

Diversity and Long-Term Dynamics of the Macrobenthos in a Mangrove Plantation and Two Natural Associations of Khanh Hoa Province, Vietnam

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Abstract—The rapid decline in the area occupied by mangrove forests has convinced the Vietnamese government to launch a program for conserving and restoring the mangrove ecosystems throughout the country. This program included an experimental planting of *Rhizophora apiculata* seedlings in Dam Bay in Khanh Hoa province. In the course of this work, the state of the macrobenthos was monitored in new mangrove plantations, and its quantitative and qualitative characteristics were compared with those in natural mangrove associations of this area. The bulk of the material was collected in three intertidal zones in the area of mangrove plantations in Dam Bay. In addition, natural mangrove associations were investigated: one in Dam Bay, and the other (the most mature and largest association of the area) in the neighboring Nha Phu Bay. The natural mangrove association in Dam Bay was represented by a narrow belt of *Rhizophora apiculata*. The intertidal zone in the area of mangrove plantations is also represented by a narrow belt of *Rhizophora apiculata*. Until 2004, the middle and lower zones were formed by the mudflat. In 2004, mangrove seedlings were planted in the middle intertidal zone below the mature trees of the upper zone. As the seedlings grew, they began to slow down tidal currents, and nutrients began to linger in the ecosystem. The developing crown of young trees began to give litter and shade, favorable for the development of microalgae. In addition, young trees formed a hard substrate. As a result, there was an increase in the species diversity of the macrobenthic eurybiotic species and an increase in the abundance of opportunistic species. Young trees in the middle intertidal zone and formed a single mangrove forest of a large area together with adult trees of the upper zone, which caused the appearance of specialized species of gastropods and bivalve mollusks, as well as crabs. During the monitoring period, the composition and structure of the macrobenthos of mangrove plantations were gradually approaching to those in the mature natural mangrove association in Nha Phu. However, significant differences still remain between these associations after ten years of observing the growth of mangrove seedlings. The macrobenthos of Nha Phu is represented by a large number of specialized mangrove species of gastropod mollusks, and it also has a completely different structure of the taxocene of bivalve mollusks. This is likely explained by the high floristic diversity in Nha Phu and the maturity of this mangrove association. As a result of qualitative and quantitative collection of the macrobenthos, 139 species of invertebrates were found in the three mangrove associations studied. The key groups of the macrobenthos are gastropods, bivalve mollusks, and crabs. The data obtained on the composition and diversity of the macrobenthos fit into the general pattern of the mangrove fauna of the Indo-West Pacific and Southeast Asia.

Keywords: bioindication, specialized species, long-term monitoring, invertebrates, crabs

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INTRODUCTION

Mangrove forests grow on the border of the sea and land on the coasts of the tropical and equatorial zones. Mangroves of Southeast Asia are of the greatest interest because they cover large areas and have a higher diversity of flora and fauna than other regions (Ellison et al., 1999). In recent decades, mangrove areas have been declining everywhere, and Vietnam is no exception (Walters et al., 2000). Earlier, Vietnamese mangroves occupied about 4000 km², but herbicides and

napalm used during the war (1962–1971) destroyed about 1050 km² (Hong and San, 1993). Population and economic growth after the Vietnam War also led to a significant reduction in the area occupied by mangrove forests. The development of shrimp and crab farms, the construction of salt ponds, agriculture, coal mining, and oil pollution of coastal waters lead to the degradation of associations, which turned into wastelands in some places (Hong and San, 1993). The majority of the surviving mangroves are located in the

Mekong Delta, and even these are predominantly secondary forests and plantations (Spalding et al., 1997).

However, it has long been known how important the role of mangrove forests is for the functioning of other ecosystems in coastal waters and for the economies of coastal countries. Mangroves serve as a habitat for a diverse fauna of invertebrates, fish, reptiles, and birds and support the productivity of other coastal communities, providing food and a place for the growth of larvae and juveniles of many species, including commercial fish and invertebrates (Kathiresan and Bingham, 2001; Twilley et al., 1992). They stabilize the coastline, filter fresh runoff, and significantly reduce damage from typhoons and tsunamis (Mazda et al., 2002, 2006). Mangroves can be an ecotourism destination (Ellison, 2008). In addition, traditional forms of mangrove use are widespread along the entire coast of Vietnam: as a building material, as a fuel, as a place for obtaining food, etc. (Hong and San, 1993).

In this regard, the need to preserve and restore mangrove forests has been recognized at the state level. The Vietnamese government has established several national parks and protected areas, as well as artificial mangrove plantations (Field 1998; Hong and San, 1993).

At present, a large amount of information has been collected and many works and reviews have been published on individual areas of study of mangroves.

Mangrove trees form a habitat for a diverse invertebrate fauna. The key invertebrate groups in the mangrove ecosystem are mollusks and crabs, which have a high diversity and population density and a significant biomass. In addition, the functioning of the ecosystem largely depends on the vital activity of these groups (Berry, 1963; Kathiresan and Bingham, 2001; Lee, 1998, 1999; Macnae, 1968).

The invertebrate species living here have different relations to the mangrove ecosystem. There are both specialized species found only in mangroves and eurybiotic species, i.e., species adapted to a wide range of conditions and inhabiting different types of ecosystems. Specialized species of gastropods include the majority of representatives of the family Potamididae, the genus *Littoraria* (Littorinidae), and some representatives of the families Neritidae, Cerithiidae, Assimineidae, etc. (Frey, 2010; Houbrick, 1985, 1992; Reid, 1985, 1986, 2014; Reid et al., 2008, 2010). Among bivalve mollusks, these are representatives of the genus *Geloina*, some representatives of the family Lucinidae, and others (Morton, 1976; Kathiresan and Bingham, 2001; Glover and Taylor, 2016). For crabs, there is no detailed information on specialized mangrove species, but it is known that a high diversity and abundance of representatives of the superfamily Grapsoidea is characteristic of mature and undisturbed mangroves, while a high abundance of species of the superfamily Ocypodoidea is inherent in young and

disturbed mangrove ecosystems (Macintosh et al., 2002).

In addition to the three key macrobenthos groups, representatives of other taxa inhabit mangrove associations. Jellyfish (Tsingalia, 2014), burrowing anemones (Mitra and Pattanayak, 2013), annelids (Metcalf and Glasby, 2008), sipunculids (Adrianov and Maiorova, 2012; Gopal and Chauhan, 2006; Macnae, 1968), hermit crabs (Gherardi and Vannini, 1993; Kathiresan and Bingham, 2001; Macnae, 1968), praying mantises (Ng, 2013), shrimps (Kathiresan and Bingham, 2001; Macnae, 1968; Yu et al., 1997), brachiopods (Mitra and Pattanayak, 2013a; Printrakoon and Kamlung-ek, 2013), acorn worms (Dittmann, 2002; Kumar, 2000), etc., live in mangroves of various regions of the Indo-West Pacific.

There are relatively few publications dealing with various aspects of the mangrove ecosystems in Vietnam. In addition, a significant part of them are written in Vietnamese. The fauna of Vietnamese mangroves is very poorly studied. Hong and San (1993) provide data from studies on crabs, polychaetes, and mollusks; Chertoprud et al. (2012) analyze the diversity and distribution of crabs found in mangroves in the vicinity of Nha Trang. Taxonomic studies on shrimp from Vietnamese mangroves have been published (Anker et al., 2006; Dworschak et al., 2006; Marin, 2008, 2014). In addition, there are a number of studies on the meiobenthos (Mokievsky et al., 2011; Tchesunov et al., 2010; Xuan et al., 2007).

The diversity and structure of invertebrate fauna is altered by disturbance, exploitation, management, or restoration of mangroves. Thus, these parameters can reflect the status of the mangrove association and can be used as an indicator of changes both in natural mangrove forests and in plantations (Macintosh et al., 2002).

In 2005, an experiment on planting *Rhizophora apiculata* Blume seedlings was started in Dam Bay (Tre Island, Nha Trang Bay). The aim of the work was to trace the qualitative and quantitative changes in the macrobenthos in plantations over time, as well as to compare the macrobenthos of plantations and natural mangrove associations. We carried out a ten-year monitoring of the macrobenthos fauna in three intertidal zones in the area of mangrove plantations of Dam Bay; the macrobenthos of these horizons correlated with the state of the nearest natural mangrove associations. Some data on gastropod mollusks have already been published as part of this large-scale project. The paper by (Zvonareva et al., 2016) provides a complete list of gastropods. In addition, some data on the quantitative characteristics of gastropods up to 2012 was published (Zvonareva et al., 2015).

This study covers all key macrobenthos groups of natural and artificial mangroves in central Vietnam, which are not often seen by researchers. For the first time, all stages of the formation of a community of

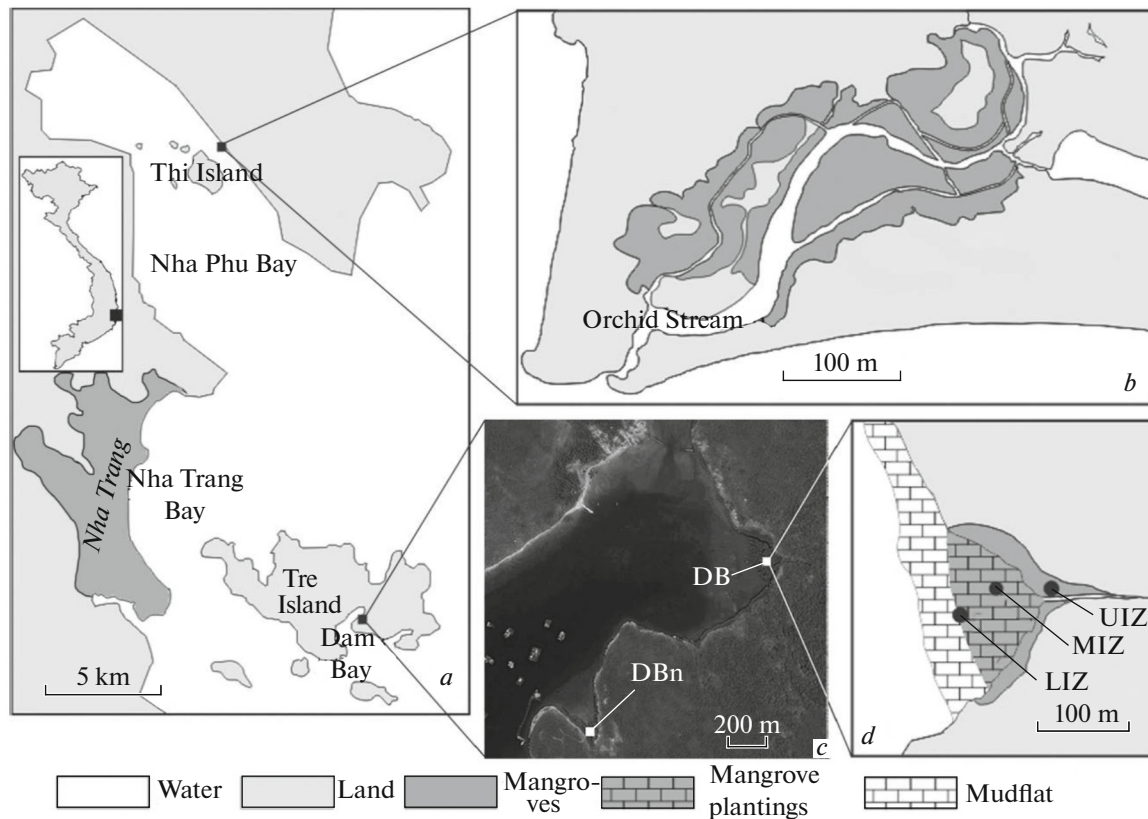


Fig. 1. Map of areas surveyed (according to Zvonareva et al., 2015): (a) map of the study area showing its location on a map of Vietnam; (b) scheme of mangrove association in Nha Phu Bay; (c) satellite image of the natural mangrove association and mangrove plantings in Dam Bay (2014); (d) scheme of mangrove plantings in Dam Bay, indicating the location of the stations studied.

macrobenthos invertebrates in mangrove plantations from the moment of planting of seedlings to their ten-year age have been recorded, which has no analogues.

MATERIAL AND METHODS

The coast of central Vietnam in Nha Trang and Nha Phu bays (Fig. 1) is often subject to storms, so mangroves are found here only in well-protected bays and lagoons (Hong and San, 1993). In Nha Trang and Nha Phu bays mangroves are scarce and often in poor condition due to anthropogenic influence. At the moment, they are present around the mariculture ponds at the mouth of the Be River within the boundaries of the city of Nha Trang and in the inner part of Nha Phu Bay. The largest natural mangrove association without mariculture is located on the northeastern coast of Nha Phu Bay. In addition, mangroves, represented by narrow belts of vegetation, are present on the islands of Nha Phu Bay and in the interior of Dam Bay.

Before the mangrove seedlings were planted, the upper intertidal zone in a small depression on the coastline of the eastern coast of Dam Bay (Tre Island, Nha Trang Bay, Fig. 1) was occupied by a narrow zone

of *Rhizophora apiculata* mangroves with a small admixture of *Avicennia marina* (Forsk.) Vierh. (coordinates: 12°13.116' N, 109°18.230' E). In 2004, seedlings of *Rhizophora apiculata* were planted in the sandy-silty mid intertidal zone (12°12.097' N, 109°18.213' E). In 2007, seedlings were planted in the lower intertidal zone (12°12.086' N, 109°18.166' E).

The material was collected not only from mangrove plantations, but also from two natural associations. There is a natural mangrove association in a small bay to the south of the plantings in Dam Bay (coordinates: 12°11.858' N; 109°17.949' E, Fig. 1), the type and size of which correspond to the upper intertidal zone in the area of plantation before planting of seedlings on the mid and lower intertidal zones. In addition, a large natural association was investigated in Nha Phu Bay near Orchid Stream Park (NP station, coordinates: 12°24.362' N; 109°14.407' E, Fig. 1). It differs from the mangroves in Dam Bay by the structure of the vegetation. Trees here grow along the stream, which is somewhat freshened by runoff from the mountains (up to 18‰ in the upper reaches). Mangrove trees are represented by seven species with dominance of the Rhizophoreacea family in the lower reaches and *Xylocarpus granatum* and *Excoecaria agallocha* in the upper

Table 1. List of mangrove surveys conducted

Work time	Sampling method		
Mangrove plantings in Dam Bay			
	UIZ	MIZ	LIZ
October 2005	3 × 0.11	3 × 0.11	3 × 0.11
November 2006	5 × 0.0225	5 × 0.0225	5 × 0.0225
October 2008	3 × 0.11	2 × 0.11, 3 × 0.026	3 × 0.025
May 2009	3 × 0.11	3 × 0.11	3 × 0.11
October 2009	4 × 0.11	4 × 0.11	4 × 0.11
May 2010	4 × 0.11	4 × 0.11	4 × 0.11
October 2010	4 × 0.11	4 × 0.11	3 × 0.11
May 2011	4 × 0.11	4 × 0.11	4 × 0.11
October 2011	4 × 0.11	4 × 0.11	4 × 0.11
September 2012	4 × 0.11	4 × 0.11	4 × 0.11
May 2013	8 × 0.11	7 × 0.11	4 × 0.11
May 2014	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01
October 2014	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01
October 2015	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01	4 × 0.11, 4 × 0.01
Natural mangrove associations			
	DBn	NP	
September 2012	–	4 × 0.11	
May 2013	7 × 0.11	qlt.	
May 2014	4 × 0.11, 4 × 0.11	qlt.	
October 2014	4 × 0.11, 4 × 0.11	qlt.	
October 2015	4 × 0.11, 4 × 0.11	3 × 0.11, 3 × 0.01	

The month and year of field work, station, method of quantitative sampling (number of samples × sample area, m²), and collection of quality samples is noted. UIZ, upper intertidal zone in the area of mangrove plantings; MIZ, mid intertidal zone of littoral plantings; LIZ, lower mid intertidal zone; DBn, natural mangrove association at Dam Bay; NP, natural mangrove association in Nha Phu Bay; qlt., only qualitative samples were collected in the survey, in all other cases qualitative samples were collected in addition to quantitative ones.

reaches. This association is subject to anthropogenic influence as it is located next to a recreational park.

Quantitative samples have been collected in the planting area since 2005. We used various sampling gear: bottom sampler, tubes, and frames of different sizes, and a frame with an area of 0.11 m² was used in most cases. The number of samples at the station also varied from year to year; four samples were usually collected. The soil was removed from the frame to a depth of 15–20 cm, then the animals were separated from the soil by elutriation in a bucket. The remaining coarse fraction of the precipitate was washed through a sieve with a mesh size of 3 mm. Starting in 2014, soil from a 0.11 m² frame was immediately placed on a sieve, and only soil from a small 0.01 m² frame was elutriated. Animals were picked from the samples after sorting at the laboratory in Nha Trang. Worm-like animals were fixed with 4% formalin, and the rest, with

75% alcohol. For each quantitative sample, the abundance and biomass were then calculated.

In addition to quantitative samples, qualitative samples were also collected from tree trunks and roots, and large and rare animals were also collected (hand picking). Table 1 shows a list of stations and sample areas in Dam Bay and Nha Phu bay.

In this work, it was decided not to include data on the phylum Annelida, since this is a very difficult group for species identification, determination is labor-intensive, and their processing was not included in the tasks of this work.

All collections are stored in the Laboratory of Morphology and Ecology of Marine Invertebrates, Severtsov Institute of Ecology and Evolution, Russian Academy of Sciences.

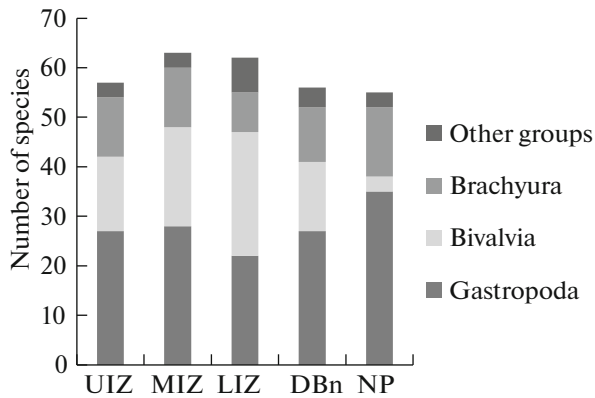


Fig. 2. Species diversity of macrobenthos invertebrates (except for annelids) in three intertidal zones of mangrove plantations and in two natural mangrove associations found over the entire study period. UIZ, upper intertidal zone in the area of mangrove plantings; MIZ, mid intertidal zone; LIZ, lower intertidal zone; DBn, natural mangrove association at Dam Bay; NP, natural mangrove association in Nha Phu Bay.

RESULTS

In the mangrove associations studied by us, 139 species of macroinvertebrates were found (excluding Annelida, the species identification of which was virtually impossible). Gastropods and bivalve mollusks and crabs were the most diverse, while other groups were represented by 1–2 species.

Figure 3 shows the species diversity of macrobenthos groups at the stations studied.

Gastropods

Gastropods are the most diverse group represented by 64 species from 24 families. The most diverse families were Neritidae (eight species), Cerithiidae (seven species), Potamididae (six species), Littorinidae (six species), Onchidiidae (six species), and Ellobiidae (five species).

Gastropods were the most diverse group at all stations, except for the lower intertidal zone. Forty-five species were found in the mangrove plantations, with the upper and mid intertidal zones having 27 and 28 species, respectively, and fewer in the lower intertidal zone (22 species). Thirty-five species were found in the natural association in Nha Phu, and 27 species were found in the natural association in Dam Bay.

Of all the species found, 17 can be called specialized species. The most diverse among them is the natural association in Nha Phu (16 species, see Fig. 2). In the plantings, the lower intertidal zone was the poorest (only three specialized species), and the upper and middle ones had 10 and 11 species, respectively. It should be noted that in the last survey two specialized mangrove species were found in the mid intertidal zone of plantings: *Terebralia sulcata* (Born 1778) and

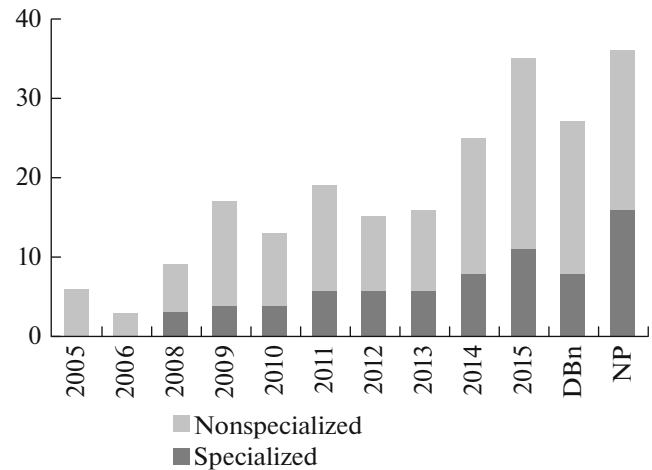


Fig. 3. The number of specialized mangrove species and nonspecialized eurybiotic species in mangrove plantations from 2005 to 2015 and two natural mangrove associations.

Cassidula nucleus (Gmelin 1791), which had not previously been found in plantings, but were present in all collections from the natural mangrove association in Nha Phu. Eight specialized mangrove species are found in the natural mangrove association at Dam Bay.

Figure 3 shows that all mangrove associations are dominated by eurybiontic species, which are characteristic mainly of the epifauna of the soft intertidal bottom. However, a significant proportion of species in the natural mangrove association in Dam Bay are eurybiontic species characteristic of the rocky intertidal bottoms, for example, *Pictocolumbella ocellata* (Link 1807), *Planaxis sulcatus* (Born 1780), etc. The majority of the mollusks found in the lower intertidal zone are species typical for the subtidal, for example, *Lataxiena blosvillei* (Deshayes 1832) and representatives of the families Rannelidae, Cypraeidae, etc.

The species diversity in mangrove plantations has changed over time. Figure 4 illustrates the growth of diversity in three zones. Figure 3 shows that this growth occurs both at the expense of specialized species and at the expense of eurybiontic species.

In terms of the quantitative characteristics, gastropods dominate among other groups of invertebrates at all stations, except for the lower intertidal zone. The values of abundance and biomass in the upper and mid intertidal zones have a pronounced tendency to increase (Fig. 5). The abundance and biomass in the natural mangrove association at Dam Bay were noticeably lower than those of the upper and mid intertidal zones during the late observation period. The lower zone was extremely poor in gastropods throughout the entire observation period.

The abundance and biomass of gastropods in some surveys were very high. Thus, the maximum density of gastropods was recorded in 2015 in the mid intertidal

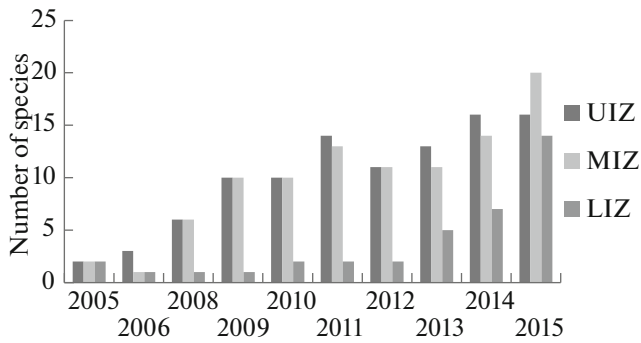


Fig. 4. Dynamics of the species diversity of gastropods in three intertidal zones in the area of mangrove plantings.

zone of plantings: 2698 ± 1127 ind./m², and the maximum biomass was recorded in the fall of 2011: 447 ± 318 g/m².

At all stations, the dominant species were eurybiotic and opportunistic species *Battilaria* sp., *Clithron oualaniense* (Lesson 1831), and *Pirenella cingulata* (Gmelin 1791). In some surveys at the late period of monitoring, their total contribution to abundance (Fig. 6a) and biomass exceeded 90%. An increase in the abundance and biomass in the upper and mid intertidal zones also occurs exclusively due to these three species, which are capable of forming very dense aggregations (Fig. 6b).

Bivalve Mollusks

In the course of this study, 43 species of bivalve mollusks belonging to 18 families were found. In terms of species diversity, this group follows gastropods at all stations, except for the lower intertidal zone, where the diversity of bivalve mollusks exceeds the diversity of gastropods, and Nha Phu, where bivalve mollusks are extremely scarce.

The lower intertidal zone is the most species-diverse among the mangrove associations studied (26 species). Slightly fewer species were found in the mid intertidal zone (21 species), and the upper intertidal zone (15 species) was the poorest in mangrove plantations. The species diversity in the natural mangrove association in Dam Bay roughly corresponded to that of the upper zone (14 species). The natural mangrove association in Nha Phu has the lowest species diversity with only three species of bivalve mollusks found here.

Only two specialized species, *Geloina erosa* (Lightfoot 1786) and *Pegophysema philippiana* (Reeve 1850), were found in the associations studied. Both were found in the natural mangrove association in Nha Phu and in the mangrove plantations of Dam Bay, and only *P. philippiana* was found in the natural mangrove association in Dam Bay. The rest of the bivalve mollusks found during the study are eurybiotic species typical for the infauna of soft s intertidal and subtidal bottoms (for example, representatives of the families Tellinidae and Cardiidae). In addition to infauna, representatives of the epifauna are found on the roots and trunks of mangrove trees, for example, *Saccostrea cucullata* (Born 1778) and representatives of the family Mytilidae. The proportion of subtidal species in the lower intertidal zone is higher than at other stations. In addition, large species, for example, representatives of the families Veneridae and Pinnidae, are also found at this station in qualitative samples.

At the initial period of monitoring (2005–2006), the diversity of bivalve mollusks did not exceed 1–2 species. In subsequent years, their diversity reached eight species in the upper zone, nine species in the middle zone, and 12 species in the lower intertidal zone (Fig. 7).

The abundance and biomass of bivalve mollusks experienced strong fluctuations throughout the period of the study, with no apparent tendency to increase or decrease over time. The highest abundance was recorded in the lower zone in 2008 (153 ± 138 ind./m²). The high-

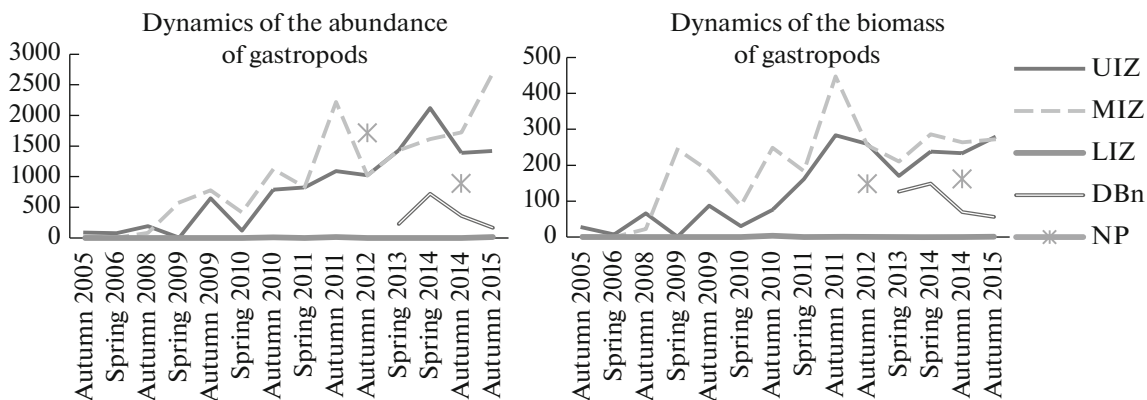


Fig. 5. Dynamics of the average abundance (ind./m²) and biomass (g/m²) of gastropods in three intertidal zones of mangrove plantings and in two natural associations.

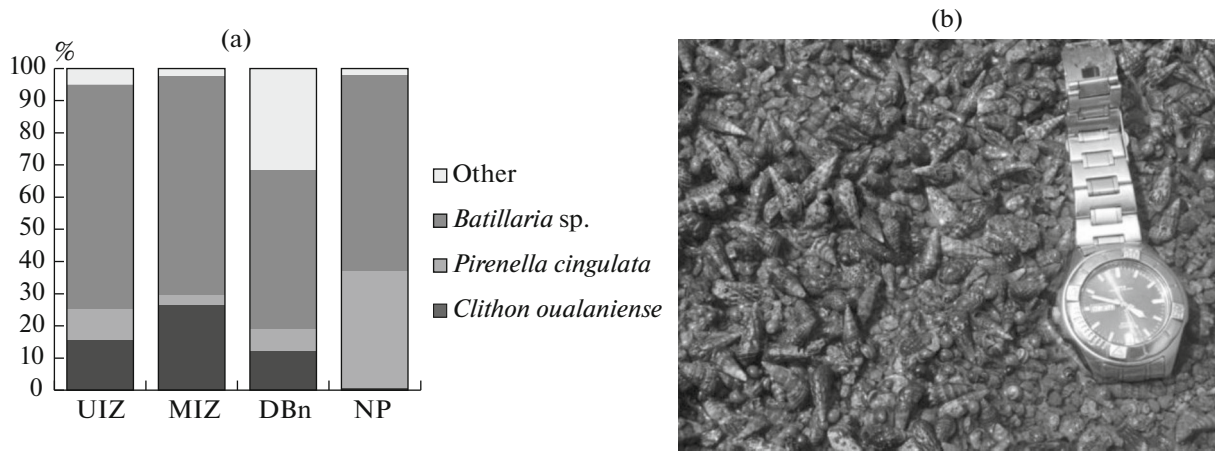


Fig. 6. Dominant species of gastropods in plantings and natural mangrove associations: (a) the percentage of the abundance of dominant species of gastropods in the upper two intertidal zones in the area of mangrove plantations in Dam Bay (the lower zone is not shown, since the abundance of gastropods is negligible here) and in two natural mangrove associations at the time of the last survey (2014 for Nha Phu, 2015 for DBn); (b) aggregation of gastropods *Batillaria sp.*, *Clithon oualaniense*, and *Pyrenella cingulata* in the mid intertidal zone.

est biomass was recorded in 2013 in the natural mangrove association in Dam Bay ($338 \pm 151 \text{ ind./m}^2$). The greatest contribution to the abundance and biomass in the upper and mid intertidal zones, as well as in the natural mangrove association in Dam Bay, is made by the eurybiotic species *Gafrarium pectinatum* (Linnaeus 1758).

Crabs

Eighteen crab species were found in the three mangrove associations over the entire observation period. Eleven species of crabs were found in the upper intertidal zone, 14 species were found in the middle zone, and eight species were found in the lower zone. The natural mangrove associations were the poorest in terms of species, and the diversity in Dam Bay and Nha Phu was represented by six species. The superfamily Ocypodoidea is represented in the studied associations by nine species. The superfamily Grapsoidea is represented by only two species: (1) *Metopograpsus latifrons* (White 1847) found at all stations and (2) a single specimen of Sesarmidae gen. sp. found in the last survey (October 2015) in the mid intertidal zone (MIZ).

The species diversity increased over time from one or two species in the first two surveys to six species in the upper, seven in the middle, and five species in the lower intertidal zone in different years of the late period of monitoring (Fig. 8).

The biomass and abundance of crabs experienced significant fluctuations with no visible trends throughout the monitoring period. In general, their values were low compared to the abundance of mollusks. In most cases, the abundance of crabs did not exceed 40 ind./m², and the biomass did not exceed 16 g/m².

At all stations studied, the greatest contribution to the abundance and biomass was made by representatives of the superfamily Ocypodoidea. In the lower intertidal zone, it was made by the species *Macrophthalmus miloti* (Crosnier 1965), while at other stations there were representatives of the genus *Uca*.

Other Groups of Invertebrates

Apart from the three key groups of invertebrates and annelids, few representatives of other taxonomic groups were found in the studied mangrove associations. In total, 13 species were found: the jellyfish *Cassiopea sp.*, the burrowing sea anemone Edwardsiidae gen. sp., the chiton *Acanthochitona ostreaphila* (Sirenko et Saito 2017), three species of hermit crabs (*Clibanarius sp.*, Paguroidea gen. sp., and Coenobitidae gen. sp.), two species of shrimps (Caridea), one species of Stomatopoda, two species of Sipunculida,

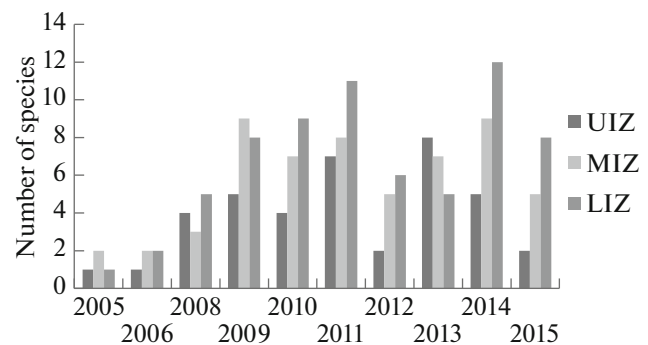


Fig. 7. Dynamics of the species diversity of bivalve mollusks in three intertidal zones in the area of mangrove plantations.

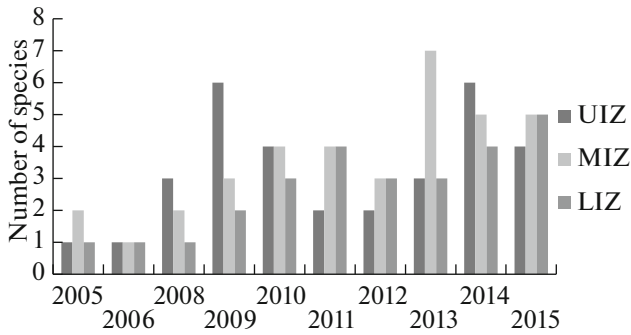


Fig. 8. Dynamics of species diversity of crabs in three intertidal zones in the area of mangrove plantations.

the brachiopod *Lingula anatina* Lamarck 1801, and one acorn worm (Ptychoderidae gen. sp.). Shrimps and hermit crabs were encountered at all stations studied. The rest of the species listed were found only in the lower intertidal zone in mangrove plantations of Dam Bay. None of these taxonomic groups was abundant, and no trends were revealed in the dynamics of their quantitative values.

DISCUSSION

The diversity of gastropods of these associations was discussed in detail in (Zvonareva et al., 2016). Comparison of lists of species in a number of works on Thailand, the Philippines, Malaysia, Vietnam, and others showed that the mangrove associations of Dam Bay and Nha Phu bay are characterized by a rather high diversity of gastropods.

The diversity of bivalve mollusks was assessed mainly on the basis of quantitative samples (as opposed to the assessment of gastropods and crabs), since the representatives of this group mainly belong to the infauna, are located in the sediment, and are poorly visible. The species diversity found depends to a large extent on the number of samples. A work on natural mangroves in northern Vietnam provides a list of 91 species of bivalve mollusks (Hong and San, 1993). Only three species are present in the material collected in this study, but the majority of the species from this list belong to the fauna of the subtidal. From four to 44 species of bivalve mollusks were found in various studies from other regions of Southeast Asia (Wells, 1983; Jiang and Lee, 1995; Macintosh et al., 2002; Lozouet and Plaziat, 2008). Thus, the species list of bivalve mollusks in this study is one of the longest. Perhaps this is explained by the extensive sampling effort and the fact that the samples were taken in the lower intertidal zone, where many species typical for the subtidal zone were found, for example, *Vastocardium angulatum*, *Ruditapes philippinarum*, etc.

Chertoprud et al. (2012) provides a list of the species from mangrove plantations in Dam Bay. We man-

aged to find all the species from this list, except for *Parasesarma unguatum*, since it occurs in the spray zone. In our study, the sampling was carried out only in the intertidal zone, but we found five species that were absent in the study of Chertoprud et al., including one species of the family Sesarmidae. For the fauna of Nha Phu Bay, the same study lists five more species that are absent in our samples (including *P. unguatum*). In that study, the collection was carried out in another mangrove association in the innermost part of the bay, that is the reason for the difference in the species lists. Hong and San (1993) report 44 species of crabs in the mangrove forests of northern Vietnam, with only four species in common with our study. In the natural associations of Malaysia in the Sarawak region, 31 crab species were found (Ashton, 2002); 30 crab species were found in the Selangor region (Sasekumar, 1974); 25 crab species were found in natural mangrove associations, 23 species were found in eight-year plantings (ten of them belong to the family Grapsidae), 13 species were found in one-year old plantations in Thailand (seven of them belong to the family Grapsidae) (Macintosh et al., 2002). Thus, the species diversity of crabs in our study is inferior to the species diversity of crabs both in natural associations and in the plantings of other regions of Southeast Asia. The number of species of the superfamily Ocypodoidea is comparable to their number in other regions, but the families Grapsidae and Sesarmidae are very poorly represented. These differences in the taxonomic composition and species diversity may be caused by imperfect sampling techniques (crabs are very mobile and quickly hide in deep burrows, and, possibly, additional fishing methods are required, for example, crab traps, to better cover the entire variety of crabs). It is also possible that the mangrove associations of other regions differ greatly in the structure and degree of complexity from those studied in this work and therefore have more diverse fauna.

The most diverse and abundant groups in the associations studied are the same key groups as in other regions of the Indo-West Pacific (Berry, 1963; Macnae, 1968; Lee, 1998, 1999; Kathiresan and Bingham, 2001). The composition of less significant groups of the macrobenthos is also typical for the mangroves in the Indo-West Pacific (Kathiresan and Bingham, 2001). Thus, the data obtained on the composition and diversity of the macrobenthos fit into the general pattern of the mangrove fauna of the Indo-West Pacific and Southeast Asia.

Summarizing the data obtained on the dynamics of the species composition and abundance, it is possible to reconstruct the events that occurred over ten years of the existence of mangrove plantations. Before the planting of seedlings in the MIZ, mangroves were represented by a very narrow zone of *Rhizophora apiculata* with the inclusion of several *Avicennia marina* trees in the upper intertidal zone. This mangrove association had a small area and was simply organized, and nutri-

ents were freely washed away by the tides. This can explain the low diversity of the macrobenthos and the low abundance of mollusks at the initial stage of observing mangrove plantations. In contrast to mollusks, crabs had a high abundance in the first year of observation, and these values are achieved exclusively by the *Uca* spp. crabs, which (according to the data published) are characteristic of immature mangroves and fragmented mangroves (Macintosh et al., 2002).

The planting of the *R. apiculata* monoculture in the MIZ in 2004 resulted in a number of changes both at this station and in the upper zone. In the middle zone, the seedlings took root well and grew quite quickly. Therefore, a large amount of free organic matter appeared in the middle zone directly in the form of litter, and also indirectly: the appearance of areas shaded by mangroves created favorable conditions for the development of microalgae and macrophytes. The appearance of additional organic matter in the ecosystem caused a sharp increase in the diversity of nonspecialized species of mollusks and crabs, an increase in the abundance of opportunistic species, predators and scavengers nonspecialized to mangroves. The attraction of new species was also facilitated by the appearance of a solid substrate in the form of growing trees. A similar increase in the abundance of the macrobenthos is reported in a study comparing plantings of different ages in Thailand (Macintosh et al., 2002). Young trees in the middle zone slow down tidal currents and prevent the leaching of organic matter from the upper zone. There is also an increase in the number of opportunistic and nonspecialized species. Thus, mangroves now occupy a significant area and provide a large number of microenvironments. As a result, specialized mangrove species begin to appear in the fauna. According to the published data (which is confirmed by our observations), the area of the mangrove association and the diversity of its vegetation are the main factors determining the diversity of mangrove fauna and especially specialized species (Hutchings and Saenger, 1987; Lee, 1998; Ellison et al., 1999). Sharp fluctuations in the biomass and abundance of different groups of the macrobenthos can be explained by natural variability.

The natural mangrove association in Dam Bay had much in common with the upper intertidal zone in the planting area before 2004 (small area and vegetation structure). This fact explains the low diversity of specialized mangrove fauna in the association, as well as the relatively low abundance of gastropods.

The natural mangrove association at Nha Phu was the most extensive and had a complex spatial structure and a high floristic diversity. This is probably the reason for the high species diversity of specialized gastropods. This association differs from the other stations studied by the extremely low diversity and abundance of bivalve mollusks. This may be explained by the fact that mangroves are not the most favorable environ-

ment for bivalve mollusks to live in. The majority of bivalve mollusks are filter feeders, and for many of them it is problematic to live in conditions of rare flooding in the upper intertidal zone. In natural conditions, mangroves are able to inhabit only the upper part of the intertidal zone (Morton, 1976). In addition, the soil in mature mangrove forests is known to be acidic, and only bivalve mollusks with a very thick shell are able to live in it (Morton, 1976). Thus, only specialized bivalve mollusks, which have certain adaptations to the difficult conditions, can live in mature mangroves while the rest live here at the limit of their ecological plasticity (Morton, 1976).

The fauna of the lower intertidal zone differed sharply from the upper and middle zones and from both natural mangrove associations in the area of mangrove plantings in all aspects even eight years after the planting of seedlings. The growth of seedlings is depressed here, and the fauna is more similar in composition to the fauna of the mudflats and upper subtidal than to the fauna of mangroves. This is probably caused by the influence of too frequent and prolonged flooding, as such conditions are not suitable for either *Rhizophora* seedlings or normal mangrove fauna.

At the time of the last survey, it can be concluded that the structure and composition of the fauna after ten years of development of the new community are still very different from that of the mature mangrove association in Nha Phu. At the same time, the fauna of the upper and middle zones of mangrove plantations is already more similar to the fauna of mature mangroves than the fauna of the natural association in Dam Bay, which is characterized by a small area, simplicity of the spatial structure, and low vegetation diversity.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

COMPLIANCE WITH ETHICAL STANDARDS

This article does not contain any research involving humans and animals as research objects.

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