The distribution of benthic foraminifera in Indonesian shallow waters

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ABSTRACT

Indonesia has diverse marine ecosystems, ranging from estuary, mangrove, seagrass beds, coral reefs, to deep sea, all suitable habitats for marine organisms. Many studies on the distribution of foraminifera in Indonesia waters have been conducted by the Research Center for Oceanography in Jakarta in recent years. Between 1994 and 2012 benthic foraminifera were recorded in environments ranging from estuary, mangrove, seagrass beds, coral reefs to deep sea. This study presents some of the results from several expeditions in shallow waters. Foraminifera were given special attention since there were relatively few records on the modern distribution of this group from Indonesia.

Samples from estuaries contain higher numbers of agglutinated foraminifera in coarser sediments. Assemblages from near the river mouth of the Solo and Delta Porong Deltas of NE Java are dominated by Textularia spp., Haplophragmoides canariensis and Ammobaculites agglutinans. The waters of Handeuleum Islands off SW Java, with three types of ecosystems, are dominated by opportunistic benthic foraminifera, i.e. Ammonia beccarii. The most abundant benthic foraminifera are in fine sandy sediments collected adjacent to the mainland in areas characterized by coral reefs communities. Benthic foraminifera are less common in samples collected from seagrass beds with silty and muddy sediments. Coral reefs ecosystems studied at Jukung and Damar Besar Islands were dominated by symbiont-bearing foraminifera like Amphistegina, Calcarina, Heterostegina, Marginopora and Operculina.

INTRODUCTION

Indonesia is referred to as the world's largest archipelago, with more than 17,000 islands between Sabang in northern Sumatra and Merauke in Papua. The archipelago has a very high marine biodiversity in many types of ecosystems, ranging from estuaries, mangrove swamps, seagrass meadows, coral reefs, down to deep sea. All of these ecosystems have specific characteristics and are inhabited by organisms that characterize these ecosystems. Foraminifera live in all types of marine waters, and many also in marsh and fresh water environments, and assemblages differ according to the type of ecosystem.

Foraminifera, both benthic and planktonic communities, are therefore very useful to solve geological problems and to interpret paleobathymetry of the depositional environments, from marsh to marine environments. Shells of dead foraminifera will accumulate in the sea floor sediments, then become potential clues for correlations of rocks and reconstructions of the geological past.

In this paper we summarize our work done on distributions of benthic foraminifera in estuarine, mangrove and coral reef environments in Indonesia, described in more detail in papers by Suhartati Natsir and co-workers (1992-2012). Deep water foraminifera distributions will be the subject of a separate paper.

SAMPLING METHODS

Many expeditions have been conducted in the waters of both the western and eastern Indonesian Archipelago, by the Research Center for Oceanography of the Indonesian Institute of Sciences and this has generated a lot of data. This study is based on the samples that were collected between 1994 and 2012. Field sampling started by measuring the depth level of the stations using a hand held submersible depth sounder. Measurements of other parameters, such as temperature, salinity and pH were carried out with a portable thermometer, salinity refractometer and pH-meter, respectively. Turbidity was measured using a turbidity meter.

Sediments in shallow water were collected using a corer and Van Veen Grab. The samples were then put in plastic bags for further analysis. Sample preparation in the laboratory was through several steps including washing, picking, description and identification, and sticking and documentation.

Sample weighing about 100 grams were collected, then 10% formaldehyde was added, left for 24 hours, and then sieved over mesh sizes 0.063, 0.25, 0.5, 1.0

and 2.0. Washing the sample is done by running water over the sieve, followed by drying in an oven at 30°C. The next stage is picking of foraminifera from evenly spread dry sample material on an extraction tray under the microscope. Foraminifera contained in the sample were stored on foraminiferal slides. In the description stage, the collected foraminifera were classified by morphology, such as shell shape, chamber shape and chamber formation, number of chambers, shell ornamentation, apertural slope, apertural position and additional chamber. Identification of specimens was done on the basis of a reference collection on benthic foraminifera, including Albani (1979), Barker (1960), Cushman (1969), Loeblich and Tappan (1992), Graham and Militante (1959) and Kaminski (2004).

The next stage is the systematic study and quantitative analysis to obtain abundance data. The numbers of collected foraminifera were classified in three groups of abundance: rare (<30 individuals), medium (30-49 individuals) and abundant (>50 individuals). For documentation selected specimens are glued on foraminiferal slides, with different orientations, including apertural, dorsal, ventral and side views.

RESULTS AND DISCUSSION

1. Distribution of agglutinated foraminifera in the estuary zone

Organisms of estuary areas form unique combinations of endemic, marine and small organisms that tolerate freshwater environments due to their good osmoregulation ability, including foraminifera. In Jakarta bay about 13 rivers bring waste disposal of Jakarta and surrounding, which is now a very populated settlement with rapidly increasing industrial activities and also the agricultural water carried away by river current or run of which finally reached the Jakarta Bay. The bay also received disposal of its ship traffic. As a result, pollution in Jakarta Bay can be solid, liquid, organic material, heat, detergent, pesticide, heavy metals, mud, and so on. Besides, in the estuaries of the river there is rapid sedimentation which affects the islands in the vicinity area.

Foraminifera from estuaries, as studied in the Porong and Solo River Deltas, East Java, are mainly agglutinated foraminifera that build their test with sediment particles, such as mud, oolites, calcitic microgranules and the tests of other microorganisms. The Solo River drains water from Mounts Lawu and Merapi of Central Java and then supplies large amount of sediment to the Solo Delta. Sediments deposited in the delta consist of mud, silt and slightly fine sand. The Porong River receives water from the Brantas River that comes from Mount Semeru and Arjuno. The sediments of the Porong Delta are dominated by sand.

The agglutinated foraminifera collected in the Porong Delta represent 19 species (Table 1). The most common species, present at all stations and abundant in several sites in the delta are *Textularia pseudogramen* and *Ammobaculites agglutinans* (Natsir 2005, Natsir and Subkhan 2012). In the other site, the Solo Delta contains fewer agglutinated foraminifera, although with an almost identical distribution of the species. The assemblages of foraminifera do not contain abundant agglutinated foraminifera (>50 individuals) in each station except for *Textularia pseudogramen*. And there are only two species of medium abundance, *Ammobaculites agglutinans* and *Textularia sp*. They are also common elsewhere in estuaries or in areas near the mouth of river with sediments dominated by sand (Boltovskoy and Wright, 1976).

Agglutinated foraminifera were also collected from three Gili islands of Lombok, Nusa Tenggara Barat (Natsir, 2010). Off Gili Air four species of agglutinated foraminifera were found abundantly, including *Gaudryina rugulosa*, *Gaudryina siphonifera*, *Textularia karimbaensis* and *Textularia candeiana*. These four species were also found at Gili Meneo and Gili Trawangan besides *Ammobaculites agglutinans* and *Textularia sagittula*. The most abundant species were *Gaudryina rugulosa* and *Textularia sagittula*, which were collected in the stations close to coastal areas dominated by sandy sediments.

In a foraminifera study in the Bekasi estuary, Bekasi, West Java, and Ciawi estuary, Banten, agglutinated foraminifera were found in only very small amounts and of very small size (Rositasari et al. 1994). Several stations located very close to the mouth of the river generally contain foraminifera in higher abundance compared with stations toward to sea.

According to Murray (2006) marginal marine environments receive nutrients from freshwater inflow and from the decomposition of organic material in the sediment. Apart from primary production, other potential sources of food for benthic foraminifera are bacteria and organic debris from decomposing plants. Therefore, it assumes that the location is fairly favourable as a habitat of foraminifera, including agglutinated foraminifera.

2. Benthic foraminiferal distribution in mangrove, seagrass beds and coral reef ecosystems

Ecosystems in the waters of Indonesia are very diverse. Estuaries, mangrove swamps, seagrass beds and coral reefs ecosystems are very favourable sites for the growth of foraminifera. Study on the foraminiferal distribution of the three ecosystems have been conducted by LIPI at many locations in Indonesia, including Handeuleum Island (Natsir 2012), Nasik Strait (Belitung Island; Natsir and

Subkhan, 2012), Pulau Seribu (Thousand Islands; Natsir 1994, 2010) and many other locations.

Handeuleum Island is located in the Ujung Kulon National Park of SW Java. The islands lie between groups of coral islands in the Selamat Datang Bay on the northeast part of Ujung Kulon peninsula. Some parts of the islands are vegetated by seagrass and mangrove, with muddy substrates, and the opposite side are coral reefs that arise on sandy substrate. Sampling locations of the Handeuleum Islands are commonly dominated by fine sediment including fine sand, silt and mud.

In samples of the Handeuleum Islands we recognized 17 species, belonging to 13 genera (Table 2). The most abundant benthic foraminifera are in the fine sand sediments. The sampling location that was dominated by seagrass community contains 50 specimens of benthic foraminifera. The samples were collected from the waters adjacent to the mainland of Ujung Kulon National Park. It may be related to nutrient availability in the area supplied from the mainland trough the rivers. *Ammonia beccarii* (opportunistic species) is the most common species in the study area, and was collected almost in all samples. Symbiont-bearing and other small, heterotrophic taxa were respectively counted as 32% and 21%. It supposed that the waters were dominated by mangrove and seagrass communities, and then symbiont-bearing that represented coral reef ecosystem is collected in small amounts. Most of the collected benthic foraminifera from Handeuleum Islands are indicators for shallow marine water environments such as *Quinqueloculina*, *Operculina*, *Pseudorotalia*, *Amphistegina* and *Elphidium*. The symbiont-bearing species are abundant in three sampling sites of Nasik Strait.

The sampling sites of the Belitung Islands (Natsir and Subkhan, 2012) include various communities, such as coral reefs, seagrass beds, mangrove, or combinations or absence of these. The most common benthic foraminifera are in the coral reefs community, with coarse sand substrate, and dominated by symbiont-bearing taxa at 58%. On the contrary, Kudus Island is the most uncommon of benthic foraminifera, with only fourteen specimens collected over the island. Overall, the most common genera of Belitung islands are *Calcarina*, *Peneroplis pertusus* and *Quinqueloculina*, which are found in almost all samples. *Calcarina* is represented in great abundance by *Calcarina calcar*. The seagrass beds community of Nasik Strait, and some areas of Kudus Island are dominated by opportunistic foraminifera, suggesting that water and sediment quality of these sites are unsuitable for coral reef growth. They contain only 8 genera, such as Heterostegina, *Calcarina*, *Elphidium*, *Ammonia*, *Acervulina*, *Spirolina*, *Quinqueloculina* and *Lenticulina*. The number of specimens in the area may be related not only to the surrounding water conditions, but also related to the sediment where they live (Suhartati Natsir, 2005, 2008).

In our sediment samples of Damar Besar and Jukung Islands of the Pulau Seribu/ Thousand Islands group off Jakarta we recognized 31 species of 20 genera of benthic foraminifera (Suhartati Natsir 2008, 2010). Symbiont-bearing foraminifera such as *Amphistegina*, *Calcarina*, *Heterostegina*, *Marginopora*, and *Operculina* were dominant both in Damar and Jukung Islands. These foraminifera represented 48% of total benthic foraminifera in Damar Besar Island and 61% in Jukung Island. The dominant benthic foraminifera at all sampling sites are *Amphistegina*, especially *Amphistegina lessonii* and *Amphistegina gibbosa*. Renema (2008) stated that the species of *Calcarina* are abundant on the reef flat and reef crest, or associated with algae and macroalgae such as *Sargassum*, *Galaxaura*, and *Chelidiopsis*. Barker (1960) encountered these species in Admiralty Island, Pacific at depths of 16 to 25 m, whereas, Graham and Militante (1959) encountered them in Puerto Galera Bay, Philippines, at 8.5 to 14.5 m.

Substrate type of the islands was dominated by mud and some fine-grained sand. Several opportunistic foraminifera species such as *Ammonia beccarii* and *Elphidium craticulatum* were abundant in all sampling sites on both Damar Besar and Jukung Island, but in different numbers. The southern islands of the Thousand Islands are affected by land-based pollution and sedimentation from the mainland (Jakarta), which worsens environmental conditions, especially for benthic foraminifera and coral reefs development. Sunlight penetration would be impeded by suspended material, and then reduces the oxygen content of the waters due to declining photosynthesis rate. Lack of oxygen content is known to affect the decrease of benthic foraminifera (Boltovskoy and Wright, 1976).

The mangrove ecosystem is dominated by muddy sediments and is not a favorable habitat for benthic foraminifera, but low diversity brackish water assemblages are present. In general, benthic foraminifera prefer locations that are dominated by fine to coarse sand with shells and coral fragments that provide patches for shelter (Renema 2002, Murray 2006). Some genera that are known to be common around mangrove forests include *Trochammina*, *Miliammina*, *Haplophragmium* and *Jadammina* (Biswas, 1976). From some of the above species, only *Trochammina*, represented by *Trochammina amicola* was found in the Porong Delta, which is also flanked by mangrove forests. The mangrove ecosystems on Handeuluem Island and Nasik Strait, Belitung, are inhabited only by rare *Ammonia beccarii* (opportunistic species) and *Quinqueloculina sp.*.

Table 1. *Collected agglutinated foraminifera from estuary habitats in Indonesia*

Species	Locations				
	Porong Delta	Solo Delta	Gili Air	Gili Meno	Gili Trawangan
Ammobaculites agglutinans	✓	✓	-	✓	✓
Ammobaculites calcareous	✓	✓	-	-	-
Ammomassilina sp.	✓	✓	-	-	-
Ammotium cassis	✓	✓	-	-	-
Clavulina sp.	✓	✓	-	-	-
Dentostomina sp.	✓	✓	-	-	-
Dorothia arenata	✓	✓	-	-	-
Eggerella subconica	✓	✓	-	-	-
Gaudryina rugulosa	-	-	✓	✓	✓
Gaudryina siphonifera	✓	✓	✓	✓	✓
Haplophragmoides canariensis	✓	✓	-	-	-
Pseudoclavulina sp.	✓	✓	-	-	-
Reophax bacillaris	✓	✓	-	-	-
Textularia candeiana	-	✓	✓	✓	✓
Textularia conica	✓	✓	-	-	-
Textularia gaesi	✓	✓	✓	✓	✓
Textularia karimbaensis	-	-	-	-	-
Textularia porrecta	✓	✓	-	-	-
Textularia pseudogramen	✓	✓	-	-	-
Textularia sagittula	✓	✓	-	✓	✓
Textularia sp.	✓	-	-	-	-
Trochammina amnicola	✓	-	-	-	-

Table 2. *Benthic foraminifera collected from mangrove, seagrass beds and coral reefs ecosystems.*

Species	Location			
	Handeuleum Islands	Nasik Strait	Damar Besar Island	Jukung Island
Acervulina inhaerens	-	✓	✓	✓
Adelosina semitriata	-	-	✓	✓
Ammomassilina alveoliniformis	-	-	-	✓
Ammonia beccarii	✓	✓	✓	✓
Ammonia umbonata	-	✓	-	-
Amphistegina gibba	✓	✓	✓	✓
Amphistegina lessonii	✓	✓	✓	✓
Amphistegina quoyii	-	✓	✓	✓
Amphistegina radiata	-	-	✓	✓
Brizalina spathulata	✓	-	-	-
Calcarina calcar	✓	✓	✓	✓
Calcarina spengleri	-	-	✓	✓
Calcarina hispida	-	-	✓	✓
Chrysadinella dimorpha	-	-	✓	✓
Cymbaloporetta bradyi	✓	-	-	-
Cymbaloporetta squammosa	-	-	✓	✓
Elphidium advenum	-	-	✓	✓
Elphidium craticulatum	✓	✓	✓	✓
Elphidium crispum	✓	✓	✓	✓
Flintina bradiana	-	-	✓	✓
Gaudryina rugulosa	-	-	✓	-
Gaudryina siphonifera	✓	-	-	-
Haplophragmoides canariensis	✓	-	-	-

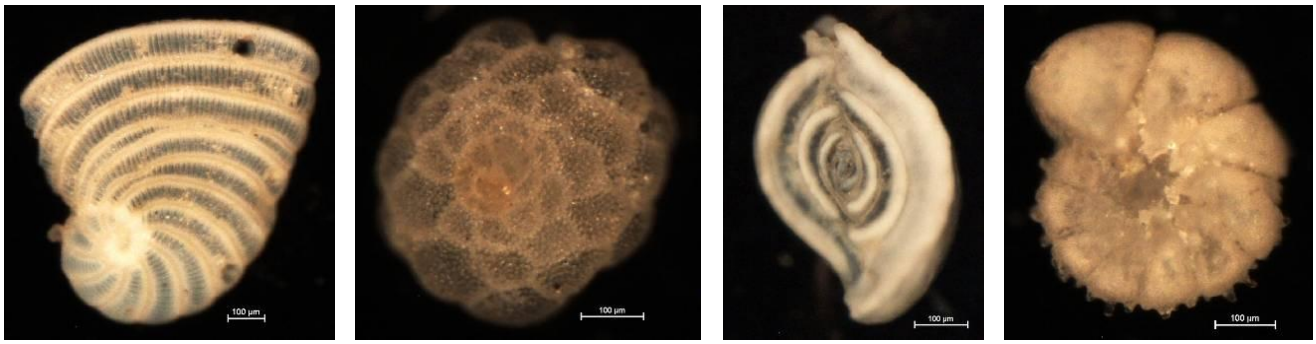
Species	Location			
	Handeuleum Islands	Nasik Strait	Damar Besar Island	Jukung Island
Hauerina bradyi	-	✓	-	-
Hauerina fragilissima	-	✓	-	-
Hauerina sp.	-	✓	-	-
Heterostegina depressa	-	✓	✓	✓
Lagena favoso-punctata	-	✓	-	-
Lenticulina sp.	-	✓	-	-
Marginophora vertebralis	-	-	✓	✓
Miliolinella sp.	-	✓	-	-
Operculina ammonoides	-	✓	✓	✓
Operculina complanata	-	-	✓	✓
Operculina gaimardii	-	-	✓	✓
Operculina tuberculata	-	-	✓	-
Peneroplis pertusus	-	✓	-	-
Planorbulinella larvata	-	✓	-	-
Pseudorotalia inflata	✓	-	-	-
Pseudorotalia schroeteriana	-	-	✓	✓
Quinqueloculina bouena	-	✓	-	-
Quinqueloculina cultrata	-	✓	✓	✓
Quinqueloculina granulocostata	✓	-	-	-
Quinqueloculina parkeri	-	-	✓	✓
Quinqueloculina sp.	✓	✓	✓	-
Rosalina globularis	-	-	-	-
Sorites marginalis	✓	✓	-	✓
Spirolina arietina	-	✓	-	-
Spiroloculina communis	✓	✓	✓	✓
Spiroloculina depressa	-	✓	-	-
Spiroloculina sp.	✓	✓	-	-
Textularia agglutinans	-	-	✓	✓
Triloculina rupertiana	-	✓	-	-
Triloculina tricarinata	-	✓	✓	✓

CONCLUSIONS

This paper summarizes some of the results of ongoing work by the Research Center for Oceanography on the distribution of modern benthic foraminifera in Indonesia. It was observed that in the estuaries of the Solo and Porong Deltas higher numbers of agglutinated foraminifera are present in coarse sediment compared to finer sediment, possibly suggesting that these provide shelter from the hydrodynamic stress. Samples from sites close to the mouth of the river in both deltas were dominated by *Textularia pseudogramen*, *T. amnicola*, *H. canariensis* and *Ammobaculites agglutinans*. The waters of Handeuleum Islands, with three types of ecosystems, are dominated by opportunistic benthic foraminifera, mainly *Ammonia beccarii*. The foraminiferal assemblages are affected by the types of sediments, with the most benthic foraminifera present in fine sand sediment from the waters adjacent to the mainland, characterized by a coral reefs community. This area may possess rich nutrients due to the influence of the mainland activity. Samples collected from seagrass beds with silt and mud sediments contain fewer specimens than those from the coral reef ecosystem. It supposed that this sediment types (silt and mud) affect the foraminiferal ability to dwell in.

The coral reefs ecosystem, represented by Jukung and Damar Besar Islands, was dominated by symbiont-bearing foraminifera, such as *Amphistegina*, *Calcarina*, *Heterostegina*, *Marginopora* and *Operculina* as well as abundant *Peneroplis pertusus*. The most abundant benthic foraminifera in Nasik strait are in the coral reef ecosystems with typical coarse sand substrate. The seagrass beds of Nasik Strait are dominated by opportunistic foraminifera and only contain 8 genera, such as *Heterostegina*, *Calcarina*, *Elphidium*, *Ammonia*, *Acervulina*, *Spirolina*, *Quinqueloculina* and *Lenticulina*.

Textularia agglutinans *Gaudryina rugulosa* *Elphidium crispum* *Peneroplis pertusus* *Quinqueloculina granulocostata*



Peneroplis planatus *Cymbaloporetta bradyi* *Spiroloculina communis* *Ammonia beccarii*

Ammonia umbonata *Amphistegina quoyii* *Calcarina* sp. *Peneroplis carinatus*

Figure 1. *Selected key foraminifera species in shallow waters of Indonesia.*

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