Foraminifera spatial analysis as bioindicator in Java Sea to Flores Sea

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Abstract. Foraminifera is potential bioindicator to understand the modern and ancient marine environment and have been widely used as bioindicator. Java Sea to Flores Sea are productive area influenced by physical and chemical reactions from nature and human activity, so that their characteristics are important to recognize. The aim of this research is to determine oceanography condition of Java Sea to Flores Sea covers the depth, temperature, thermocline, and upwelling according to foraminifera analysis. The method used were inventory and species analysis from 12 stations along study area. The analysis was conducted based on species and abundance. Foraminifera species which are warm water bioindicators are Globigerinoides rubra and Globigerinoides sacculifera, upwelling bioindicators are Globigerina bulloides and Globorotalia menardii, and shallow thermocline bioindicators are Pulleniatina obliquiloculata and Neogloboquadrina dutertrei. The result show that Java Sea has more benthonic species and abundance because of its shallow depth while Flores Sea has more planktonic species and abundance because of its deep depth and part of open ocean. In Flores Sea the abundance of warm water species bioindicators fall significantly and high abundance of upwelling and shallow thermocline species bioindicators indicates that there are upwelling phenomenon with shallow thermocline, thin mix layer, and high productivity.

1. Introduction

Java Sea and Flores Sea are located in between Java, Kalimantan, and Sulawesi and play important roles in human activities such as transportation. The seas are also part of the pathways that allow the passage of water mass from Pacific Ocean to Indian Ocean that forms the Indonesia Throughflow (ITF). The bathymetry of Java Sea varies with an average of 120 m, while the bathymetry of Flores Sea reaches 5000 m [1, 2]. Population explosion as well as human activity in land and ocean produced substantial waste that might influence the waters in the area.

The complex bathymetry of the Indonesian Seas, such as narrow channel and sills, is a result of geological processes working in the archipelago involving transform faults and subduction zone in plate boundaries. Those architectures mix inflowing the Pacific water mass with freshwater to produce Indonesian water mass [3] that in turn affect the type and distribution of organisms living in the area and also influence productivity of the area [4]. Indonesian Throughflow (ITF) transport became determinant factor for marine organism distribution [5]. According to [6] Indonesian Archipelago has high foraminifera diversity so that foraminifera can be used as potential bioindicator to recognize oceanography characteristics.

The characteristics of Java Sea and Flores Sea are influenced by both natural and anthropogenic-induced physical and chemical reactions that are important to recognize. One of the method to understand them is by studying the foraminifera assemblage. Foraminifera is a useful tool and easy to
handle bioindicator. They reflect general and accurate environmental condition, thus changes in their assemblage would reflect environmental changes. After their deaths, foraminifera sink to the bottom, and accumulate for million of years to then form 75% of seafloor sediment [6]. Some of foraminifera characteristics are small size, simple body structure, hard test, widely distributed in marine environment and high ability to react to environmental changes [7, 8].

Water mass movement yields physical and chemical reactions such as as upwelling and changes in thermocline depth. One of the movement is surface current that changes semiannually in the Indonesian Seas. During different monsoon seasons, water mass from the Indian Ocean and Pacific Ocean flow to the Indonesian Seas and cause variation in temperature, salinity, and others [9]. During Southeast Monsoon, cold surface water mass from Banda and Flores Seas flow into the eastern part of Java Sea to the North Natuna Sea through Karimata Strait [10].

When the ITF reaches the southern part of Makassar Strait, it flows to two directions: straight to the Indian Ocean via Lombok Strait and flows to the east (Flores and Banda Sea) before going to the Indian Ocean through Timor Sea and Ombai Strait. Those pathways are very complex because of topographic variation of the three Straits (Makassar, Malaka, and Lombok) that yield the mixing and reversal of water mass. Local process working in the Indonesian Seas that is connected to local monsoonal wind such as upwelling and downwelling along with high tide, ocean heat flux, precipitation volume and river runoff change the Pacific water mass temperature and salinity stratification to become specific Indonesian Seas profile [9]. The aim of this study is to determine the depth, temperature, thermocline, and upwelling condition of Java Sea and Flores Sea based on foraminifera analysis.

2. Materials and methods

Map of sample locations and their depths show in figure 1. The method of this research including sampling, sample preparation, species identification, and data analysis. The samples that are existing samples that stored at the Core Laboratory of the Marine Geological Institute (MGI). Some of the samples were obtained during MAJAFLOTE cruise in 2015 on brand Geomarin III. The cruise is a collaboration of Marine Geological Institute and Bogor Agriculture University. The samples are acquired by multicorer in 4 stations in Java Sea and gravity corer in 1 stations in Makassar Strait and 7 stations in Flores Sea. This study used surface sample (0-2 cm) for foraminifera analysis. Sample preparation was conducted at Marine Geological Institute Core Laboratory, Cirebon. The samples were washed and dried in the oven before sieved in multilevel sieves (-0.5; 0; 0.5; 1; 1.5; 2; 2.5; and 3ø in diameter). The dry weight of each size fraction then weighed separately. Foraminifer identification was carried out between February 1 to March 11, 2016 at the Petrology and Micropaleontology Laboratory of Marine Geological Institute in Bandung. Size fraction from 0.5 to 2ø was split until the smallest fraction is estimated to consist of ±300 foraminifera individus.

![Figure 1. Map of sample locations and their depths (data from Marine Geological Institute).](image)
Foraminifera which had been picked and separated from other sediment and tests fractions was identified below electronic microscope SMZ 800r following key identification of Saito et al. (1981), identification book Postuma [11], Loeblich and Tappan [12], and Maryunani [13]. A collection of foraminifera specimens from 12 stations were put together in chartman slide showing the dorsal and ventral view of each species. The documentation of the specimens was conducted using binocular microscope connected to Nikon camera and NIST Element software. Data analysis involved calculation of P/B ratio as well as abundance of specific foraminifera that serve as bioindicator for temperature, upwelling, and thermocline. Identification of bioindicator species follows previous studies such as [14]. The calculation of P/B ratio uses the following equation:

\[
P/B \text{ ratio} = \frac{\sum \text{planktonic species}}{\text{planktonic and benthonic species}}
\]

3. Results and discussion

Identification of foraminifera yields 59 species from 12 samples that compose of 31 benthonic species (1,111 individuals) and 28 planktonic species (2,240 individuals). Benthonic species show higher diversity than planktonic species, although planktonic species show higher abundance than benthonic species (figures 2 and 3).

Our results showed that samples from the shallow Java Sea has higher benthonic species diversity and number of individuals while from deeper Makassar Strait and Flores Sea have higher planktonic species diversity and number of individuals. The result shows that planktonic foraminifera are more
abundant in deeper water while benthonic foraminifera are more abundant in shallow water. This pattern is reflected in P/B ratio.

3.1. P/B ratio
The P/B ratio of the Java Sea show low P/B ratio value compare to Makassar Strait and Flores Sea. All four stations from Java Sea which is categorized as inland and shallow seas (±13-50 m) have low P/B ratio. All stations from Makassar Strait and Flores Sea which is categorized as open and deep seas (±400-1500 m) have higher P/B ratio up to 1 (figure 4).

The results show correlation between P/B ratio and water depth. P/B ratio has been traditionally used to estimate water depth on continental margins. Water depth often shows a relationship to the distribution patterns of living planktonic foraminifera, but depth-correlated factors such as temperature, salinity, dissolved oxygen, photic conditions, and nutrient levels probably exert direct control over foraminiferal depth habitats [15]. P/B ratio will increase along with the distance from shore and type of the water body toward the open ocean [18]. It can be concluded that Java Sea with shallow depth is an inland sea while Makassar Strait and Flores Sea with deeper water depth is part of open seas that is close to oceanic condition.

![Figure 4. Map of P/B ratio and chart that show relation of P/B ratio to water depth.](image)

3.2. Environment characteristics based on foraminifera assemblage
Environmental characteristics such as temperature, thermocline, and upwelling are observed from foraminifera assemblage. The analysis involved species identification, counting, and literature review of bioindicator species that can be applied to understand the oceanography of Java Sea and Flores Sea. Previous studies show that *Globigerinoides rubra* and *Globigerinoides sacculifera* can be used as warm water bioindicators considering their living distribution in tropical ocean; *Globigerina bulloides* and *Globorotalia menardii* as upwelling bioindicators; *Pulleniatina obliquiloculata* and *Neogloboquadrina dutertrei* as shallow thermocline indicators. Table 1 shows the references for bioindicator species.
**Table 1.** Foraminifera that serve as bioindicator species for warm water, upwelling, and shallow thermocline.

| No | Indication     | Species                                | References               |
|----|----------------|----------------------------------------|--------------------------|
| 1  | Warm water     | *Globigerinoides sacculifera* and *Globigerinoides rubra* | [6, 15, 17, 18]          |
| 2  | Upwelling      | *Globigerina bulloides* and *Globorotalia menardii* | [6, 17, 19, 20]          |
| 3  | Shallow thermocline | *Pulleniatina obliqueloculata* and *Neogloboquadrina dutertrei* | [6, 17, 18, 20, 21]       |

The abundance of *Gs. sacculifera* and *Gs. rubra* in 4 samples from Java Sea are quite low while no *G. bulloides*, *Gr. menardii*, *P. obliqueloculata*, and *N. dutertrei* were found. All of bioindicators use planktonic foraminifera that are rarely found in Java Sea. The abundance of *Gs. sacculifera* and *Gs. rubra* in Makassar Strait was high and decrease toward the Flores Sea. The lowest abundants of the six species in Flores Sea was observed in Station 10.

High abundance of *G. bulloides* and *Gr. menardii* abundance was observed in Makassar Strait and some stations in Flores Sea. The highest abundance of those species were found at Station 10 and Station 11 in Flores Sea. *N. dutertrei* and *P. obliqueloculata* are abundant in Flores Sea with highest abundance were observed at Station 11 and Station 12 (figure 5).

Figure 5. Species of foraminifera that are used as bioindicators for a) *Gs. rubra* and *Gs. Sacculifera* abundance as warm water bioindicators b) *G. bulloides* and *Gr. menardii* as upwelling bioindicators, and c) *N. dutertrei* and *P. obliqueloculata* as shallow thermocline bioindicators.

Higher abundance of *N. dutertrei* and *P. obliqueloculata* was observed in Flores Sea. High abundance of those species in Stations 11 and 12 indicate that shallow thermocline layer in those stations. This interpretation is supported by high abundance of *G. bulloides* and *Gr. menardii* in Station 11 that show upwelling activity. Low abundance of *Gs. sacculifera* and *Gs. rubra* as warm water bioindicators was observed at Stations 10, 11 and 12. This interpretation is also supported by highest abundance of *N. dutertrei* and *P. obliqueloculata* at Stations 11 and 12.
[20] studied that *Gr. menardii* lived within the upper thermocline (UTH) during the late Miocene, but Fairbanks and Wiebe (1980) in [20] found that today, *Gr. menardii* is known to occur in greatest abundances in association with the chlorophyll maximum zone, similar to *N. dutertrei* [20]. Therefore, their position in the upper thermocline is likely controlled by the availability of food rather than temperature. The abundance of *Gr. menardii* and *N. dutertrei* at Stations 11 and 12 indicate upwelling phenomenon that was accompanied by shallow thermocline, thin mixed layer, and high primary productivity. The mechanism behind high surface productivity in the Eastern Indonesia is monsoon-related upwelling. From foraminiferal tests, we know that monsoon system disturbance will lead to decrease on marine organism productivity [6].

4. Conclusion
A study on foraminifera assemblage from Java Sea, Makassar Strait and Flores Sea show the relationship between P/B ratio and water depth. In general, benthonic species show higher diversity but lower abundance compared to planktonic species. Java Sea is characterized by higher abundance and diversity of benthonic species due to its shallow water depth and inland position. Flores Sea is characterized by higher abundance and diversity of planktonic species because of its deeper water depth and relatively open sea. Analysis of foraminifera as bioindicators of environmental condition show that upwelling phenomenon was observed in Flores Sea. The upwelling phenomenon was accompanied by shallow thermocline, thin mixed layer, and high primary productivity.

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