Foraminiferal Abundance at the Western Water of Kai Islands, Molucca Province, Related to Oceanographic Condition

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Abstract. Foraminifera is a single-celled marine organism known as a potential proxy for (paleo)environment and (paleo)oceanography conditions. It also has been widely used as an indicator of coral reef health. We analyzed microfauna foraminifera from nine core top of marine sediments. Marine sediments have been collected by gravity core from western Water of Kai Islands, on board Geomarin III of MGI. The study aims to understand the microfaunal community and the oceanographical condition of Kai islands. The result indicates the high abundance and diversity of foraminifera, comprised of 95 species, including 28 species of planktonic and 67 benthic species. Planktonic type is very dominant (95.4% on average), typical for a bathyal environment. The dominant species are Neogloboquadrina dutertrei (21.21% on average), Globorotalia menardii (16.67% on average), Globigerina bulloides (11.73%), and Pulleniatina obliquiloculata (7.83%). Those are indicator species for a high productivity environment. However, Globigerinoides ruber, an oligotrophic warm water type, is also abundant (13.86% on average). Furthermore, the dominant genera of benthic types are Bolivina, Bulimina, dan Uvigerina (1.2% on average). This finding indicates relatively eutrophic and warm water conditions of west waters surrounding Kai Islands, with dysoxic bottom water conditions.

1. Introduction
Waters surrounds Kai Islands have water depths between 100 – 300 m in the water between Kai Islands, while at the western part that is the eastern part of Weber Deep, its water depths are more than 6000 m, and at the east part that is a part of Aru Trench, the water depths are more than 3000 m. This water is a part of the Indonesian throughflow pathway, a current system that carries water mass from the Pacific Ocean to the Indian Ocean through the Indonesian waters [1] (Figure 1). The differences in sea level between the Pacific and the Indian oceans lead to a pressure gradient occurrence. As a result, water from the North Pacific enters the Sulawesi Sea and flows further through the Makassar Strait and the Lifamatola Passage. The ITF then outflows via Lombok Strait or circulates through the Banda and Flores seas, then enters the Indian Ocean via Ombai Strait and Timor Passage [2]. Therefore, it is necessary to understand the oceanographical properties of the Kai Islands' waters that will influence the local and global circulation.

Foraminifera is a single-celled organism that possesses test, belongs to Kingdom Protista and subkingdom Protozoa found abundant within marine water and sediment. Foraminifera is a potential bioindicator because it has a high response to environmental parameter changes. Several studies have used foraminifera as an environmental bioindicator for modern and ancient conditions. Certain foraminiferal types will characterize the typical environment. The diversity of foraminifera will be different between shallow marine, deep marine, coral habitat, etc. [3–5]. A previous study has used foraminifera for heavy metal pollution indicators [6]. Recent research utilizes foraminifera as a potential indicator for environmental changes.
proxy for paleoceanography and paleoclimatology, e.g., [7-9]. This study aims to understand the foraminiferal abundances, foraminiferal diversity, and to understand Kai Island’s water conditions.

2. Materials and Methods

2.1 Sample collection, preparation, and determination
For this study, we analyzed nine core top marine sediment gravity core samples from the Western part of the Kai Islands, from water depths between 270 – 700 m (Figure 2). The samples were collected by using gravity corer onboard Geomarin III of the Marine Geological Institute, Bandung. Approximately 10-20 grams of the core top samples were taken using a spatula, then wet-washed by water and sieved through a 150 µm sieve. Furthermore, the samples were dried at < 60°C temperature for 24 hours. Afterward, if it is possible, we counted approximately 300 specimens of foraminifera. If the sample volume is too large, composed of more than 300 specimens, we first divided each sample by micro splitter. Furthermore, the foraminiferal shells were identified based on several references including [3], [10], [11], [12], [13], [14], and www.foraminifera.eu website.

2.2 Quantitative analysis

2.2.1 Relative abundance
Relative abundance is the percentage of each species foraminifera in each sample. It is obtained by dividing the specimen number of each species by the total specimen number in every sample. The formula is:

\[ \frac{N_i}{N} \times 100\% \]

\( N_i \) = Total specimen of species
\( N \) = Total foraminifera at one sample
2.2.2 PB ratio
PB ratio is the planktonic percentage of the total foraminiferal community [16]. PB ratio of foraminifera gives information of the seawater depth. In normal marine conditions, PB ratio will be higher in deep water than in shallower water. It is calculated by:

\[ \text{PB ratio} = \frac{P}{P+B} \times 100\% \] (2)

\( P \) = total planktonic
\( B \) = total benthic

2.2.3 Diversity, Dominance, and Evenness indices analyzed using software Past, Paleontological Statistics Software version 3.22 by [17], free downloaded at [http://folk.uio.no/ohammer/past][18].

A. Diversity index, Shannon index value based on formula:
It is based on the number of individuals and the number of taxa [18]. It informs the variety level of species in each sample. The higher value commonly indicates good environmental conditions, and the lower value might be due to the occurrence of the environment's unique condition. It is calculated by:

\[ H' = - \sum \frac{n_i}{n} \ln \frac{n_i}{n} \] (3)

\( H' \): Shannon Index
\( n_i \): Number of individual of species i at one sample
\( n \): Total number of foraminifera at one sample

**Figure 2.** Gravity core samples location at Western Water of Kai Islands, red rectangular is study area
(Modified from [15])
Index range:
H' = 0-2: Low diversity of foraminifera
H' = 2-3: Moderate diversity of foraminifera
H'>3: High diversity of foraminifera

B. Dominance index ranges from 0 (an assemblage of all taxa are equal) to 1 (one taxon dominates the community completely).

\[ D = \sum_{i} \left( \frac{n_i}{n} \right)^2 \]  

4

\( n_i \): Number of individual of species i at one sample
\( n \): Total number of foraminifera at one sample

C. Buzas and Gibson's Evenness (E) indicate each species' similarity in one sample. Similar to the dominance index, it is ranged from 0 (the assemblage between species varies) to 1 (the assemblage between species is uniform).

\[ E = \frac{e^{H}}{S} \]  

5

E: Evenness index
H: Shannon Index
S: Total number of species

3. Result and discussion
For this study, foraminifera were found very abundant and dominant among other organisms (i.e. mollusc, ostracoda). Foraminifera is composed of 95 species, 28 species of planktonic, and 67 species of benthic (Appendix A1). Planktonic is dominant, with a percentage of 95.43% on average (Figure 3). The highest percentage is at location 25 and 13 (percentage 98.45% dan 98.4% respectively) from the nine samples studied in this research. The high percentage of planktonic foraminifera is typical for the bathyal environment. Planktonic type lives within the water column, and the water depth of all the collected sediment samples were more than 200 m. Although foraminifera is extremely abundant in sample locations of 12 and 19, all the shell sizes are relatively small. Therefore, we found difficulty identifying species, particularly from site 12, that we did not consider this sample.

The highest diversity index of foraminifera found at location no. 11 (578 m water depths) lies near the islands between Kai Besar and Kai Kecil, with a diversity index value of 2.42, 35 species, 18 planktonic species, and 17 benthic species (Figure 4). The second is location no. 17 (464 m water depth), diversity index value is 2.3, comprised of 34 species, 18 planktonic species and 16 of benthic. The dominance value is relatively low (< 0.5), with an average value of 0.18. The highest value is 0.27 at location no. 19. At this location, in contrast to the dominance level, the evenness value is the lowest (0.215). This location also exhibits a small size of foraminifera, hence with very abundant assemblage. Therefore, the environmental condition of this area might be less favorable for foraminifera.
Figure 3. PB ratio indicates an average percentage of 95.43% (dash line).

Figure 4. Diversity value, dominance and evenness value

3.1 Planktonic foraminifera
Planktonic foraminifera live within the water column. Therefore, it is very abundant in deep open marine, while in shallow water, the abundance will be lower. In the study area, planktonic foraminifera found in 10 genera and 32 species. It is dominated by Neogloboquadrina dutertrei, with average percentage 21.21%, Globorotalia menardii (16.67%), Globigerinoides ruber (13.86%), Globigerina bulloides (11.73%), Pulleniatina obliquiloculata (7.83%), and Hastigerina siphonifera (5.53%). Other species present with an average percentage < 1% are Globigerinoides trilobus, Globigerinoides sacculifer, Globigerinoides immaturus, Globigerinoides conglobatus, Globorotalia scitula, and Thinopodella ambitacrena (Figure 5).
The high dominant of *N. dutertrei*, *G. menardii*, and *P. obliqueloculata* indicate that this area has a high nutrient rate, as these species prefer to live in high productivity conditions [7], [9], [19]. Furthermore, the high abundance of *G. ruber*, *G. sacculifer*, and *G. trilobus* might indicate relatively warm water conditions. *N. dutertrei* as typical of eutrophic environment occur at all sediment sample.
with a high percentage (± 20%), except at location 19, its abundance is low (1.66%). As has been mentioned above, foraminifera found at site 19 exhibit small size (< 300 µm). At this location, the dominant species is *G. bulloides* (49.83%). *G. bulloides* is found with average assemblage < 10% at other sites, at the most southern part (area 13), this species is absent. *G. bulloides* is an upwelling indicator [7], [9]. At site 19, water temperature declined due to upwelling, hence decreasing *N. dutertrei* and *G. menardii’s* abundances.

The dominant species at site 13 in the southern part of the study area is *G. menardii* (35.77%). This percentage is the highest percentage of this species among other locations. Another location with a high *G. menardii’s* assemblage is at the northern part of the study area, at site 25, with a percentage of 29.1%. Its lowest abundance is at location 11 and 19 (3%). According to [19] and [7], this species prefers to live at relatively warm and high productivity conditions and low salinity.

Another species presented at all locations is *G. ruber*, an indicator for a warm oligotrophic environment [7]. The highest abundance of *G. ruber* is at site 9, which lies between Kai Besar and Kai Kecil Island (20.03%), and at site 23 (20.78%) at the western part. *P. obliqueloculata* is another species found at all locations. Its highest assemblage is at location 1 (northern of Kai Besar) and site 25 with percentages of 17.04% and 17.03%, respectively. Similar to *N. dutertrei*, *P. obliqueloculata* is also typical for a high nutrient environment [7].

### 3.2 Benthic foraminifera

The assemblage of benthic foraminifera is low, with an average percentage of 4.57%. There are 48 genera and 69 species of benthic. Their diversity is also low. The most various benthic foraminifera are at location no. 19, which contained 21 species, no. 11 (17 species), and location no. 17 (16 species). Meanwhile, at sites no. 13, 23, and 25, benthic species number is low, comprised of four, three, and five species, respectively. Dominant benthic foraminifera is dysoxic indicator species (low oxygen level condition 0.1 – 0.3 mL/L O$_2$, according to [20], are: *Bolivina*, *Bulimina*, and *Uvigerina* with average percentage (1.2%). The highest abundance is at location no. 19 (3.32%), and 11 (1.99%), at location no. 25 (the most northern area), these genera are absent (Figure 6). Another dominant species is *Gyroidina neosoldanii* with a percentage of 0.55% on average, which occurred only at 3 locations: site 1, 11, and 17. Other species that are considered dominant are *Euuvigerina aculeate* (0.33%), *Melonis barleeanus* (0.24%), *Globocassidulina bisecta* (0.23%), and *Hoeglundina elegans* (0.20%). Both *G. neosoldanii* and *H. elegans* are species that prefer low-level oxygen conditions. *G. neosoldanii* can survive until oxygen level 0.5 mL/L, and the lowest oxygen level that can be tolerated by *H. elegans* is 0.2 mL/L [21] and reference therein.

![Figure 6](image_url)  
*Figure 6.* The abundance of dysoxic indicator species (low-level oxygen content) indicates the highest assemblage at site 19 (3.32%).

Figure 7 shows that site 19 indicates distinctive different assemblage and diversity compared to the others. At this site, *G. bulloides* is highly dominant, with a low percentage of *P. obliqueloculata*, *N. dutertrei*, and planktonic type, in contrast, the highest abundance of *Cibicides*, and dysoxic species. The
shell size is relatively smaller than in other locations. It might be that at site 19, upwelling is somewhat more intense. Although resulting in nutrient increase, it also leads to lower temperature and oxygen level declined. Hence species other than dysoxic and upwelling indicators exhibit smaller shells size and lower assemblage instead.

![Graph showing microfaunal (foraminifera) assemblage, including PB ratio, dominant species, and percentage of dysoxic genera.](image)

**Figure 7.** Microfaunal (foraminifera) assemblage, including PB ratio, dominant species, and percentage of dysoxic genera

4. **Conclusion**
The assemblage of foraminifera at Western waters of Kai Islands is of relative abundance and significantly dominated by planktonic type (95.4% on average). Planktonic types are dominated by *Neogloboquadrina dutertrei*, *Globorotalia menardii*, *Globigerina bulloides*, and *Pulleniatina obliquiloculata*. These are indicator species for high productivity environments. As warm tropical water, the assemblage of *G. ruber* is abundant in the marine sediment. The dominant benthic type is dysoxic species (*Bolivina*, *Bulimin*, *dan Uvigerina*) with 1.2% on average. This finding indicates relatively eutrophic and warm water conditions of west waters surrounding Kai Islands, with dysoxic bottom water conditions. Site 19 in the middle part of the water exhibits distinctively different assemblage than the other area, mainly highly dominated by *G. bulloides*, indicating that upwelling at this area is considerably more active.

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### Table A1. Foraminiferal assemblages and Diversity index value

| Sample Number | Foraminiferal assemblages | Diversity Index Value |
|---------------|--------------------------|-----------------------|
| 1             | ?                         | 0.00                  |
| 2             | ?                         | 0.00                  |
| 3             | ?                         | 0.00                  |
| 4             | ?                         | 0.00                  |
| 5             | ?                         | 0.00                  |
| 6             | ?                         | 0.00                  |
| 7             | ?                         | 0.00                  |
| 8             | ?                         | 0.00                  |
| 9             | ?                         | 0.00                  |
| 10            | ?                         | 0.00                  |
| 11            | ?                         | 0.00                  |
| 12            | ?                         | 0.00                  |
| 13            | ?                         | 0.00                  |
| 14            | ?                         | 0.00                  |
| 15            | ?                         | 0.00                  |
| 16            | ?                         | 0.00                  |
| 17            | ?                         | 0.00                  |
| 18            | ?                         | 0.00                  |
| 19            | ?                         | 0.00                  |
| 20            | ?                         | 0.00                  |
| 21            | ?                         | 0.00                  |
| 22            | ?                         | 0.00                  |
| 23            | ?                         | 0.00                  |
| 24            | ?                         | 0.00                  |
| 25            | ?                         | 0.00                  |
| 26            | ?                         | 0.00                  |
| 27            | ?                         | 0.00                  |
| 28            | ?                         | 0.00                  |
| 29            | ?                         | 0.00                  |
| 30            | ?                         | 0.00                  |
| 31            | ?                         | 0.00                  |
| 32            | ?                         | 0.00                  |
| 33            | ?                         | 0.00                  |
| 34            | ?                         | 0.00                  |
| 35            | ?                         | 0.00                  |
| 36            | ?                         | 0.00                  |
| 37            | ?                         | 0.00                  |
| 38            | ?                         | 0.00                  |
| 39            | ?                         | 0.00                  |
| 40            | ?                         | 0.00                  |
| 41            | ?                         | 0.00                  |
| 42            | ?                         | 0.00                  |
| 43            | ?                         | 0.00                  |
| 44            | ?                         | 0.00                  |
| 45            | ?                         | 0.00                  |
| 46            | ?                         | 0.00                  |
| 47            | ?                         | 0.00                  |
| 48            | ?                         | 0.00                  |
| 49            | ?                         | 0.00                  |
| 50            | ?                         | 0.00                  |
| 51            | ?                         | 0.00                  |
| 52            | ?                         | 0.00                  |
| 53            | ?                         | 0.00                  |
| 54            | ?                         | 0.00                  |
| 55            | ?                         | 0.00                  |
| 56            | ?                         | 0.00                  |
| 57            | ?                         | 0.00                  |
| 58            | ?                         | 0.00                  |
| 59            | ?                         | 0.00                  |
| 60            | ?                         | 0.00                  |
| 61            | ?                         | 0.00                  |
| 62            | ?                         | 0.00                  |
| 63            | ?                         | 0.00                  |
| 64            | ?                         | 0.00                  |
| 65            | ?                         | 0.00                  |
| 66            | ?                         | 0.00                  |
| 67            | ?                         | 0.00                  |
| 68            | ?                         | 0.00                  |
| 69            | ?                         | 0.00                  |
| 70            | ?                         | 0.00                  |
| 71            | ?                         | 0.00                  |
| 72            | ?                         | 0.00                  |
| 73            | ?                         | 0.00                  |
| 74            | ?                         | 0.00                  |
| 75            | ?                         | 0.00                  |
| 76            | ?                         | 0.00                  |
| 77            | ?                         | 0.00                  |
| 78            | ?                         | 0.00                  |
| 79            | ?                         | 0.00                  |
| 80            | ?                         | 0.00                  |
| 81            | ?                         | 0.00                  |
| 82            | ?                         | 0.00                  |
| 83            | ?                         | 0.00                  |
| 84            | ?                         | 0.00                  |
| 85            | ?                         | 0.00                  |
| 86            | ?                         | 0.00                  |
| 87            | ?                         | 0.00                  |
| 88            | ?                         | 0.00                  |
| 89            | ?                         | 0.00                  |
| 90            | ?                         | 0.00                  |
| 91            | ?                         | 0.00                  |
| 92            | ?                         | 0.00                  |
| 93            | ?                         | 0.00                  |
| 94            | ?                         | 0.00                  |
| 95            | ?                         | 0.00                  |
| 96            | ?                         | 0.00                  |
| 97            | ?                         | 0.00                  |
| 98            | ?                         | 0.00                  |
| 99            | ?                         | 0.00                  |
| 100           | ?                         | 0.00                  |
| 101           | ?                         | 0.00                  |
| 102           | ?                         | 0.00                  |
| 103           | ?                         | 0.00                  |
| 104           | ?                         | 0.00                  |
| 105           | ?                         | 0.00                  |
| 106           | ?                         | 0.00                  |
| 107           | ?                         | 0.00                  |
| 108           | ?                         | 0.00                  |
| 109           | ?                         | 0.00                  |
| 110           | ?                         | 0.00                  |
| 111           | ?                         | 0.00                  |
| 112           | ?                         | 0.00                  |
| 113           | ?                         | 0.00                  |
| 114           | ?                         | 0.00                  |
| 115           | ?                         | 0.00                  |
| 116           | ?                         | 0.00                  |
| 117           | ?                         | 0.00                  |
| 118           | ?                         | 0.00                  |
| 119           | ?                         | 0.00                  |
| 120           | ?                         | 0.00                  |
| 121           | ?                         | 0.00                  |
| 122           | ?                         | 0.00                  |
| 123           | ?                         | 0.00                  |
| 124           | ?                         | 0.00                  |
| 125           | ?                         | 0.00                  |
| 126           | ?                         | 0.00                  |
| 127           | ?                         | 0.00                  |
| 128           | ?                         | 0.00                  |
| 129           | ?                         | 0.00                  |
| 130           | ?                         | 0.00                  |
| 131           | ?                         | 0.00                  |
| 132           | ?                         | 0.00                  |
| 133           | ?                         | 0.00                  |
| 134           | ?                         | 0.00                  |
| 135           | ?                         | 0.00                  |
| 136           | ?                         | 0.00                  |
| 137           | ?                         | 0.00                  |
| 138           | ?                         | 0.00                  |
| 139           | ?                         | 0.00                  |
| 140           | ?                         | 0.00                  |
| 141           | ?                         | 0.00                  |
| 142           | ?                         | 0.00                  |
| 143           | ?                         | 0.00                  |
| 144           | ?                         | 0.00                  |
| 145           | ?                         | 0.00                  |
| 146           | ?                         | 0.00                  |
| 147           | ?                         | 0.00                  |
| 148           | ?                         | 0.00                  |
| 149           | ?                         | 0.00                  |
| 150           | ?                         | 0.00                  |

*Note: The table values are placeholders and need to be replaced with actual data.*
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