FORAMINIFERA DISTRIBUTION AS AN INDICATOR OF PALEOCEANOGRAPHY IN WAIPOGA WATERS, NORTHERN PAPUA

DISTRIBUSI FORAMINIFERA SEBAGAI INDIKATOR PALEOSEANOGRAFI DI PERAIRAN WAIPOGA, PAPUA UTARA

Joleen Felicia Wijaya[1], Resti Samyati Jatiningrum[1*], Luli Gustiantini[2], Mardhatillah Kurnia Putri[3], Yulinar Firdaus[2]

[1] Geological Engineering Study Program, Faculty of Exploration and Production Technology, Universitas Pertamina, Jl. Teuku Nyak Arief, Jakarta

[2] Marine Geological Institute, Jl. Dr. Junjunan no.236, Bandung

[3] Department of Oceanography, Faculty of Earth Sciences and Technology, Bandung Institute of Technology, Jl. Ganesha No. 10, Bandung

*Corresponding author: resti.sj@universitapertamina.ac.id

(Received 16 September 2025; in revised from 17 September 2025; accepted 29 December 2025)

DOI : 10.32693/bomg.40.2.2025.965

ABSTRACT: Foraminifera are widely used as indicators for reconstructing past marine environmental conditions. This study aims to investigate the ecological conditions of Waipoga waters, North Papua, by analyzing the distribution of foraminifera during the late Middle Holocene to Late Holocene. The study area plays an important role in the dynamics of the Indonesian Throughflow (ITF/ITF) and ENSO. Sediment core samples were prepared and identified for foraminifera, followed by quantitative analyses including relative abundance, P/B ratio, and ecological indices. In addition, sortable silt analysis was applied as an environmental proxy to support the reconstruction of past environmental changes. The results show that foraminiferal abundance throughout the sediment core varies. Planktonic foraminifera are more dominant, comprising 12 genera with 22 species. The most dominant species are *Globigerinoides ruber* (41,7%), *Neogloboquadrina dutertrei* (11%), *Neogloboquadrina incompta* (13,2%), *Pulleniatina obliquiloculata* (4%), *Hastigerina pelagica* (6,65%), and *Globigerinoides immaturus* (6,7%). Meanwhile, benthic foraminifera consist of 42 genera with 62 species, dominated by *Bulimina marginata* (1,8%), *Cibicidoides pachyderma* (1,89%), and *Lenticulina calcar* (1,3%). During the late Middle Holocene to Late Holocene, the Waipoga waters were influenced by variations in bottom current intensity and thermocline stability. Zones I and III reflect oligotrophic conditions with weak circulation, while Zone II indicates increased bottom current intensity, high productivity, and dysoxic conditions, suggesting possible intensification of upwelling events.

Keywords: Distribution, Foraminifera, Holocene, Waipoga Waters

***ABSTRAK**: Foraminifera merupakan indikator yang sering digunakan untuk merekonstruksi kondisi lingkungan perairan masa lampau. Penelitian ini bertujuan untuk mengetahui kondisi lingkungan Perairan Waipoga, Papua Utara, dengan menganalisis distribusi foraminifera selama Kala akhir Holosen Tengah hingga Holosen Akhir. Wilayah penelitian berperan dalam dinamika ITF dan ENSO. Sampel inti sedimen dianalisis melalui preparasi dan identifikasi foraminifera, kemudian dilakukan analisis kuantitatif berupa perhitungan kelimpahan relatif, rasio P/B, dan indeks ekologi. Selain itu, analisis ukuran butir sedimen digunakan sebagai proksi kondisi lingkungan untuk mendukung rekonstruksi perubahan lingkungan purba. Hasil penelitian menunjukkan kelimpahan foraminifera sepanjang inti sedimen bervariasi. Foraminifera* *planktonik lebih dominan terdiri atas 12 genus dengan 22 spesies. Spesies yang lebih dominan adalah Globigerinoides ruber (41,7%), Neogloboquadrina dutertrei (11%), Neogloboquadrina incompta (13,2%), Pulleniatina obliquiloculata (4%), Hastigerina pelagica (6,65%), dan Globigerinoides immaturus (6,7%). Sementara itu, foraminifera bentonik terdiri dari 42 genus dengan 62 spesies, didominasi oleh Bulimina marginata (1,8%), Cibicidoides pachyderma (1,89%), dan Lenticulina calcar (1,3%). Sepanjang akhir Holosen Tengah hingga Holosen Akhir, kondisi perairan Waipoga dipengaruhi oleh variasi intensitas arus dasar laut dan stabilitas termoklin. Zona I dan III mencerminkan kondisi oligotrofik dengan sirkulasi lemah, sementara Zona II menunjukkan peningkatan intensitas arus dasar laut, produktivitas tinggi, dan kondisi disoksik yang mengindikasikan kemungkinan intensifikasi peristiwa upwelling.*

Kata Kunci: *Distribusi, Foraminifera, Holosen, Perairan Waipoga*

INTRODUCTION

The Waipoga waters are located in the eastern part of Cenderawasih Bay (Figure 1), north of Papua Island in the Pacific Ocean, and hold a strategic position as an area that is passes through by New Guinea Coastal Current (NGCC) and New Guinea Coastal Under Current (NGCUC) which flow from the Pacific Ocean enters the Indonesian Waters as the Indonesian Throughflow (ITF) (Gordon, 1986). The Indonesian Throughflow (ITF) is a flow of water masses between the Pacific Ocean and the Indian Ocean that passes through Indonesian waters, with the ITF pathways shown in Figure 2. The ITF transports warm water masses from the Pacific Ocean toward the Indian Ocean, which has relatively cooler temperatures (Wyrtki, 1987). The ITF occurs due to density differences influenced by pressure, temperature, and salinity between the two oceans (Hasanudin, 1998; Nining, 2002 in Azis, 2006). In addition, as the source of the Indonesian Throughflow, the northern Papua waters are also situated within the Western Pacific Warm Pool (WPWP), thus influenced by the El Niño Southern Oscillation (ENSO). WPWP is a pool of warm water located in the western Pacific region, including the eastern Indonesian waters, that can shift eastward or westward across the Pacific, generating a circulation known as the ENSO cycle or El Niño Southern Oscillation. ENSO is a periodic phenomenon caused by unusual interactions between the ocean and atmosphere along the equatorial Pacific Ocean, which impacts climate variability in the region as well as in several other parts of the world. El Niño occurs when sea surface temperatures in the eastern Pacific Ocean rise, while those in the western Pacific decline (with the WPWP shifting further eastward), resulting in reduced rainfall in the western Pacific and increased rainfall in the eastern Pacific. La Niña, on the other hand, has the opposite effect, with sea surface temperatures decreasing in the eastern Pacific while increasing in the western Pacific, leading to higher rainfall in the western Pacific, including Indonesian waters (Ashok & Yamagata, 2009; Darmawan et al., 2021), meaning the WPWP shifts further westward. The variation in sea surface temperatures in the northern Papua waters influenced by ENSO is related to the formation of cyclonic and anticyclonic eddies, which drive upwelling and downwelling processes (Simanungkalit et al., 2018). The formation of anticyclonic eddies is caused by high sea surface temperatures during La Niña conditions, leading to the accumulation of water masses at the eddy's center. Cyclonic eddies, in turn, can trigger upwelling processes by bringing cooler water masses to the sea surface. ENSO events affect the ITF and monsoon circulation, hence influence the climate over the Asian region.

Foraminifera are unicellular microorganisms that are commonly found from shallow to deep marine environments, as well as in brackish waters, and exhibit very high diversity. Foraminifera tend to prefer specific environmental conditions, although some species can thrive in a wide range of settings. Therefore, foraminifera are known as proxies for paleoclimate changes, and their presence can reflect the ecological conditions of their habitats. Both benthic and planktonic foraminifera are recognized as potential indicators of environmental, ecological, oceanographic, and climatological conditions, both in the past and present. Based on their characteristics—such as a simple body structure with a hard shell, relatively short life cycles, wide distribution in aquatic environments, and high adaptability to environmental changes—foraminifera are often considered bioindicators with great potential for understanding environmental conditions in both ancient and modern waters(Nurruhwati et al., 2012). The distribution,

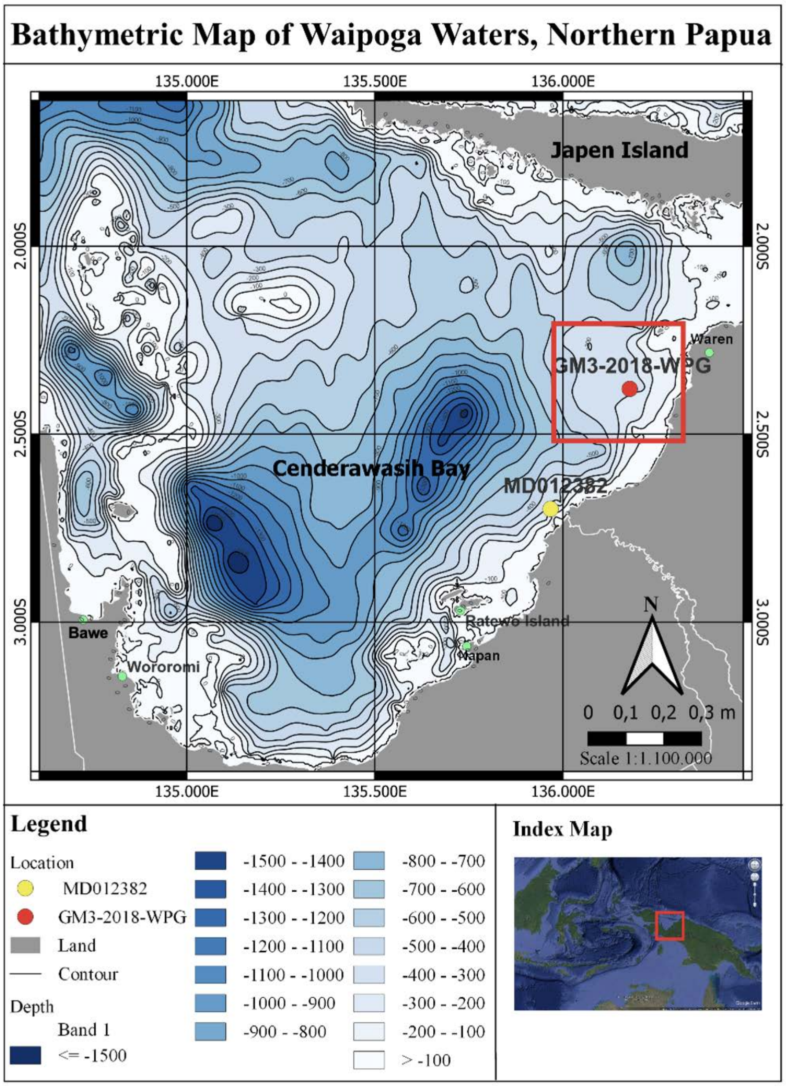

Figure 1. Bathymetric map of Waipoga waters, Northern Papua, red dot is the sediment core for this study, yellow dot is the sediment core for age modelling (Maryunani, 2009).

morphology, and abundance of foraminifera are influenced by various environmental factors in their habitats, such as depth, salinity, temperature, nutrient availability, oxygen concentration, and others (Boltovskoy and Wright, 1976; Jurnaliah et al., 2019). Previous studies (e.g. Peeters et al., 2001; Gustiantini, 2018; Gustiantini et al., 2018; Jurnaliah et al., 2019; Damanik et al., 2020; Fabbrini et al., 2023; Jatiningrum et al., 2023) have concluded that the distribution of foraminifera in different marine regions is influenced by climate change. Therefore, this research was conducted to further study the distribution of foraminifera in relation to paleoceanographic conditions in Waipoga waters.

METHODS

The data used in this study consist of marine sediment core sample from Waipoga waters with the code NAME GM3-2018-WPG.04. The collection of marine sediment core was carried out by the Marine Geological Institute (MGI/BBSPGL) of the Geological Agency, Ministry of Energy and Mineral Resources, using a gravity corer on aboard the survey vessel Geomarin III in 2018, retrieved from a water depth of 462 m.

Observations and data collection began with the description of a 206 cm-long gravity core sediment sample. The core description included color, grain size classification following Wentworth (1922), and observed structures. Preparation of sediment samples for foraminiferal analysis started with the extraction

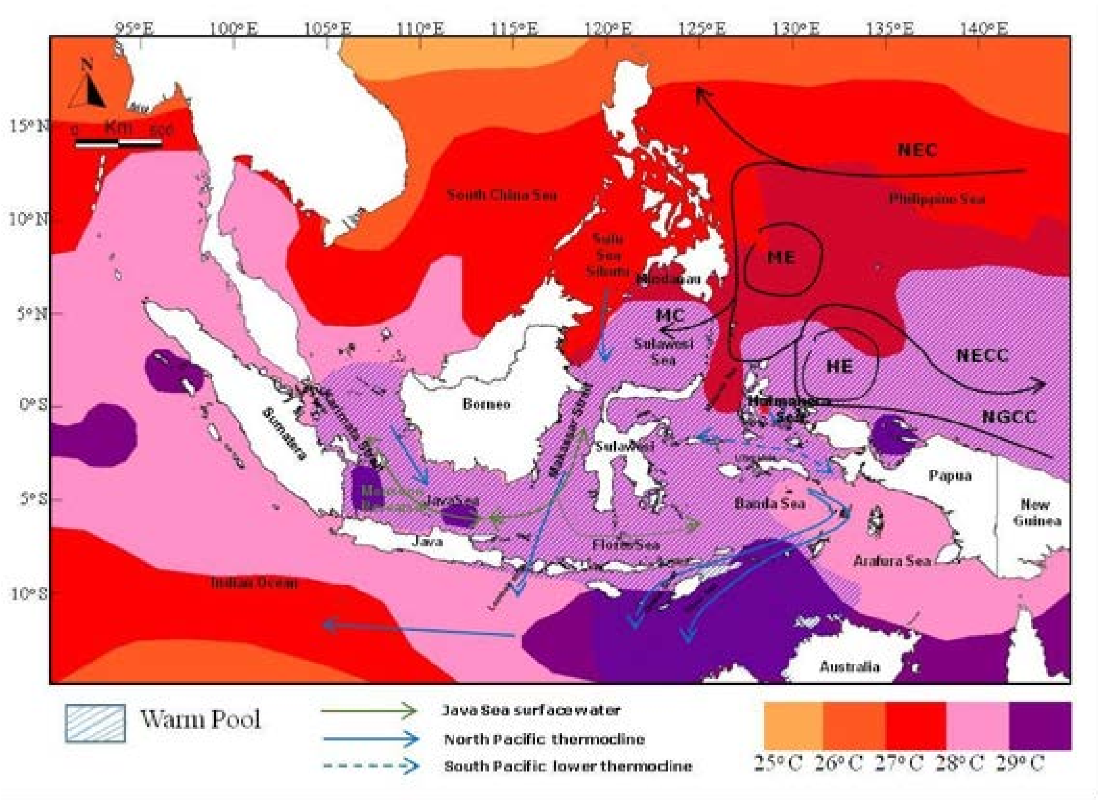

Figure 2. Oceanography and climatology within Indonesian waters. Black arrows indicate the major ocean currents influencing Indonesian waters, including the NGCC (New Guinea Coastal Current), NEC (North Equatorial Current), NECC (North Equatorial Counter Current), HE (Halmahera Eddy), ME (Mindanau Eddy), while blue arrows show the pathway of the Indonesian Throughflow (ITF) (Gustiantini, 2018).

of 5–7 cc of sample using a syringe at 2 cm depth intervals. Sediment samples were firstly weighed, before and afterwards they were dried to obtain wet and dry weights, then soaked, washed with a 0.063 mm sieve, and dried again. Subsequently, splitting and picking of foraminifera were carried out, with approximately 300 specimens separated from the sediment. Identification referred to Loeblich & Tappan (1994), Hemleben et al. (1989), and Holbourn et al. (2013). Quantitative analysis was then performed, including normalization, relative abundance (%), P/B ratio, ecological indices (diversity index, evenness index, and dominance index), and clustering. The calculation of ecological indices and the construction of clustering dendrograms were carried out using the PAST (Paleontological Statistics) software version 4.03, available at https://paleoelectronica.org/2001_1/past/pastprog/index.html, developed by Paul D. Ryan (1995) in Hammer et al. (2001), with manual book of PAST (Hammer, 1999-20224).

Normalization to the number of splits (dividers) with the sample weight and the number of individual specimens in the normalized sample can be carried out by (Ardi et al., 2019) :

$$(N) = 2^n \, x \, A \qquad (1)$$

$$(Nz) = \left(\frac{Ma}{Mb}\right) \qquad (2)$$

Where:

N = number of individuals of a species in the total sample
n = number of splits (dividers)
A = number of individuals of a species in one split
Nz = number of individuals in the normalized sample
Ma = measured mass
Mb = expected mass

Relative abundance analysis was carried out to calculate the percentage of abundance of each species present in the sample (Junita et al., 2020)
.

Relative Abundance = $\frac{Ni}{N}$ (3)

Where:
Ni : Total individuals of the species
N : Total foraminifera in one sample

The calculation of the ratio between the number of planktonic and benthic foraminifera (P/B ratio) in each sample indicates paleobathymetric changes based on the classification of Grimsdale & Morkhoven (1955), using the following formula, according to the study conducted by van Marle (1989) dalam Jurnaliah et al. (2017):

$$P/B\ Ratio = \frac{P}{P+B}\ x\ 100\% \quad (4)$$

Where:
P = number of planktonic individuals
B = number of benthic individuals

Ecological Indices

Diversity Index

Hammer et al. (2009) explained that the Shannon index, also called entropy, considers both the number of taxa and their relative abundances. Its value approaches 0 when only a single taxon is present, while higher values indicate richer and more even communities. The calculation of the diversity index uses the Shannon-Weaver formula (Bakus, 1990, in Jurnaliah et al., 2019):

$$H' = -\Sigma\, pi \log pi \quad (5)$$

Where:
H' = Diversity index
Pi = $\frac{Ni}{N}$
S = Number of species
Ni = Number of individuals of i1, i2, i3, etc.
N = Total number of individuals

With the H' value range as follows:

1. H' < 1.0: Low, indicating high ecological stress, low productivity, and a disturbed ecosystem
2. 1.0 < H' < 3.0: Moderate, indicating moderate ecological stress, moderate productivity, and a slightly disturbed ecosystem
3. H' > 3.0: High, indicating low ecological stress, high productivity, and a stable ecosystem

Evenness Index

Evenness can also be expressed as Shannon diversity divided by the logarithm of the number of taxa, reflecting how evenly individuals are spread among taxa (Hammer et al., 2009). Evenness index obtained from the formula of Buzas and Gibson's evenness in Hammer (1999-2024):

$$Buzas\ and\ Gibson'evenness = \frac{e^H}{S} \quad (6)$$

Where:
E = Evenness index
H' = Diversity index
Hmax = log2 S
S = Number of species

With the E criteria as follows:

1. E > 0.6: High species evenness
2. 0.6 ≥ E ≥ 0.4: Moderate species evenness
3. E < 0.4: Low species evenness

Dominance Index

The dominance index is closely related to Simpson's index, reflecting the probability that two randomly chosen individuals belong to the same taxon (Hammer et al., 2009). The calculation of the dominance index uses Simpson's dominance index, range from 0 (all taxa are equally present) to 1 (one taxon dominates the community completely):

$$D = \Sigma_i [\frac{ni}{N}]^2 \quad (7)$$

Where:
D = Dominance index
ni = Number of individuals of genus i
N = Total number of individuals

With C evaluated based on the following criteria (Odum, 1996 in Munthe et al., 2011):

1. 0 < C < 0.5: No dominant genus (low)
2. 0.5 < C < 1: Presence of a dominant genus (high)

Clustering

Foraminiferal biozonation was carried out using cluster analysis with the hierarchical single linkage method and the Euclidean similarity index, through the PAST application. Indicator species reflecting certain environmental conditions were determined based on the formula by Dufrêne & Legendre (1977):

IndVal= A_ij B_ij×100(8)

Where:

A_ij = ⟦Nindividuals⟧_ij/⟦Nindividuals⟧_i

B_ij = ⟦Nsites⟧_ij/⟦Nsites⟧_i

With the following explanation:

⟦Nindividuals⟧_ij = mean abundance of species/genus j in cluster i

⟦Nindividuals⟧_i = total mean abundance of all species/genera in cluster i

⟦Nsites⟧_ij = number of sites in cluster i where species/genus j occurs

⟦Nsites⟧_i = total number of sites in cluster i

The determination of sediment type from the collected samples was carried out using grain size analysis with the Particle Size Analyzer (PSA) method, employing a Malvern Mastersizer 3000, available at the laboratory of Marine Geological Institute (MGI), Geological Agency, Ministry of Energy and Mineral Research of Indonesia, to obtain the grain size distribution of each sample. The results of the grain size distribution obtained from the Particle Size Analyzer (PSA) method were then analyzed using the GRADISTAT v9.1 application, developed by Blott and Pye (2001). For the intensity of bottom current estimation, we considered only silt sediment type (10-63 µm size fraction), by calculating it's sortable silt mean size ($\overline{ss}$), that were translated into bottom current intensity following the equation of Ledbetter (1986). According to McCave et al. (1995), this silt size fraction reflects the bottom current intensity better, because it is not influenced by surface currents dynamics, and is non-cohesive. Bottom currents generally rarely move sand fractions (>63 µm in size), while sediment fraction <10 µm tends to be cohesive. The detailed grain size preparation and analysis have been described in Putri (2023).

The age estimation of the GM3-2018-WPG.04 sediment core, was reconstructed by using the MD012382 sediment core studied by Maryunani (2009) as a reference (Figure 1), also has been described in Putri (2023). The determination of the GM3-2018-WPG.04 sediment age was obtained from the correlation between the mean size sortable silt pattern of GM3-2018-WPG.04 and the abundance of *Cibicides* spp (benthic microfauna influenced by bottom current) from the MD012382 sediment core (Maryunani, 2009).

RESULTS

Sediment Core Description of Site GM3-2018-WPG.04

The sediment core description shows no lithological changes. The core is dominated by dark gray silt with a uniform texture and the presence of bioturbation structures. This indicates that the sediments were deposited in a deep-sea environment with low depositional energy. The description of core GM3-2018-WPG.04 is summarized in the lithological column shown in Figure 3.

Grain size

The grain size analysis using the GRADISTAT v9.1 application also shows that the largest fraction in the GM3-2018-WPG.04 samples is silt, with all samples ranging from 53.6% to 90.0%. Some samples contain sand (6.2–44.5%), while a small portion contains clay (1.5–4.3%). Therefore, this study uses silt-sized sediments. The sediment types, based on the classification of Blott and Pye (2001), are presented in Table 1.

The mean grain size of the sediment at the bottom of the core shows relatively finer material (medium silt), then becomes coarser (coarse silt–very coarse silt) in the 120–40 cm interval, and returns to finer material (medium silt) at the top of the core (Figure 4). Afterwards, we calculated the mean size of sortable silt fraction ($\overline{SS}$) to identify the bottom current variability. The ($\overline{SS}$) value was then translated into deep-sea current velocity following the calculation of Ledbetter (1986), yielding values ranging from a minimum of 33.8 cm/s at a core depth of 130 cm to a maximum of 49 cm/s at a depth of 40 cm (Figure 5 and Table 2).

Darmawan et al. (2021) stated that at 50-1000 m water depth of the northern Papua flows an undercurrent water (New Guinea Coastal Undercurrent - NGCUC). Previous research on the NGCUC was conducted by Lindstrom et al. (1987) and Kuroda et al. (2000) in the waters of Papua New Guinea. According to Lindstrom et al. (1987), the current velocity of NGCUC is around 50 cm/s, while according to Kuroda et al. (2000), the average speed of NGCUC in northern Papua New Guinea is 54 cm/s with a standard deviation of 15 cm/s. These finding suggest that our bottom current velocity estimation in this study are not very different compared to those two previous studies.

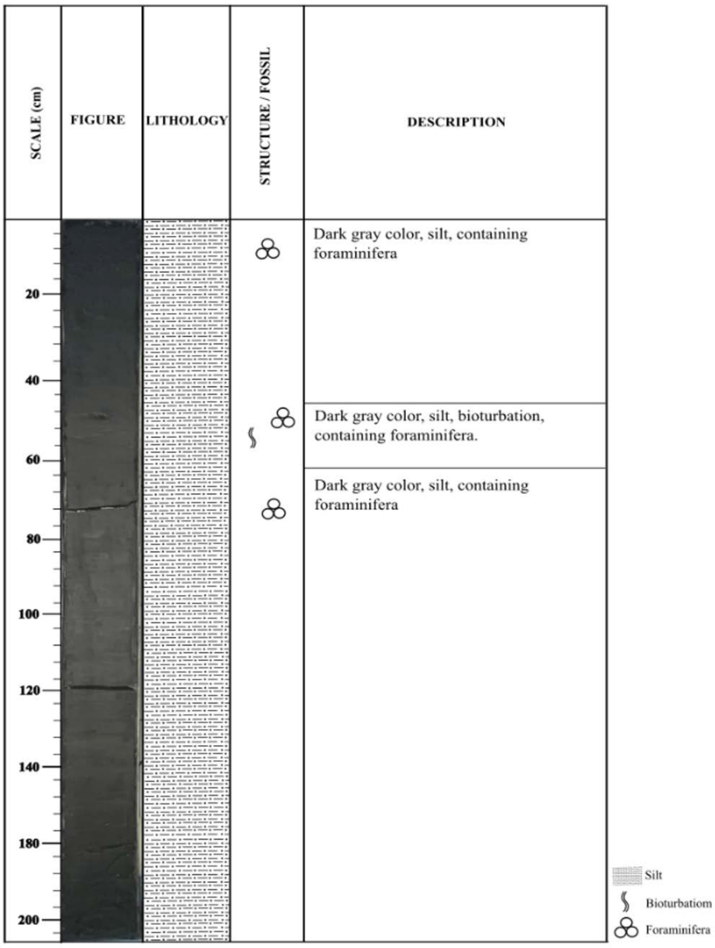

Figure 3. Lithological column of sediment core GM3-2018-WPG.04

Table 1. Sediment classification of sample GM3-2018-WPG.04

Depth of Layer Sediment Core (cm)	Sediment Classification
0	medium silt
10	medium silt
20	medium silt
30	medium silt
40	very coarse silt
50	medium silt
60	coarse silt
70	coarse silt
80	coarse silt
90	coarse silt
100	coarse silt
110	coarse silt
120	coarse silt
130	medium silt
140	medium silt
150	medium silt
160	medium silt
170	medium silt
180	medium silt
190	medium silt

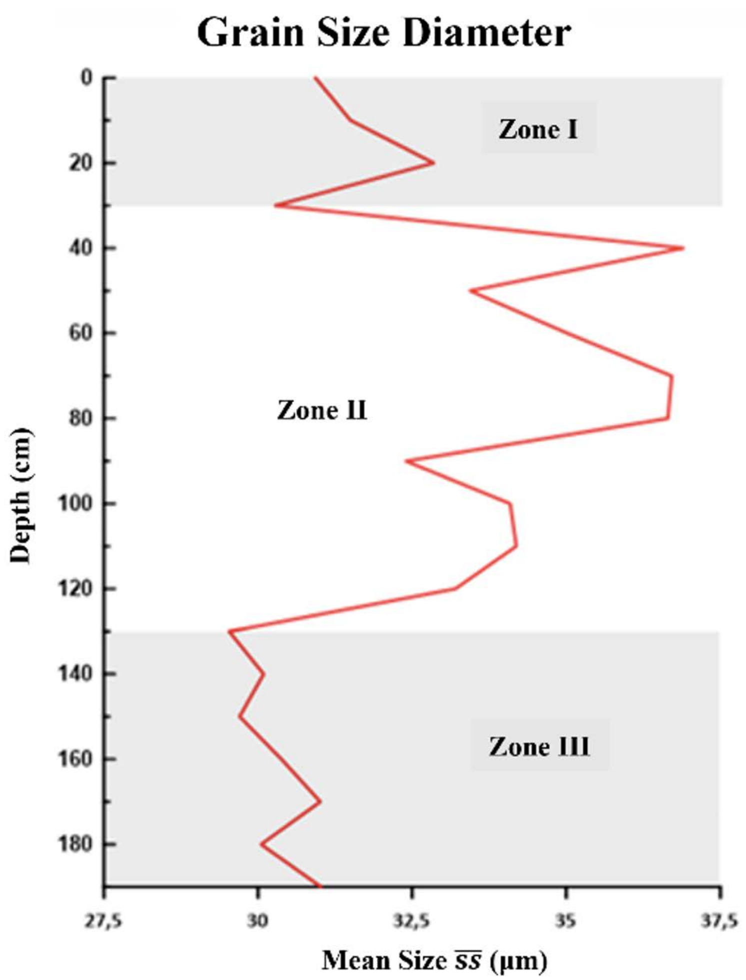

Figure 4. Mean grain size diameter of sediment core GM3-2018-WPG.04 (µm)

Table 2. Velocity of bottom current translated from the sortable silt mean size ($\overline{ss}$) value (Ledbetter, 1986)

Depth Intervals (cm)	Mean size of Sortable Silt (µm)	Bottom Current of Ledbetter (1986) (cm/s)
0	30,930	36,72994
10	31,50	37,903
20	32,85	40,6813
30	30,28	35,39224
40	36,90	49,0162
50	33,44	41,89552
60	35,02	45,14716
70	36,71	48,62518
80	36,65	48,5017
90	32,40	39,7552
100	34,09	43,23322
110	34,19	43,43902
120	33,20	41,4016
130	29,53	33,84874
140	30,09	35,00122
150	29,70	34,1986
160	30,38	35,59804
170	31,01	36,89458
180	30,05	34,9189
190	31,02	36,91516

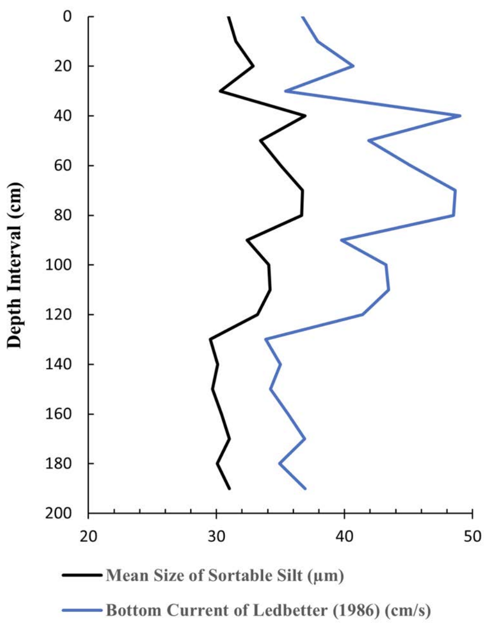

Figure 5. Fluctuations of mean size of sortable silt and estimated deep-sea current velocity based on Ledbetter's (1986) equation

Foraminifera in Waipoga Waters

Foraminiferal Distribution and P/B Ratio

Foraminifera in sample GM3-2018-WPG.04 were found throughout the sediment core intervals and exhibited good preservation conditions, such as intact shells with no discoloration. Based on the identification results, the foraminifera in the study area consist of 12 planktonic genera with 22 species and 41 benthic genera with 61 species, with varying abundances at different depths. The abundance of planktonic foraminifera was more dominant compared to benthic foraminifera. In the analysis of 20 sediment samples, the total number of planktonic individuals was 818200, while the number of benthic individuals was 114000.

Planktonic Foraminifera

In the Waipoga waters sediment samples, planktonic foraminifera species were found in abundant numbers at all depths (Figure 6), with *Globigerinoides ruber* being the most dominant species (41.7%). The abundance of *G. ruber* indicates that the waters at the study site had warm surface temperatures and oligotrophic conditions (low nutrient content). This species is generally found above the thermocline (within the mixed layer) and is associated with low-productivity environments (Fairbanks et al., 1982; Troelstra and Kroon, 1989).

In addition to *G. ruber*, the species *G. immaturus* (6.7%) was also found in abundance across all depths. This finding emphasize the indication that the study area represents warm waters with low productivity levels. However, unlike *G. ruber*, *G. immaturus* is more common found in waters with higher salinity.

Other planktonic foraminifera found in high abundance and present at all sampled depths in Waipoga waters include *Neogloboquadrina incompta* (13.2%), *Neogloboquadrina dutertrei* (11%), *Hastigerina pelagica* (6.65%), and *Globigerinoides immaturus*. *Neogloboquadrina dutertrei* and *Neogloboquadrina incompta* are species abundant above the pycnocline, preferring warmer and shallower surface waters, as well as eutrophic (nutrient-rich) environments, often associated with upwelling events (Curry et al., 1983; Fairbanks et al., 1982; Ortiz et al., 1995; Cannariato and Ravelo, 1997; Kawahata et al., 2002; Kuroyanagi and Kawahata, 2004). *Hastigerina pelagica* generally inhabits warm, shallow waters with high salinity (Bé and Hutson, 1977).

The species *Pulleniatina obliquiloculata* (4%) was also found in considerable abundance at several depths. This species is known to commonly live within the thermocline layer and prefers eutrophic conditions, often associated with upwelling processes(Ravelo et al., 1990; Baohua et al., 1997; Pflaumann and Jian, 1999).

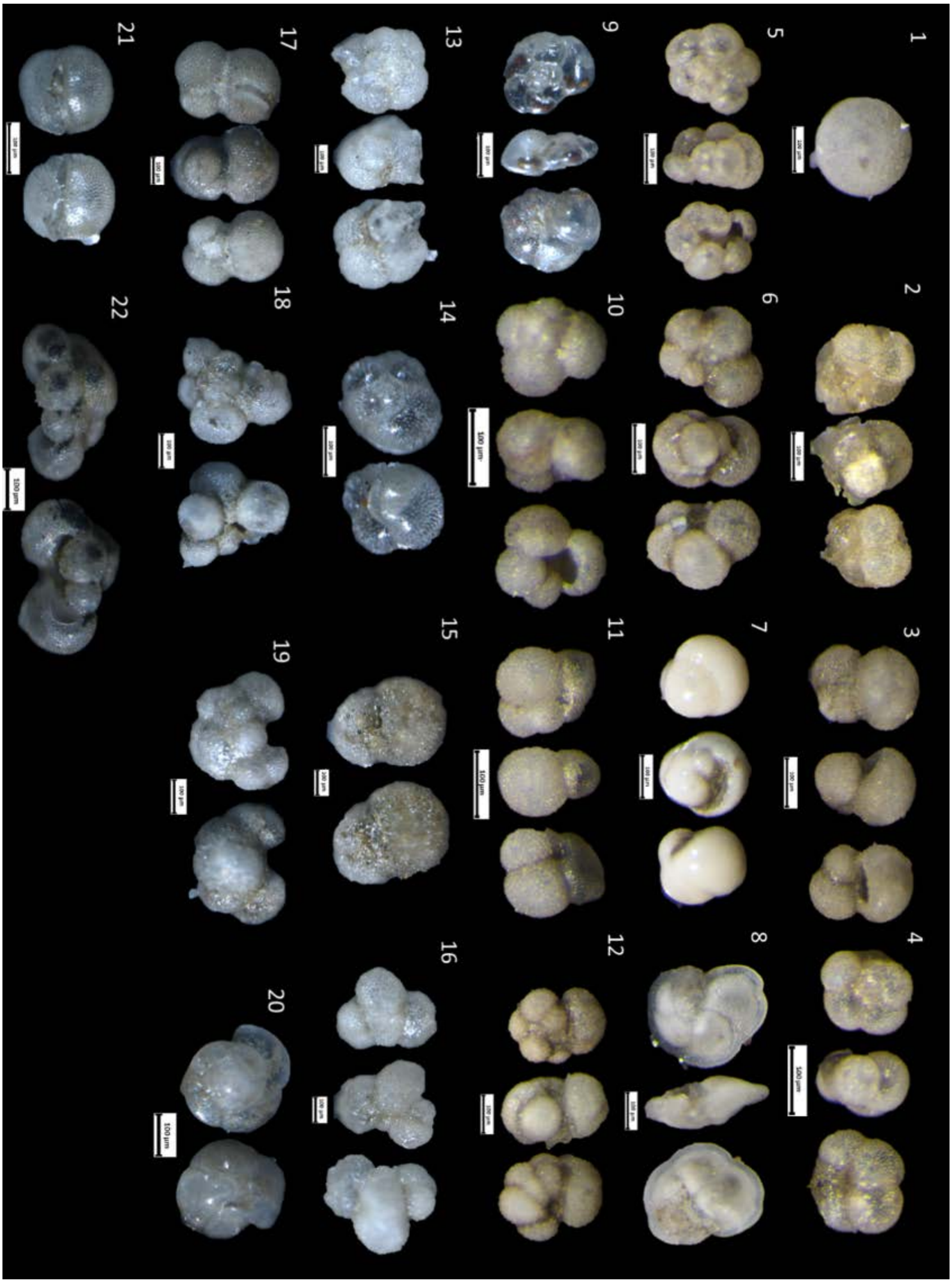

Figure 6. The planktonic foraminifera identified in this study are: (1) *Orbulina universa*, (2) *Tinophodella ambitacrena*, (3) *Globigerinoides ruber*, (4) *Neogloboquadrina incompta*, (5) *Neogloboquadrina dutertrei*, (6) *Hastigerina pelagica*, (7) *Pulleniatina obliquiloculata*, (8) *Globorotalia tumida*, (9) *Globorotalia wilesi*, (10) *Globigerina bulloides*, (11) *Globigerinoides sacculiferus*, (12) *Alloglobigerinoides conglobatus*, (13) *Neogloboquadrina* sp., (14) *Globigerinita uvula*, (15) *Globigerinoides trilobus*, (16) *planktonik unidentify*, (17) *Globigerinoides immaturus*, (18) *Hastigerinella* sp., (19) *planktonik unidentify* (1), (20) *Globorotalia hirsuta*, (21) *Sphaeroidinella excavata*, dan (22) *Neogloboquadrina blowi*.

Benthic Foraminifera

Benthic foraminifera were found in relatively smaller numbers compared to planktonic foraminifera. However, their diversity was higher than that of planktonic species. The most abundant benthic foraminifera identified in the study area include *Bulimina marginata* (1.8%), *Cibicidoides pachyderma* (1.89%), and *Lenticulina calcar* (1.3%) (Figures 7 and 8).

Bulimina marginata is known as a species adapted to low-oxygen (dysoxic) conditions, commonly associated with upwelling processes and high organic carbon content in the seafloor sediments (Rathburn et al., 1996; Martins et al., 2015). *Cibicidoides pachyderma* is considered an indicator species of environments with strong bottom currents. It can inhabit both eutrophic and oligotrophic settings. In oligotrophic conditions, *C. pachyderma* tends to live shallower within the sediments, while in eutrophic conditions, it can burrow deeper (Wollenburg et al., 2018). *Lenticulina calcar* is recognized as a species that thrives in environments with intermediate oxygen levels (suboxic conditions) (Kaiho, 1994).

From the planktonic and benthic foraminifera species, it can be inferred that, in addition to variations in productivity, the study area also experiences fluctuations in salinity and nutrient availability, which may influence the distribution of foraminifera species.

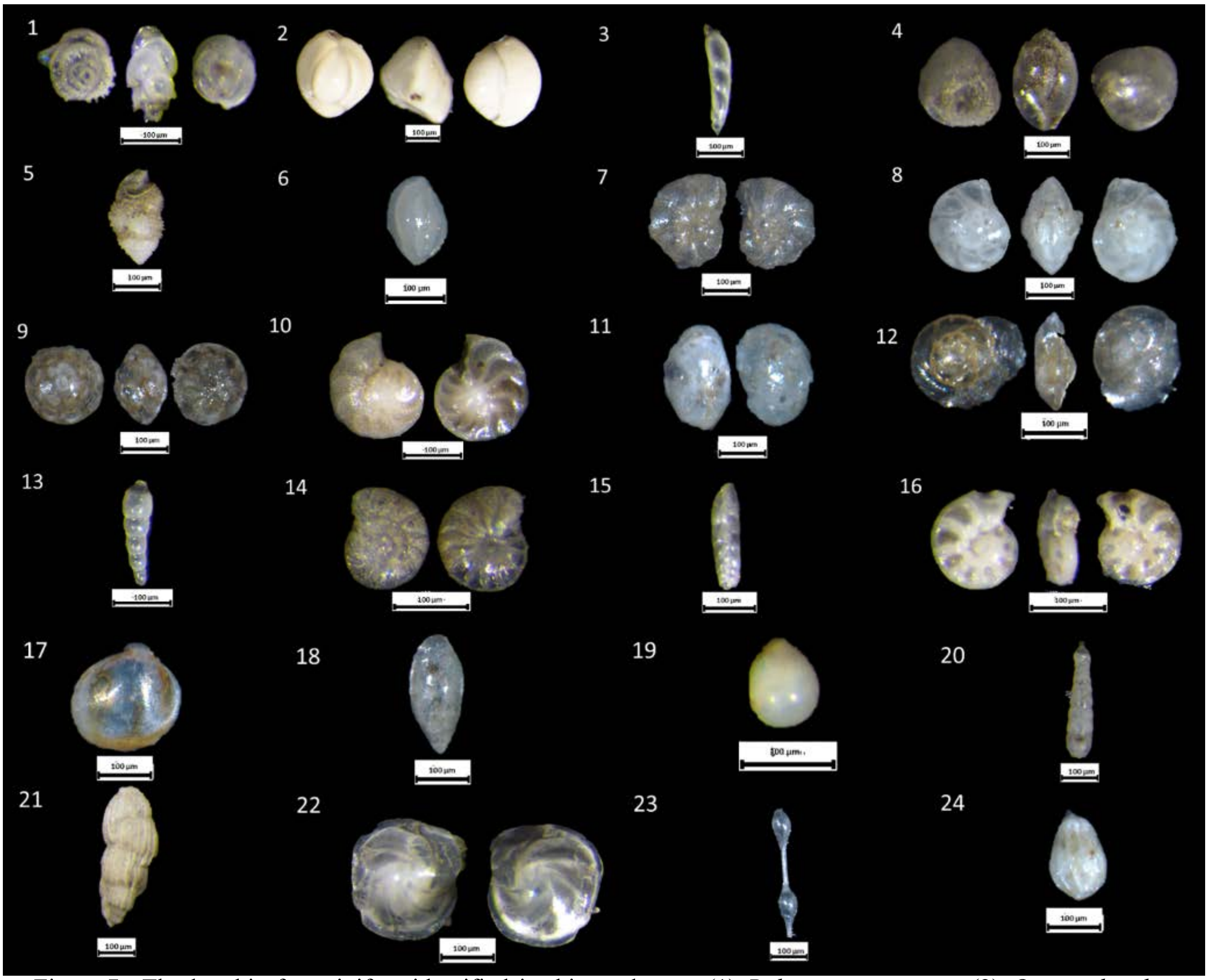

Figure 7. The benthic foraminifera identified in this study are: (1) *Bulimina marginata,* (2) *Quinqueloculina seminulum,* (3) *Enantiodentalina timorensis,* (4) *Praeglobobulimina spinescens,* (5) *Uvigerina proboscidea,* (6) *Quinqueloculina* sp., (7) *Hyalinea balthica,* (8) *Lenticulina lamarck,* (9) *Ammonia* sp., (10) *Cibicidoides pachyderma,* (11) *Globocassidulina subglobosa,* (12) *Epistominella exigua,* (13) *Laevindentalina* sp., (14) *Cibicidoides alazanensis,* (15) *Bolivina spathulata,* (16) *Hyalinea florenceae,* (17) *Parafissurina subventricosa,* (18) *Oolina baukalionilla,* (19) *Triloculina triquetrella,* (20) *Laevidentalina translucens,* (21) *Euuvigerina reineri,* (22) *Lenticulina calcar,* (23) *Grigelis orectus,* (24) *Oolina portseaensis*

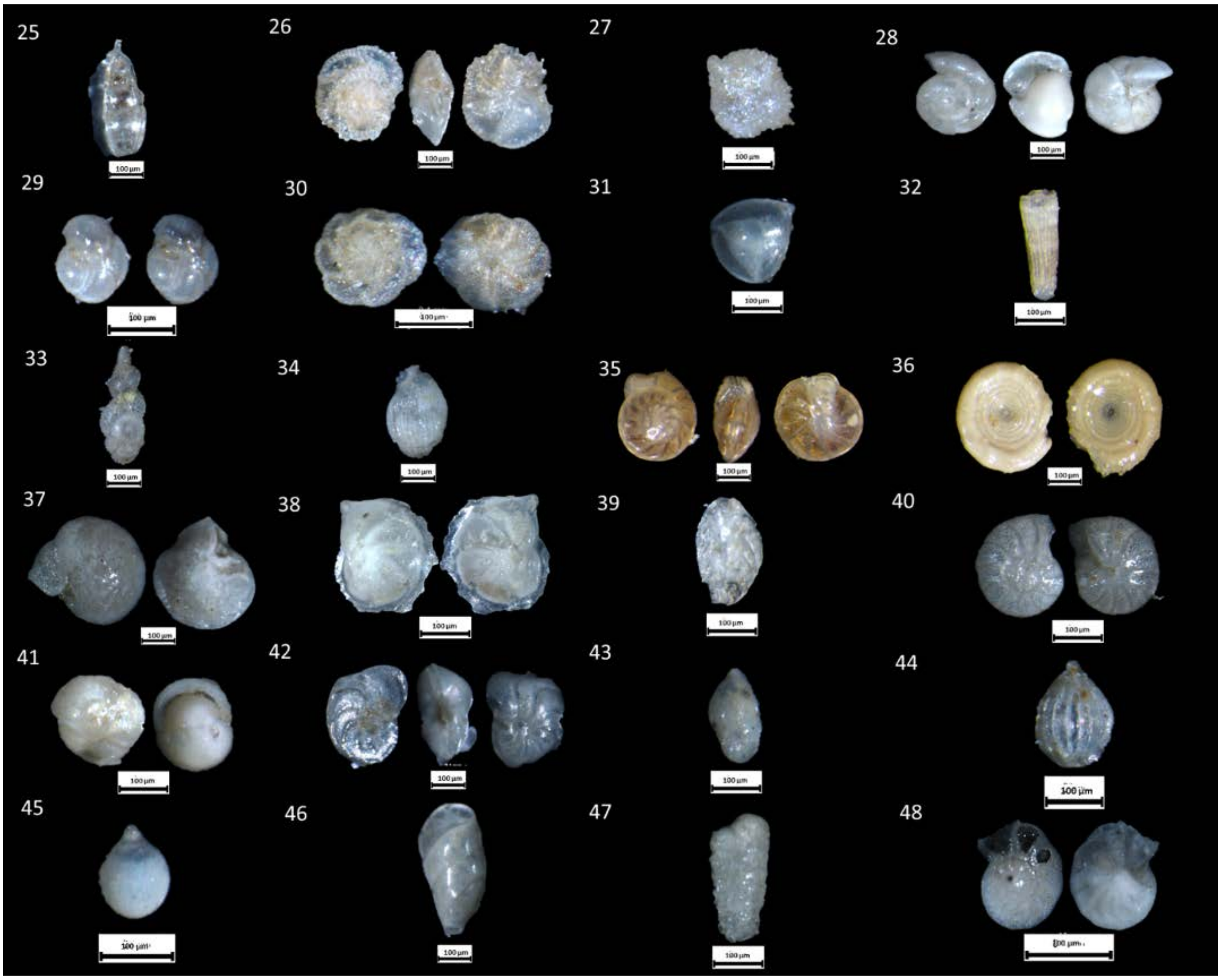

Figure 8. The benthic foraminifera identified in this study are: (25) *Bolivinita quadrilatera*, (26) *Siphonina australis*, (27) *Uvigerina aculeata*, (28) *Gyroidina soldanii*, (29) *Hansenisca soldanii*, (30) *Osangularielloides rugosus*, (31) *Neolenticulina peregrina*, (32) *Siphogenerina* sp., (33) *Neouvigerina ampullacea*, (34) *Uvigerina dirupta*, (35) *Hoeglundina elegans*, (36) *Ammodiscus intermedius*, (37) *Heterolepa praecincta*, (38) *Lenticulina* sp., (39) *Bolivina vadescens*, (40) *Hanzawaia concentrica*, (41) *Pullenia bikiniensis*, (42) *Discorbinella bertheloti*, (43) *Pyrulina cylindroides*, (44) *Lagena sulcata*, (45) *Reussoolina stellula*, (46) *Laevidentalina antartica*, (47) *Siphotextularia concava*, (48) *Cibicides* sp.

The average P/B ratio across all depths is 87.7%, with values ranging from 77.8% to 94.6% (Figure 9). A high P/B ratio indicates that the study area is dominated by planktonic foraminifera, with only a small proportion of benthic foraminifera at each depth. Based on the P/B ratio results, the study area can be classified as an upper bathyal environment, with all sediment samples representing depths greater than 200 m (the core samples were taken from a depth of 462 m). However, within the depth intervals of 20–22 cm to 2–4 cm, the P/B ratio values show a decrease compared to other depth intervals.

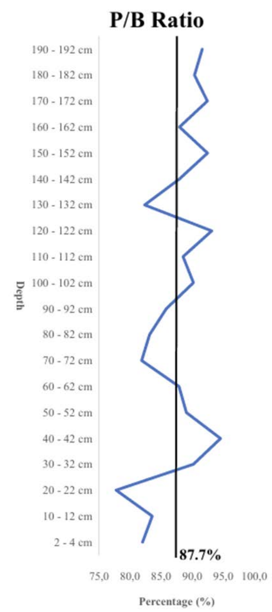

Figure 9. P/B Ratio Graph

Ecological Indices

The foraminiferal diversity index in all sediment samples from Waipoga waters ranges between 1.702 and 2.284, which falls into the moderate category. This indicates a fairly good species diversity and a relatively stable ecosystem, although still experiencing moderate ecological stress. The evenness index ranges from 0.2462 to 0.4318, indicating low to moderate evenness, where the distribution of individuals among species is not uniform. Meanwhile, the dominance index is relatively low, ranging from 0.1662 to 0.3209, suggesting that no single species strongly dominates the foraminiferal community in the sediment samples from the study area (Figure 10).

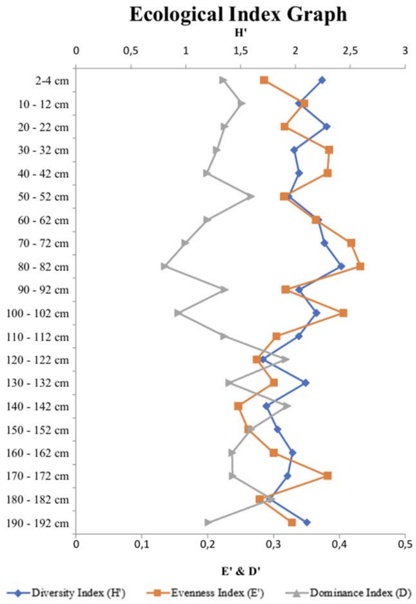

Figure 10. Ecological Index Graph

Cluster

Cluster analysis was conducted to group each depth based on the similarity of foraminiferal composition. The clustering results were grouped using a distance value of 20,000. This distance index value was chosen because it represents the distribution of foraminifera based on ecological similarity. The dendrogram results (Figure 11) show that the samples are divided into six main zones, reflecting changes in foraminiferal communities.

In each zone, the species *Globigerinoides ruber* is highly abundant; therefore, this species is not a major factor in cluster formation. Instead, species with more significant fluctuations in abundance, such as *Neogloboquadrina dutertrei*, *Hastigerina pelagica*, *Neogloboquadrina incompta*, and *Globigerinoides immaturus*, play a greater role in distinguishing between zones.

Zone 1 (190–192 cm)

Zone 1 is characterized by an average foraminiferal abundance of around 300 specimens/g. The dominant species are *Neogloboquadrina dutertrei* (15.35%), *Globigerinoides immaturus* (12.87%), and *Hastigerina pelagica* (8.13%), indicating that the waters in this zone were deposited under relatively deep thermocline conditions, warm, and oligotrophic. The abundance of *N. dutertrei* suggests that this zone may be associated with a stable thermocline layer, while *G. immaturus* reflects waters with low nutrient content and high oxygen levels (oxic).

Zone 2 (150-182 cm)

Zone 2 shows an increase in *Neogloboquadrina incompta* (14.18%), with a decrease in *Globigerinoides immaturus* (7.83%) and *N. dutertrei* (9.41%). *Cibicidoides pachyderma* (1.69%) increased compared to Zone 1 (0.90%); this species is typically found in environments with stronger currents and can adapt to both oligotrophic and eutrophic conditions. *Lenticulina calcar* (2.54%) also increased, indicating suboxic conditions. These increases may suggest enhanced ocean currents and nutrient input, resulting in more eutrophic conditions with intermediate oxygen levels (suboxic).

Zone 3 (110-142 cm)

This zone is marked by the dominance of *Neogloboquadrina incompta* (16.8%), which further increased compared to the previous zone, along with decreases in *Globigerinoides immaturus* (5.83%) and *H. pelagica* (5.03%). The high abundance of *N. incompta* indicates more eutrophic conditions and an increase in nutrient supply, which may be related to changes in thermocline stability

Zone 4 (100-102 cm)

This zone is dominated by *Pulleniatina obliquiloculata* (16.3%), *Neogloboquadrina dutertrei* (14.67%), and *Globigerinoides immaturus* (13.59%), with a decrease in *Cibicidoides pachyderma* (0.54%). *Globigerinoides ruber* shows a drastic decline in this zone, which may indicate disruption in surface water stability and cooler conditions. The increase in *P. obliquiloculata*, typically associated with the thermocline and eutrophic conditions, suggests the possibility of a shallower thermocline, potentially linked to

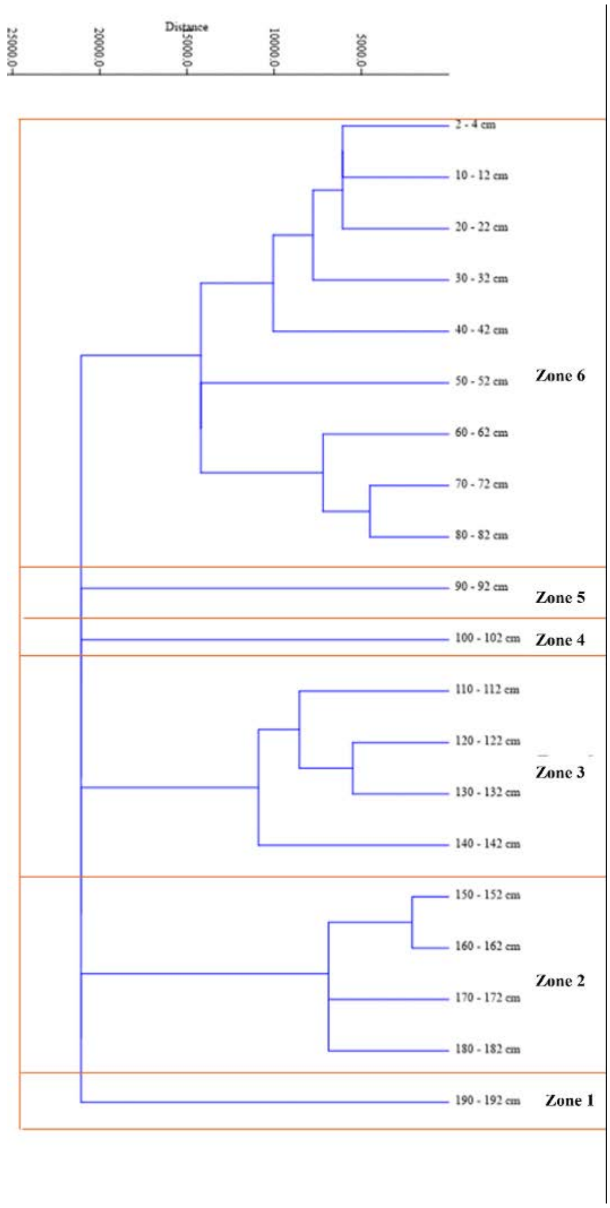

Figure 11. Dendrogram of foraminifera abundance cluster analysis

upwelling events, though further confirmation is needed.

Zone 5 (90-92 cm)

This zone is dominated by *Neogloboquadrina incompta* (12.93%), *Hastigerina pelagica* (10.17%), *Bulimina marginata* (3.67%), and *Cibicidoides pachyderma* (2.82%). Meanwhile, *N. dutertrei* (6.5%), *Pulleniatina obliquiloculata* (5.93%), and *Globigerinoides immaturus* (5.65%) declined. The increase in *Bulimina marginata* indicates low oxygen levels (dysoxic). *Globigerinoides ruber* rebounded after its previous decline in Zone 4, suggesting a return to warmer conditions and a deeper thermocline following a possible earlier upwelling event.

Zone 6 (2-82 cm)

This zone is still dominated by *Neogloboquadrina incompta* (11.93%) and *Neogloboquadrina dutertrei* (12.63%), indicating eutrophic conditions and warm waters. The decrease in *H. pelagica* (6.23%) may suggest a shift toward lower salinity conditions compared to the previous zone.

Age Reconstruction of The Sediment Core

According to Maryunani (2009) study, the abundance of *Cibicides* spp. in sediment core MD012382, which was also collected from Waipoga waters (Figure 1), served as a proxy for bottom ocean current velocity. This was then correlated with the sortable silt mean size from the core in this study,

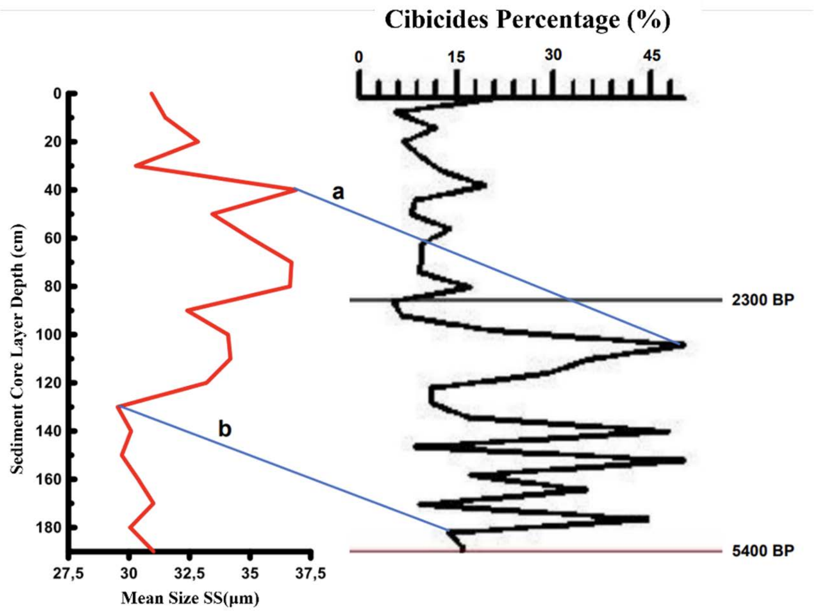

Figure 12. Age model reconstruction by correlated mean size sortable silt of GM3-2018-WPG.04 sediment core to the *Cibicides* spp. assemblages of the MD012382 (Putri, 2023).

Table 3. Age model reconstruction

Depth Interval (cm)	Age (yr BP)
40	3170
60	3651
80	4133
100	4614
120	5095
130	5336

which also reflects bottom current velocity. The sediment core MD012382 already has absolute age constraints, as radiocarbon dating and Pb-210 analyses were conducted on that core. Therefore, when correlating the abundance of *Cibicides* spp. in core MD012382 with the mean size sortable silt in this study's core, the correlated intervals can be considered to represent the same age. Derived from age model reconstruction in Figure 12, we can suggest that the interval depth of 40 cm, which has a maximum average sortable silt grain size (36.9 µm), which occurs just after a minimum value in the deeper (older) interval, and then decreases sharply afterwards, associated with the age of 3170 yr BP of the MD012382, which characterized by maximum abundance of the *Cibicides* group (> 45% in average), which also occurs after a minimum abundance at an older age, and abruptly decrease again afterwards. Another interval that can be associated and considered as a tie point is the 130 cm depth interval of GM3-2018-WPG.04, correlated to the age of 5336 Yr BP of the MD012382. This interval is characterized by relatively low value of mean size sortable silt and low abundances of *Cibicides* group. These two tie points will later be used as the basis for age modeling through interpolation and extrapolation, which is presented in Table 3. Based on the age model reconstruction, the age of this studied core can be inferred to fall within the Middle to Late Holocene. The more detailed of this age reconstruction method has been described by Putri (2023).

DISCUSSION

Several oceanographic parameters can be interpreted from the assemblage of foraminifera found in the sediment core from Waipoga waters. The P/B ratio indicates an upper bathyal environment; however, in the depth interval between 20–22 cm and 2–4 cm, there is a relative decrease in the P/B ratio. Thermocline variability can be interpreted from the group of thermocline-dwelling planktonic foraminifera, such as *Neogloboquadrina blowi*, *Neogloboquadrina incompta*, *Neogloboquadrina eggeri*, *Neogloboquadrina* sp., and *Pulleniatina obliquiloculata*. These species inhabit the thermocline layer, so variations in their abundance indicate changes in thermocline depth and productivity levels, which may be linked to the influence of upwelling that lead to the more productive Waipoga waters. Another parameter observed is the oxygenation level of the seafloor, inferred from benthic foraminifera that characterize dysoxic conditions, such as *Bulimina* spp., *Ceratobulimina* spp., *Uvigerina* spp., and *Bolivina* spp. In addition, *Globigerinoides ruber* is also observed due to its highest abundance compared to other planktonic species. *G. ruber* serves as an indicator of warm and oligotrophic surface ocean conditions. These oceanographic proxy parameters were then compared with element ratio data as well as silt grain-size data, as presented in Figure 13.

The variability in sortable mean size ($\overline{SS}$) can reflect changes in bottom current energy related to the Indonesian Throughflow (ITF), with each zone representing different bottom current conditions. That study identified three distinct zones based on this mean of sediment grain size. In Zone III, at the depths interval of 190–130 cm (the deepest/oldest interval), the sediments are relatively finer (medium silt). In Zone II, sediments become coarser (coarse silt–very coarse silt) between 120–40 cm. Finally, sediments return to finer (medium silt) in Zone I, at 30–0 cm. In this study, the *Cibicides* group was combined with the *Cibicidoides* group, which shares the same ecological characteristics. This includes species such as *Cibicidoides pachyderma*, *Cibicidoides alazanensis*, *Cibicidoides pseudoungerianus*, *Cibicidoides mundulus*, *Cibicides refulgens*, and *Cibicides* sp. *Cibicidoides* and *Cibicides* are benthic foraminifera that characterize high-energy marine environments influenced by strong currents (Pérez et al., 2024). The *Cibicides* and *Cibicidoides* groups were then correlated with foraminiferal parameters such as the P/B ratio, ecological index, the abundance of thermocline dwellers, dysoxic groups, and *G. ruber*.

Zone III (depth interval 190–130 cm; 5653–5336 yrs BP) is characterized by relatively finer silt-sized sediments (medium silt) compared to the younger Zone II, reflecting lower bottom current energy. This interpretation is supported by the lower abundance of *Cibicides* and *Cibicidoides* groups—indicators of high-energy bottom environments—as well as by the reduced occurrence of dysoxic taxa, suggesting better-oxygenated (suboxic) conditions. Ecological indices support this; the diversity index and evenness are lower in Zone III than in Zone II, indicating that species were less evenly distributed, while dominance values are higher, suggesting that a few species dominated the assemblage. In contrast, dominance values are higher, indicating that a few species contributed significantly more to the assemblage. Furthermore, the decreased abundance of thermocline dwellers indicates a deeper thermocline layer and lower nutrient availability. This is also consistent with the relatively higher proportion of *G. ruber*, a species that thrives in oligotrophic conditions, where higher abundances reflect lower nutrient levels. The cluster analysis also supports this interpretation, grouping Zone III within clusters that represent a deep thermocline, warm temperatures, and low to moderate nutrient levels. In addition, the relatively higher P/B ratio in this zone indicates an increase in water depth. Altogether, these conditions suggest a weakening of bottom current circulation and a deepening of the thermocline, likely linked to enhanced precipitation and subsequent sea-level rise. A deeper thermocline further reflects warmer, oligotrophic surface waters, in agreement with the observed increase in *G. ruber*.

In contrast, Zone II (depth interval 120–40 cm; 5095–3170 yrs BP) is characterized by coarser grain sizes (coarse–very coarse silt), indicating stronger bottom current energy, which is also supported by a slight increase in the ln(Zr/Rb) ratio (a grain-size proxy). This is accompanied by an increase in the *Cibicides* and *Cibicidoides* groups, which reflect high-energy, more oxygen-demanding (dysoxic to oxic) bottom-water environments. The ecological indices also confirm these conditions, as diversity and evenness reach their highest values in this interval, while dominance is lowest, suggesting a more balanced and diverse foraminiferal community supported by stronger circulation and nutrient availability. The increased abundance of *Cibicides* and *Cibicidoides* indicates that Zone II represents a dynamic setting, with oxygen levels beginning to decline. In addition, the higher abundance of thermocline dwellers suggests a shallower thermocline, often associated with upwelling that enhances nutrient supply, or possibly linked to stronger bottom currents transporting nutrients upward. Cluster analysis places Zone II within clusters 3, 4, and 5, which depict conditions of elevated nutrient availability and thermocline instability. This interpretation is further supported by the decreased abundance of *G. ruber*, a warm-water oligotrophic indicator species, confirming a shift

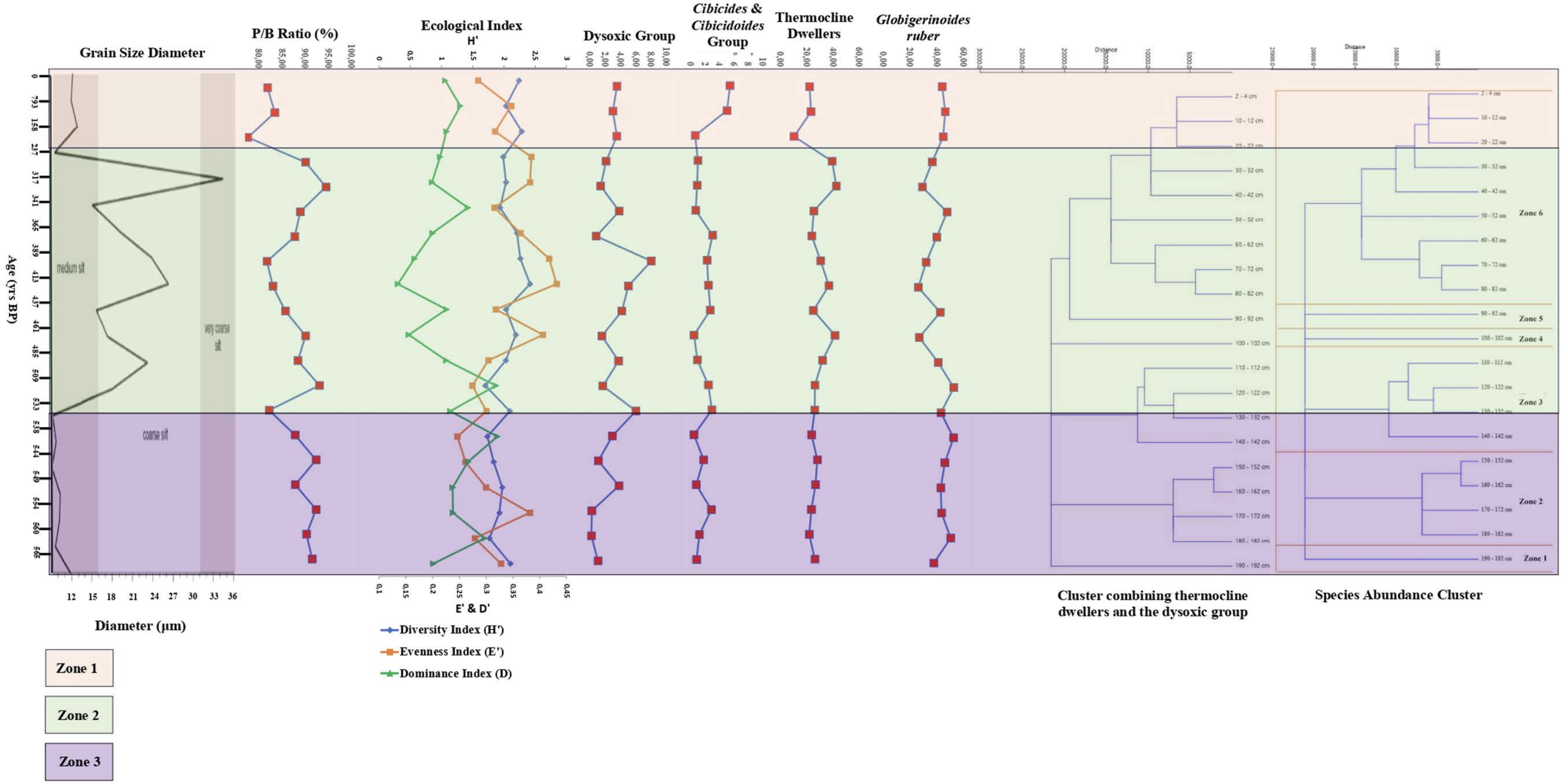

Figure 13. Correlation of the dendrogram of foraminiferal abundance cluster analysis and the combined cluster of thermocline dwellers and the dysoxic group with the grain size diameter graph, P/B ratio (%), ecological index, thermocline dwellers, dysoxic group, as well as the *Cibicides* and *Cibicidoides* groups.

toward more eutrophic conditions during this interval. Meanwhile, the increased abundance of dysoxic benthic foraminifera indicates a reduction in bottom-water oxygenation to dysoxic levels. Overall, Zone II reflects an intensification of bottom current circulation, which likely contributed to enhanced productivity, both through upwelling processes and through stronger current activity. This interpretation is consistent with the maximum current velocity of ~49 cm/s recorded at a depth of 40 cm, dated to approximately 3170 yrs BP. This period correlates with Zone II in this study, which indicates intensified ocean circulation and higher productivity. The increased abundance of *Cibicides* and *Cibicidoides*, as indicators of high-energy and dysoxic environments, also aligns with stronger deep-ocean circulation and with the increased frequency of El Niño-like events during the Middle Holocene (Maryunani, 2009). These phenomena likely contributed to a shallower thermocline and enhanced upwelling in Waipoga waters, as further reflected in the higher abundance of thermocline dwellers in this study.

In Zone I (depth interval 30–0 cm; 2378–0 yrs BP), the silt grain size becomes finer again (medium silt), similar to the conditions observed in Zone III. This indicates a weakening of bottom current energy. Ecological indices also reflect this transition, diversity and evenness decrease compared to Zone II, while dominance increases, suggesting that the community became less diverse and less evenly distributed, with certain species becoming more dominant. In addition, the abundance of thermocline dwellers decreases, suggesting a deepening of the thermocline. Based on the cluster results, this interval falls into Zone 6, which characterizes warm, eutrophic surface-water conditions with lower salinity and a relatively more stable environment. On the other hand, *G. ruber* once again shows relatively high abundance, indicating warmer and oligotrophic surface-water conditions. The abundance of dysoxic benthic foraminifera decreases, suggesting that bottom-water oxygenation increased, returning toward suboxic conditions. Zone I therefore, reflects a transitional phase into a more stable environment, with reduced current energy and weakened bottom-water circulation, implying that the inflow of ITF into Indonesian waters also diminished. Furthermore, the decrease in dysoxic taxa supports the interpretation that oxygen conditions improved, becoming more suboxic.

This indicates that deep-sea/bottom-water dynamics (which constitute the source of ITF entering Indonesian waters) exert a strong influence on foraminiferal abundance. The circulation of Southern Ocean bottom waters, as the source of ITF, is considered to significantly affect the oceanographic conditions in Waipoga waters, including the distribution and abundance of foraminiferal communities.

CONCLUSSIONS

Based on the study conducted to reconstruct past ocean productivity using foraminiferal distribution from sediment core GM3-2018-WPG.04, several conclusions can be drawn as follows:

1. Sediment sample analysis from Waipoga waters, North Papua, revealed various species of planktonic and benthic foraminifera. The dominant planktonic species are *Globigerinoides ruber*, *Neogloboquadrina dutertrei*, *Neogloboquadrina incompta*, *Pulleniatina obliquiloculata*, *Hastigerina pelagica*, and *Globigerinoides immaturus*. The dominant benthic species include *Bulimina marginata*, *Cibicidoides pachyderma*, and *Lenticulina calcar*. Planktonic foraminifera are more dominant, as the study site is located in a deep-sea (bathyal) zone.

2. The distribution of foraminifera in Waipoga waters during the late Middle to Late Holocene was strongly influenced by bottom-water circulation dynamics (the source of ITF), which affected thermocline stability, nutrient levels, and oxygenation. Zones III and I reflect oligotrophic and suboxic conditions with weakened bottom-water circulation, while Zone II represents an intensification of bottom-water currents, higher nutrient levels and productivity, as well as more dysoxic conditions, likely related to upwelling events. Deep-ocean circulation in the Southern Hemisphere, which serves as the source of ITF, exerts a significant influence on the abundance and composition of foraminifera in eastern Indonesian waters.

ACKNOWLEDGEMENTS

The author would like to express gratitude to the Head of BBSPGL or Marine Geological Institue (MGI), Geological Agency, Ministry of Energy, and Mineral Resources of Indonesia, for granting permission to conduct research at the MGI. Sincere thanks are also extended to all team members of Waipoga Cruise, the captain of the Geomarine III vessel of MGI, and the ship's crew for their support during the survey and sample collection in Waipoga waters, which greatly contributed to the smooth progress of this research. Appreciation is also given to the MGI laboratory staff for their assistance and guidance throughout the laboratory work.

REFERENCES

Ardi, R.D.W., Maryunani, K.A., Yulianto, E., Putra, P.S., Nugroho, S.H., 2019. Biostratigrafi dan Analisis Perubahan Kedalaman Termoklin di Lepas Pantai Barat Daya Sumba Sejak Pleistosen Akhir Berdasarkan Kumpulan Foraminifera Planktonik. *Bulletin of Geology*, 3(2): 355–362. https://doi.org/10.5614/bull.geol.2019.3.2.3

Ashok, K., Yamagata, T., 2009. Climate change: The El Niño with a difference. *Nature*, 461(7263): 481-484. https://doi.org/10.1038/461481a

Azis, M.F., 2006. Gerak Air di Laut. *Oseana*, Vol. 31, no. 4. pp 9-21.

Baohua, L., Zhimin, J., Pinxian, W., 1997. *Pulleniatina obliquiloculata* as a paleoceanographic indicator in the southern Okinawa Trough during the last 20,000 years. *Marine Micropaleontology*, 32, 59-69.

Bé, A.W.H., Hutson, W.H., 1977. Ecology of Planktonic Foraminifera and Biogeographic Patterns of Life and Fossil Assemblages in the Indian Ocean. *Micropaleontology,* 369-414.

Blott, S.J., Pye, K., 2001. Gradistat: A Grain Size Distribution and Statistics Package for The Analysis of Unconsolidated Sediment. *Earth Surface Processes and Landforms*, 26: 1237–1248.

Boltovskoy, E., Wright, R., 1976. *Recent Foraminifera*, Dr. W. Junk, The Hague, Boston, 515p. https://doi.org/10.1007/978-94-017-2860-7

Cannariato, K.G., Ravelo, A.C., 1997. Pliocene–Pleistocene evolution of eastern tropical Pacific surface water circulation and thermocline depth. *Paleoceanography*, 12: 805–820. https://doi.org/10.1029/97PA02514

Curry, W.B., Thunell, R.C., Honjo, S., 1983. Seasonal changes in the isotopic composition of planktonic foraminifera collected in Panama Basin sediment traps. *Earth and Planetary Science Letters*, 64(1), 33-43.

Damanik, A., Maryunani, K.A., Nugroho, S.H., Putra, P.S., 2020. Climate Variability Since Last Glacial Maximum Based on Distribution of Foraminifera in North Papua Waters, Pacific Ocean. *Marine Research in Indonesia*, 45(2): 59–66. https://doi.org/10.14203/mri.v45i2.572

Darmawan, A., Atmadipoera, A.S., Nugroho, D., Kamal, M.M., Koch-Larrouy, A., 2021. Sirkulasi Laut dan Biogeokimia di Kawasan Teluk Cendrawasih. *POSITRON*, 11(2): 63-76. https://doi.org/10.26418/positron.v11i2.46780

Dufrêne, M., Legendre, P., 1977. Species assemblages and indicator species: the need for a flexible asymmetrical approach. *Ecological Monographs*, 67: 345–366.

Fabbrini, A., Greco, M., Iacoviello, F., Kucera, M., Ezard, T.H.G., Wade, B.S., 2023. Bridging the extant and fossil record of planktonic foraminifera: implications for the *Globigerina* lineage. *Palaeontology*, 66(6), e12676. https://doi.org/10.1111/pala.12676

Fairbanks, R.G., Sverdlove, M., Free, R., Wiebe, P.H., Bé, A.W.H., 1982. Vertical Distribution and Isotopic Fractionation of Living Planktonic Foraminifera from the Panama Basin. *Nature*, 298(5877), 841-844.

Grimsdale, T.F., Morkhoven, F.P.C.M.V., 1955. The Ratio Between Pelagic and Benthonic Foraminifera As A Means of Estimating Depth of Deposition of Sedimentary Rocks. *Micropaleontology*, 1: 473–491.

Gustiantini, L., 2018. *Paleoclimate Reconstructions by Multiproxy Approaches in the Halmahera Sea since the Late Pleistocene–Holocene*. Dissertation, Institut Teknologi Bandung, Bandung.

Gustiantini, L., Piranti, S.A., Zuraida, R., Hyun, S., Ranawijaya, D.A.S., Harkinz, F.X., 2018. Foraminiferal Analysis Related to Paleoceanographic Changes of Arafura Sea and Surrounding During Holocene. *Bulletin of the Marine Geology*, 33(2).

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. *Palaeontologia electronica*, *4*(1), 1.

Hammer, Ø., Harper, D.A.T., Ryan, P.D., 2009. PAST – Palaeontological Statistics, ver. 1.89. *Palaeontologia Electronica*, 12(1): 1–9. https://www.researchgate.net/publication/228393561

Hammer, Ø., 1999-2024. *PAST – PAleontological STatistics. Version 4.17 Reference Manual*. Natural History Museum, University of Oslo.

Hasanudin, O.M., 1998. Arus Lintas Indonesia (ARLINDO). *Oseana*, 23(2), 1-9.

Hemleben, Ch., Spindler, M., Anderson, O.R., 1989. *Modern Planktonic Foraminifera*. Springer Science & Business Media, 363p.

Holbourn, A., Henderson, A.S., MacLeod, N., 2013. *Atlas of Benthic Foraminifera*. John Wiley & Sons, 651p. https://doi.org/10.1002/9781118452493

Jatiningrum, R.S., Mutika, A., Gustiantini, L., Gerhaneu, N.Y., Latuputty, G., Divina, A.R., 2023. Distribution Of Benthic Foraminifera In The Waters From Off Putri Island, Northern Batam, Riau Archipelago. *Bulletin of The Marine Geology*, 37(2). https://doi.org/10.32693/bomg.37.2.2022.783

Junita, D.R., Gustiantini, L., Sartimbul, A., Sahudin, 2020. Study of microfauna foraminifera as bioindicator for coral reef condition in Tambelan Island, Riau Island Province. In *IOP Conference Series: Earth and Environmental Science* (Vol. 429, No. 1, p. 012005). IOP Publishing.

Jurnaliah, L., Muhamadsyah, F., Barkah, M.N., 2017. Lingkungan Pengendapan Formasi Kalibeng Pada Kala Miosen Akhir di Kabupaten Demak Dan Kabupaten Semarang, Jawa Tengah Berdasarkan Rasio Foraminifera Planktonik dan Bentonik (Rasio P/B). *Bulletin of Scientific Contribution*, 14(3): 233-238. https://doi.org/10.24198/bsc.vol14.yr2016.art10965

Jurnaliah, L., Syafri, I., Sudradjat, A., Kapid, R., 2019. Biofasies dan Ekologi Perairan Jawa Tengah Bagian Utara Berdasarkan Kumpulan Foraminifera Bentik Kecil. *Jurnal Geologi Kelautan*, 17(2). https://doi.org/10.32693/jgk.17.2.2019.614

Kaiho, K., 1994. Benthic foraminiferal dissolved-oxygen index and dissolved-oxygen levels in the modern ocean. *Geology*, 22(8): 719-722.https://doi.org/10.1130/00917613(1994)022%253C0719:BFDOIA%2532.3.CO;2

Kawahata, H., Nishimura, A., Gagan, M.K., 2002. Seasonal change in foraminiferal production in the western equatorial Pacific warm pool: evidence from sediment trap experiments. *Deep-Sea Research II: Topical Studies in Oceanography,* 49(13-14), 2783-2800.

Kuroyanagi, A., Kawahata, H., 2004. Vertical distribution of living planktonic foraminifera in the seas around Japan. *Marine Micropaleontology*, 53: 173–196. https://doi.org/10.1016/j.marmicro.2004.06.001

Ledbetter, M.T., 1986. A Late Pleistocene Time-Series of Bottom Current Speed in the Vema Channel. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 53: 97–105.

Loeblich, A.R., Tappan, H., 1994. *Foraminifera of the Sahul Shelf and Timor Sea, Cushman Foundation Special publication,* 31, Cushman Foundation for Foraminiferal Research. Cambridge, U.S.A., 661p.

Martins, M.V.A., Zaaboub, N., Aleya, L., Frontalini, F., Pereira, E., Miranda, P., Mane, M., Rocha, F., Laut, L., Bour, M.E., 2015. Environmental quality assessment of Bizerte Lagoon (Tunisia) using living foraminifera assemblages and a multiproxy approach. *PLoS ONE*, 10(9), e0137250. https://doi.org/10.1371/journal.pone.0137250

Maryunani, K.A., 2009. *Microfossil Approach Based on Cendrawasih Bay Data, to Interpreting and Reconstructing Equatorial Western Pacific Paleoclimate Since Last Glacial (Late Pleistocene)*. Dissertation, Institut Teknologi Bandung. Unpublished.

Munthe, Y.V., Aryawati, R., Isnaini, 2011. Struktur Komunitas dan Sebaran Fitoplankton di Perairan Sungsang, Sumatera Selatan. *Maspari Journal*, 4(1), 122-130.

Nurruhwati, I., Kaswadji, R., Bengen, D.G., Isnaniawardhani, V., 2012. Kelimpahan Foraminifera Bentik Resen pada Sedimen Permukaan di Perairan Teluk Jakarta. *Jurnal Akuatika*, 3(1): 11–18.

Ortiz, J.D., Mix, A.C., Collier, R.W., 1995. Environmental control of living symbiotic and asymbiotic foraminifera of the California

Current. *Paleoceanography*, 10(6), 987-1009.

Peeters, F.J.C., Brummer, G.-J.A., Ganssen, G., 2001. The effect of upwelling on the distribution and stable isotope composition of *Globigerina bulloides* and *Globigerinoides ruber* (planktic foraminifera) in modern surface waters of the NW Arabian Sea. *Global and Planetary Change*, 34(3-4), 269-291.

Pérez, S.R., Bernasconi, E., Candel, M.S., 2024. Benthic foraminifera diversity from the South Atlantic Ocean: Tierra del Fuego and surrounding waters (South America). *Anais da Academia Brasileira de Ciências*, *96*, e20231342. https://doi.org/10.1590/0001-3765202420231342

Pflaumann, U., Jian, Z., 1999. Modern distribution patterns of planktonic foraminifera in the South China Sea and western Pacific: a new transfer technique to estimate regional sea-surface temperatures. *Marine Geology*, *156*(1-4), 41-83.

Putri, R., 2020. *Rekonstruksi Perubahan Lingkungan Laut Berdasarkan Foraminifera di Perairan Selatan Jawa*. Tesis, Program Pascasarjana, Institut Teknologi Bandung, 87p.

Rathburn, A.E., Corliss, B.H., Tappa, K.D., Lohmannt, K.C., 1996. Comparisons of the ecology and stable isotopic compositions of living (stained) benthic foraminifera from the Sulu and South China Seas. *Deep Sea Research Part I: Oceanographic Research Papers*, *43*(10), 1617-1646.

Ravelo, A.C., Fairbanks, R.G., Philander, S.G.H., 1990. Reconstructing Tropical Atlantic Hydrography Using Planktontic Foraminifera and an Ocean Model. *Paleoceanography*, 5(3), 409-431.

Simanungkalit, Y.A., Pranowo, W.S., Purba, N.P., Riyantini, I., Nurrahman, Y., 2018. Influence of El Niño Southern Oscillation (ENSO) phenomena on Eddies Variability in the Western Pacific Ocean. *IOP Conference Series: Earth and Environmental Science* (Vol. 176, No. 1, p. 012002). IOP Publishing. https://doi.org/10.1088/1755-1315/176/1/012002

Supono, 2008. Analisis Diatom Epipelic sebagai Indikator Kualitas Lingkungan Tambak untuk Budidaya Udang. Thesis, Universitas Diponegoro.

Troelstra, S.R., Kroon, D., 1989. Note on Extant Planktonic Foraminifera from the Banda Sea, Indonesia (Snellius-II Expedition, Cruise G5). *Netherlands Journal of Sea Research,* 24(4), 459-463.

Wollenburg, J.E., Zittier, Z.M.C., Bijma, J., 2018. Insight Into Deep-Sea Life – *Cibicidoides pachyderma* Substrate and pH-dependent Behaviour Following Disturbance. *Deep-Sea Research Part I: Oceanographic Research Papers*, 138: 34–45. https://doi.org/10.1016/j.dsr.2018.07.006

Wyrtki, K., 1987. Indonesian through flow and the associated pressure gradient. *Journal of Geophysical Research: Oceans*, 92: 12941–12946. https://doi.org/10.1029/jc092ic12p12941