Planktonic foraminifera in the seafloor of Wulan Estuary of Demak, Central of Java, Indonesia

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Abstract. Planktonic foraminifera are marine heterotrophic protists that surround their unicellular body with elaborate calcite shells. They exhibit a range of trophic behaviors from indiscriminate omnivory to selective carnivory. The species inhabit the photic zone with various density. The present work was aimed to identify and determine the density of planktonic foraminifera in the seafloor of Wulan Estuary of Demak regency, Central of Java, Indonesia. The sediment in the seafloor was taken using van veen grab sampler from 5 stations based on their position in the estuary. Upon arriving in the laboratory, the samples was washed and sun-dried. The dry sediment samples then were ground and sieved with following mesh sizes, i.e. 0.063, 0.125, and 0.250 mm and put in the plastics sample. The samples of foraminiferan then were hand picking in the picking tray. Classification of planktonic foraminifera is based entirely on the properties of their shells, i.e. wall composition and structure, chamber shape and arrangement, the shape and position of any apertures, surface ornamentation, and other morphologic features of the shell. The present work found 7 genera of planktonic foraminifera from the seafloor of Wulan estuary, i.e. Candeina, Globigerina, Globigerinoides, Globorotalia, Neogloboquadrina, Orbulina, and Pulleniatina. The lowest density was found in the Station 1 (7429 indv.m⁻²) which was the furthest station from estuary, and the highest density was 7886 indv.m⁻² present in Station 3 which was the closest to estuary. Since all seafloor were consisted of silt sediment, these density differences were more influenced by salinity of the water.

1. Introduction
The Wulan Delta is formed by a more dominant fluvial process (Fluvial Dominated Process) which can be seen from its morphology which resembles the formation of a bird's foot. The process of deposition in this delta occurs very quickly, resulting in a progradation of deltaic deposits. The rapidly increasing sediment supply and the influence of ocean currents have made the development of this delta reach 2 km to the sea during the last 40 years with the main river systems, namely the Wulan Lama River (old-riverine) and the Wulan Baru River (new-riverine) [1]. Along with the development process of the delta which continues to
increase, there is an increase in fluctuations in ocean currents which makes the sediment deposition pattern which initially leads to the sea to become lateral to form longshore bar deposits at the Wulan Estuary. This change in depositional patterns affects the ecology of living things in the delta.

The activities of sediment entry into a water can cause changes in the ecosystem, both in terms of sediment texture, total organic matter content and abundance of foraminifera. Environmental changes this can affect the abundance and horizontal distribution of foraminifera. Single-celled creatures (protists) bearing shells or tests are known as foraminifera (forams) (a technical term for internal shells). For the last 540 million years, they have been abundant as fossils. Although the simplest forms are open tubes or hollow spheres, the shells are often split into chambers that are added throughout development. The shell may be composed of organic substances, sand grains or other particles fused together, or crystalline CaCO3 depending on the species (calcite or aragonite). Today, the world's waters are home to an estimated 4,000 species. 40 of these are planktonic, meaning they float in the water. Despite planktonic, they dwell on or in the mud, sand, and rocks, that make up the seafloor, together with the benthonic forams. Foraminifera may be found in varied marine habitats, where in the intertidal zone it can be found in brackish estuaries such as in Wulan estuary. Therefore, it is necessary to do preliminary research which aimed to gather information on planktonic foraminifera, the genera composition and their density in the seafloor of Wulan Estuary, Demak.

2. Material and Method
The sediment in the seafloor was taken using Van Veen grab sampler from 5 stations based on their position in the estuary and their type of fine seafloor substrate, i.e. mud, silt and sand of the Wulan estuary, Demak which may affect the species and distribution of planktonic foraminifera. The maps of research station was presented in Figure 1 and the geographic position was shown in Table 1. Environmental parameters were also measured during data collection includes temperature, pH, water salinity and DO (Dissolved Oxygen).

Figure 1. Study area showing the stations of planktonic foraminifera samples taken from seafloor of Wulan Estuary, Demak, central of Java.

Upon arriving in the laboratory, after being washed, the samples was then was dried under the sun. The dry sediment samples then were ground and sieved with following mesh sizes, i.e. 0.063, 0.125, and 0.250 mm[2] and put in the plastics sample. The samples of foraminiferal then were hand picking in the picking tray. Each representative specimen was collected into a foraminiferal slide collector. The function of the specimens collected is only for the identification process and genus documentation using NIS software Elements in the form of photos genus is equipped with the size/ magnification of the shell. Identification process of foraminiferal based on [3][4][5]. The characteristic of their shells, such as wall
composition and structure, chamber form and arrangement, the shape and location of any openings, surface decoration, and other morphologic aspects of the shell, are used for classification of planktonic foraminifera.

Table 1. Geographic position of research station in Delta Wulan, Demak, Indonesia

| Station | Latitude   | Longitude  |
|---------|------------|------------|
| 1       | 110° 32’ 12.60” E | 6° 43’ 38.44” S |
| 2       | 110° 32’ 4.72” E  | 6° 44’ 7.92” S  |
| 3       | 110° 32’ 17.22” E | 6° 44’ 49.56” S |
| 4       | 110° 32’ 25.68” E | 6° 43’ 59.23” S |
| 5       | 110° 32’ 2.94” E  | 6° 43’ 38.98” S |

3. Results and Discussion

Based on their life strategy, foraminifera are classified into planktonic and benthic foraminifera [6]. Benthic foraminifera include many species that live attached to a substrate or that live freely and include organic-walled and agglutinated small foraminifera that dominate the deep-sea benthic microfauna, as well as a major group of foraminifera with complicated internal structures, the so-called larger benthic foraminifera [7], that include major reef-forming species. While planktonic foraminifera have globular chambers tests made of secreted calcite or aragonite by which they buoyancy) [8]. They float freely in the upper water, and are found all throughout the world, occupy a wide latitudinal and temperature range. As part of the marine zooplankton, the majority of planktonic foraminifera float on the surface or near-surface waters [9]. The depth where they live partly influenced by the mass of its test. More ornamented and more massive tests planktonic foraminifera dwell in deeper water. The tests drop to the ocean floor after death and are known as foraminiferal ooze.

In this present work, seven genera of planktonic foraminifera were found from the five stations of seafloor of Wulan Estuary, i.e. *Globigerina*, *Globigerinoides*, *Neogloboquadrina* and *Orbulina* of family *Globigerinidae*; *Globorotalia* of family Globorotaliidae; *Candeina* of family Candenidae; and *Pulleniatina* of Family Pulleniatiidae. The genera compositions were presented in Figure 2. *Globigerina* has a globose, trochospirally enrolled test with spherical to ovate but not radially elongate chambers that grow fast as they are added, with only three to five chambers in the final whorl. It has a polythalamus or 3 to 4 chambers, uniserial chamber arrangement, trochospiral light brown and has a circular aperture shape, has a hyaline test composition and is globular in shape [10].

*Globigerina's* test (or shell) wall is calcareous, perforate, and has cylindrical pores. During life, the surface features several long thin spines that are broken on dead or fossil shells, resulting in a hispid surface with short blunt remains [11]. The aperture a high umbilical arch that may be bordered by an imperforate rim or narrow lip. No secondary apertures.

*Globigerinoides* has a polythalamus or three room with uniserial arrangement, bright white in color and has a crescentic aperture shape. It is an extant genus of shallow-water planktonic foraminifera with spinose forms formed of hyaline calcite and has a test composition of hyaline and is globular in shape [12]. This genus lives in the euphotic zone, which is found at depths of 10-50 meters in waters with a wide variety of salinities and temperatures [13]. The majority of species in this genera have trochospiral chamber arrangements, while some species have streptospiral. Individual chambers are made up of thin perforated walls with big holes and spines added at the end of the process. These foraminifera use pseudopodia for feeding, locomotion, protection, and chamber construction. Many Globigerinoides species have photosynthetic symbiotic algae [14] [15]. The symbiotic algae's connection with its host foraminifera offers the host with at least three major benefits: energy from photosynthesis, improved calcification, and absorption of host metabolites.
Figure 2. The genera composition of planktonic foraminifera in the seafloor of Wulan Estuary, Demak, Central of Java, Indonesia

Globorotalia have a polythalamus or four to six rooms, shape and composition of hyaline and subglobular tests, and there is a punctate ornament, and has a brown color dark[16]. With four chambers in the final whorl and scattered pustules on earlier chambers, this genus is non-spinose. Aperture extraumbilical - peripheral; usually smooth-walled. Low trochospiral with prominent keel on the periphery [17][18].

Neogloboquadrina has a polythalamus or more than five chambers, the shape and composition of the test is hyaline and globular, the aperture is circular, and has a white color. [19] discovered five morphotypes of N. pachyderma that could be distinguished through their morphology and geochemical, and their size
and distribution are connected to water mass characteristics and depth. When contrasted to small morphotypes, this connection is viewed as suggestive of water column location, with big morphotypes residing in shallower (but also fresher, colder, and more productive) waters. The higher pore concentration in bigger morphotypes, which is tentatively viewed as a tactic to improve buoyancy and adapt to reduced salinity, supports the earlier hypothesis.

The orbulina has a polythalamus or four chambers, the shape and composition of the hyaline and globular tests, the location of the umbilical aperture is round, the ornament is smooth and it has a light brownish white color. *O. universa* d’Orbigny is a spinose planktonic foraminifer that may be found in the tropical, subtropical, and transitional zones of the global ocean’s surface waters. [11]. *O. universa* is omnivorous which feed from phytoplankton to copepods, depending on their size and quality. Furthermore, each individual contains thousands of zooxanthellae, which are thought to provide an additional source of nourishment for the foraminifera. [20]. Pulleniatina, one of the most common genera of planktonic foraminifera in the tropical oceans. Pulleniatina has a polythalamus or four chambers, the shape and composition of hyaline and subglobular tests, the location of the umbilical aperture, and has a light brownish white color[21].

*Candeina* has microperforate species with large proloculus (26 µm), smooth surface and distinct sutural multi-apertures which are unique among extant planktic species. This genus has a polythalamus or four to six spaces chamber, the shape and composition of hyaline and subglobular tests, the location of the umbilical aperture, and has a color bright yellow [22]. [23] found this genus from eruption source from Ciuyah, Ciniru – Kuningan, West Java.

The habits, diets, and life cycles of foraminifera are diverse. Some species have individuals that survive barely a few weeks, while others have individuals who live for many years. Some benthic organisms dig through sediment at rates of up to 1cm per hour, while others cling to the surface of rocks or marine plants. Marine snails, sand dollars, and tiny fish are among the predators of foraminifera, which are plentiful enough to form a significant part of the marine food chain. [7].

Now, *Globigerina* oozes can can reach great thickness and cover large areas of the ocean floor that are above the calcium carbonate compensation depth (the depth below which all CaCO3 dissolves) on today’s ocean floors. Planktonic and larger benthic calcareous foraminifera are now among the most important calcifying protists, accounting for almost 25% of total carbonate production in the oceans [24]. As a result, planktonic foraminifera may be found in a wide range of marine sediments, resulting in carbonates or limestones after lithification. On lithification, these rocks grow harder and denser, and their component microfossils can frequently only be investigated in thin sections. They may be dated by the presence of a few important planktonic foraminiferal species, which are often the sole forms that can be used to date carbonate successions and provide good biostratigraphy markers.

In both appearance and biology, planktonic foraminifera exhibit a great deal of variation and flexibility. Since their initial emergence from benthic species in the Late Triassic or Jurassic, planktonic foraminifera have experienced substantial evolution [25]. Because planktonic foraminiferal tests are abundant in most marine sediments, and their structures and taxonomic variety are regular, they give continuous evidence of evolutionary changes [9] from which precise phylogenetic connections may be constructed. Their well-defined biostratigraphy ranges and phylogenetic connections have proven valuable in academic studies of world evolution as well as in the hydrocarbon sector for sedimentary sequence correlation. The petroleum exploration industry, in particular, considers planktonic foraminifera to be extremely useful since they are simple to remove from outcrop and subsurface samples.

Overall, the lowest density was found in the Station 1 (7429 indv.m\(^{-2}\)) which was the furthest station from estuary, and the highest density was 7886 indv.m\(^{-2}\) present in Station 3 which was the closest to estuary (Figure 3). The density of planktonic foraminifera in each research station was shown in Table 2. Since all seafloor were consisted of silt sediment, these density differences were more influenced by salinity of the water. The water quality measurement was presented in Table 3.
Most planktonic foraminifera species are found in great abundance around the globe and in a wide range of climatic zones, making them an important component of open marine ecosystems [22]. They are conveyed by ocean current systems in a passive manner, including through the gateways that connect the major ocean basins. Each creature secretes a calcium carbonate shell that is made up of interconnected chambers. Most species add chambers in a trochospiral (expanding helical) pattern, creating a coiling direction in the process. The flow of dead shells to the seafloor is a substantial element of the global carbonate budget, with a drape of sediment consisting mostly of planktonic foraminifer shells and the remnants of other mineralizing plankton covering roughly a third of the planet's solid surface [25][26].
silt builds up slowly, at a pace of a few centimeters every thousand years, but it can pile up for millions of years, reaching hundreds of meters thicknesses. Coring of these sediments across the planet has resulted in a very detailed and comprehensive fossil record, making the group essential for understanding micro- and macroevolutionary patterns and processes [9].

4. Conclusion

Seafloor of Wulan Estuary was habitat of seven genera belongs to four families of planktonic foraminifera, i.e. Globigerinidae, Globorotaliidae, Candenidae; and Pulleniatinidae. The two genera of Globigerina and Globigerinoides were dense in all stations, which showed that they were extant genus of shallow-water planktonic foraminifera. The lowest density was found in furthest station from estuary, and vice versa. It is related to salinity of the sea water.

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References

[1] Atmojo H T 2015 Permodelan 3D Endapan Longshore Bar pada sistem Fluvial Dominated Delta di Delta Wulan Demak . Laporan Penelitian. Universitas Diponegoro. (Semarang)
[2] Pringgoprawiro H, Kapid R and Barmawidjaja 1994 Mikropaleontologi Umum
[3] Postuma J A 1971 Manual of planktonic foraminifera (New York: Elsevier)
[4] Van Morkhoven F P C M, Berggren W A and Edwards A S 1986 Cenozoic cosmopolitan deep-water benthic foraminifera Bull. des centres Rech. Explor. elf-aquitaine
[5] Loeblich A and Tappan H 1994 Foraminifera of the Sahul Shelf and Timor Sea (Washington)
[6] BouDagher-Fadel M K 2018 Evolution and geological significance of larger benthic foraminifera (UCL Press)
[7] BouDagher-Fadel M K 2012 Globigerinitoidea, a new Cenozoic planktonic foraminiferal superfamily, with an emended family and species Micropaleontology 58 396
[8] Baldauf S L 2008 An overview of the phylogeny and diversity of eukaryotes J. Syst. Evol. 46 263–73
[9] Aze T, Ezard T H G, Purvis A, Coxall D R M, Wade B S and Pearson P N 2011 A phylogeny of Cenozoic macroperforate planktonic foraminifera from fossil data Biol. Rev. 86 900–27
[10] Takagi H, Kimoto K, Fujiki T, Saito H, Schmidt C, Kucera M and Moriya K 2019 Characterizing photosymbiosis in modern planktonic foraminifera Biogeosciences 16 3377–96
[11] Leles S G, Mitra A, Flynn K J, Stoecker D K, Hansen P J, Calbet A, McManus G B, Sanders R W, Caron D A and Not F 2017 Oceanic protists with different forms of acquired phototrophy display contrasting biogeographies and abundance Proc. R. Soc. B Biol. Sci. 284 20170664
[12] Hayward B W, Cedhagen T, Kaminski M and Gross O 2013 Globigerinoides Cushman, 1927 (World Foraminifera Database)
[13] Gupta B K Sen and Gupta B K Sen 1999 Modern foraminifera (Springer)
[14] Spero H J and Lea D W 1993 Intraspacific stable isotope variability in the planktic foraminiferaGlobigerinoides sacculifer: Results from laboratory experiments Mar. Micropaleontol. 22 221–34
[15] Bé A W H, Spero H J and Anderson O R 1982 Effects of symbiont elimination and reinfection on the life processes of the planktonic foraminifer Globigerinoides sacculifer Mar. Biol. 70 73–86
[16] Reynolds C E, Richey J N, Fehrenbacher J S, Rosenheim B E and Spero H J 2018 Environmental controls on the geochemistry of Globorotalia truncatulinoides in the Gulf of Mexico: Implications
for paleoceanographic reconstructions Mar. Micropaleontol. 142 92–104
[17] Hayward B W, Le Coze F, Vachard D and Gross O 2021 World Foraminifera Database (Globorotalia Cushman, 1927)
[18] Friesenhagen T 2021 Test-Size Evolution of the planktonic Foraminifera Globorotalia menardii in the Eastern Tropical Atlantic since the Late Miocene Biogeosciences Discuss. Impres 1–43
[19] Altuna N E B, Pieńkowski A J, Eynaud F and Thiessen R 2018 The morphotypes of Neogloboquadrina pachyderma: Isotopic signature and distribution patterns in the Canadian Arctic Archipelago and adjacent regions Mar. Micropaleontol. 142 13–24
[20] Caron D A, Faber W W and Bé A W H 1987 Growth of the spinose planktonic foraminifer Orbulina universa in laboratory culture and the effect of temperature on life processes J. Mar. Biol. Assoc. United Kingdom 67 343–58
[21] Pearson P N and Penny L 2021 Coiling directions in the planktonic foraminifer Pulleniatina: A complex eco-evolutionary dynamic spanning millions of years PLoS One 16 e0249113
[22] Petró S M, Pivel M A G and Coimbra J C 2018 Foraminiferal solubility rankings: A contribution to the search for consensus J. Foraminifer. Res. 48 301–13
[23] Isnaniawardhani V, Muhamadsyah F and Sudrajat A 2018 Foraminifera Assemblages As A Marker Of Mud Eruption Source In Cuyah, Ciniru Kuningan, West Java Riset Geol. dan Pertamb. 28 239–49
[24] Langer M R 2008 Assessing the Contribution of Foraminiferan Protists to Global Ocean Carbonate Production 1 J. Eukaryot. Microbiol. 55 163–9
[25] Schiebel R and Hemleben C 2017 Planktic foraminifers in the modern ocean (Berlin: Springer)
[26] Setiawan R Y, Wirasatriya A, Shaari H Bin, Setyobudi E and Rachman F 2017 Assessing the Reliability of Planktic Foraminifera Ba/Ca as a Proxy for Salinity off the Sunda Strait Ilmu Kelaut. Indones. J. Mar. Sci. 22 201–12