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Diversity model of Pliocene-Pleistocene nannofossil of Kendeng Zone

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Abstract. Quantitative analyses of Pliocene-Pleistocene calcareous nannofossils from the Kendeng Zone, East Java have been performed on 181 samples collected from 4 river sections (Ngawi, Bojonegoro, Nganjuk and Jombang). The research method consists of field study and quantitative statistical analysis. Field study is to measure sections of the 4 selected sections. The samples taken include fine-grained rock (marl, shale) and carbonaceous. The sample preparation has been carried out using smears slide method. Quantitative analysis uses nannotex determination and diversity index. The river sections that have been selected consist of a continuous sediment sequence from Pliocene Kalibeng to Pleistocene Sonde Formation. The results of quantitative analysis indicate the following model of diversity nannofossil Kendeng Zone: (1) Bengawan Solo River section, Ngawi, has an average 46 species; Diversity Index \(H'\)=0.053, Homogeneity \(E\)=0.009, aged NN12-NN20 (Early Pliocene-Middle Pleistocene); (2) Kedungsumber River section, Soko Area, Distric of Temayang, Bojonegoro, has an average 26 specieses and Diversity Index \(H'\)=0.035; and Evennes/Homogeneity index \(E\)=0.006; and age NN12-NN20 (Early Pliocene-Early Pleistocene); (3) Kaliasin River section, Pinggir area, Distric of Lengkong, Nganjuk, has an average 40 specieses and Diversity Index \(H'\) = 0.050; and Evennes/Homogeneity index \(E\)=0.009 and NN12-NN20 (Early Pliocene-Early Pleistocene); (4) Kalibeng River section, Kedungringin Area,Distric ofPlandaan, Jombang hasan average 33 specieses, Diversity Index \(H'\)=0.043 and Evennes/Homogeneity index \(E\)=0.007, aged NN12-NN19 (Early Pliocene-Early Pleistocene).This nannofossil diversity model indicate that there is a paleoclimate change in Pliocene-Pleistocene of Kendeng zone; and methods applied by the present study has not been used by previous researchers.

Keywords: diversity, nannofossil, Pliocene-Pleistocene, Kendeng zone.

1. Introduction
Nannofossil (calcareous nanoplankton) is included in Haptophyta and found in the photic zone of the oceans [1, 4]. Their presence and distribution are affected by many factors, particularly, temperature and available amount of nutrients [6]). Whilst the usage of nannofossils as a tool for Cenozoic biostratigraphic analysis is well established and widely recognized, their application in paleoecological studies is still limited issue [2, 22] and Guerreiro et al., 2013 in [1].
The diversity of nannofossils is strongly influenced by paleoecological changes such as salinity, temperature, paleobathymetric, PH, etc. Nannofossil has been proved very important and is used as indicator of paleoecology, biostratigraphy, stratigraphic sequence and hydrocarbon exploration. During Pliocene-Pleistocene, the earth had global climate change occurring as Glacial Ice Age, so that the decrease of sea water reaching 100-125 m. Climate change is causing changes in the diversity of marine fauna species indicated by the decline in the number of marine fauna species including nannoplankton. Nannoplankton diversity declined dramatically during the late Pliocene and early Pleistocene [5], Aubry, 2007 in [16]. Cenozoic nannofossil data suggest that cold climates tend to encourage a decrease in nannofossils diversity. This study aims to determine the model of nannofossil diversity at the Pliocene-Pleistocene (Glacial Ice) in Kendeng zone. The resulted model can be used to identify paleoclimate change, transgression-regression phases, stratigraphic sequence and basin development in the Kendeng zone. Measurement of species diversity is important in some sciences and has evolved mainly within paleoecology[12].

2. Method

2.1. Study Area
The research area consists of four selected locations in the Kendeng Zone, East Java Basin. The locations are (1) Bengawan Solo River section, District of Ngawi; (2) Kedungsumber River section, Soko Area, Distric of Temayang, Bojonegoro; (3) Kaliais River section, Pinggir area, Distric of Lengkong, Nganjuk; and (4) Kalibeng River section, Kedungriung Area, Distric of Plandaan, Jombang. All sections consist of Kalibeng and Klitik/Sonde Formations (Figure 1).

![Figure 1](image)

Figure 1. (A).Study Area in East Java Province; (B). Selected locations for measuring section in Ngawi, Bojonegoro, Nganjuk and Jombang. [19, 23]

2.2. Analysis Tools
The research method consist of field mapping and microscope-based quantitative statistical analysis. Measuring section of 4 selected sections and representative sampling have been conducted during the field mapping, as well as taking rock samples consisting of fine-grained rock (marl, shale) and carbonaceous. Sample preparation for the fossils uses smear slide method. Nannofossils were determined under two light microscope technique (parallel light and crossed nicols) at magnification of 1000x. Species was identified using standar taxonomy as described by Gartner, 1981, Perch-Nielsen,and the Nannotax3 website [10,24]

The selected sections is expected to have a continuous sediment sequence from Early Pliocene to Early Pleistocene, from older to younger, namely: Kalibeng Formation to Sonde Formation (consisting of Klitik and Atasangin Members). The parameters measured were the average number of species of nannofossils in each section, the number of species in each sample (random but representative) and levels of nannofossils species in diversity in the 4 sections (Ngawi, Bojonegoro, Nganjuk and Jombang area). Quantitative analysis uses nannotex determination while diversity index
analysis was based on Shannon Index and and Simpton Index [11,18,25]

2.3. Formula of Diversity

Diversity Index:
- A diversity index is a mathematical measure of species diversity in a given community.
- Diversity Index is determined based on the species richness (the number of species) and species abundance (the number of individuals per species).
- The diversity index that will be used by the present study is the Diversity Index by Shannon-Weiner (1949), and Simpson Index.

Calculation of Nannofossil Diversity Index[4, 9, 10]:
To calculate the diversity of nannofossil used Shannon Index Diversity and Simpton Index.
Shannon Index is an index of statistical information, which means it assumes all species (nannofossils) are represented in samples and samples randomly (rock samples).
In this index, $P_i$ is the proportion ($n_i/N$) of an individual of a particular species found ($n_i$) divided by ($N$) the total number of individuals found, $ln$ is the natural log, $\Sigma$ is the sum of the calculations, and $S$ is the number of species. The index formula (1, 2) is as follows :

$$H' = \sum P_i \ln P_i$$  \hspace{1cm} (1)

$$D = \frac{\sum P_i}{\sum P_i^2}$$ \hspace{1cm} (2)

Simpson Index is the dominance index because it gives more weight to the common or dominant species. In this case, some rare species with only a few representatives will not affect diversity. In this index same of Shannon index (3) :

$$E = \frac{H'}{H_{max}} = \frac{\sum P_i \ln P_i}{S \log S}$$ \hspace{1cm} (4)

$$H_{max} = S \log S$$ \hspace{1cm} (5)

The Range of Diversity :

The range of Diversity Index (Shannon - Weiner) [11, 18, 25] :

$H' < 2.3026$ : Small diversity and low community stability

$2.3026 < H' < 6.9078$ : Medium diversity and moderate community stability

$H' > 6.9078$ : High diversity and high community stability

The Range of Homogeneity [11, 25]:

$E < 0.4$ : Small population

$0.4 < E < 0.6$ : Moderate population

$E > 0.6$ : High population

3. Result

3.1. Geological Setting

North east Java region based on tektonofisiography of Java Island divided into four units tektonofisiografi, successively from south to north are: Kendeng Zone, Randublatung Zone, Rembang Zone and Shelf of Java Sea (Figure 2).
Regional Stratigraphy of Kendeng Zone, North East Java Basin indicates the age of the rock outcrops found in this zone ranges from Oligocene to Pleistocene [17]. The sequence of litostratigraphy units in the Kendeng Zone are characterized by the composite lithology and age as presented in Figure 3.

The Kendeng zone is an anticlinorium situated between the North East Java hinge belt and the axis of the central trough of Java. It appears to be a distinct geological unit from the standpoints of structure, lithostratigraphy and tectonics [17]. From late Oligocene to Holocene, sediments were deposited within this area under dominant regressive conditions which prevailed at first in the West then progressively extended eastwards and finally resulted in the emersion of the entire Kendeng zone. Volcanoes were almost permanently active in the western and southern adjacent areas during this period. Stratigraphy Regional of Kendeng Zone, North East Java Basin [17]. Outcrops found in this zone from Oligocene to Pleistocene. The sequence litostratigraphy units in the Kendeng Zone, characterized by the composite lithology and age, is presented in Figure 3 [7, 17].
Local stratigraphy of research area consists of Kalibeng Formation and Klitik/Sonde Formation. Lithology of the Kalibeng Formation consists of the dominant marl, massive, containing abundant many foraminifera and nannofossil, some calcareous sandstone are found as intercalation layers (Figure 4A, 4B). The thickness of Kalibeng Formation ≥ 650 meters, relative age of this formation is Early Pliocene (NN12-NN18), based on last appearance of Discoaster brouweri. The Kalibeng Formation is deposited at the deep water environment, a lower bathyal (200-2000 meters) depth based on appearance of Gyroidina soldanii.

Lithology of the Klitik/Sonde Formation consists of the dominant limestones, calcarenites, marl (Figure 5C, 5D) containing abundant foraminifera and few of nannofossil. The thickness of Klitik/Sonde Formatian about 100 meters, age of this formation is Late Pliocene to Pleistocene (NN14-NN21), based on first appearance of Pseudoemiliania lacunosa and Gephyrocapsa oceanica. The Klitik Formation is deposited at the shallow water environment, bathymetric of the neritic (20-100meter) based on appearance of benthonic Ammonia beccarii, Amphystegina lessonii, and larger foraminifera.

Regional Structure of Java
The main structure of Java Island are three main structural patterns, namely the Meratus Pattern (NE-SW trend), Sunda trend (N-S Trend) and Java pattern (E-W trend) (Figure 6) [15]. In East Java, this pattern is indicated by faults and folds in the Kendeng Zone. The structure of Sumatra is mainly found in West Java, whereas in Eastern Central Java this structure is no longer visible. The Java pattern (East-West) in the East Java basin is older than the Early Miocene, and is called SAKALA trend (Figure 6) in [20].
3.2. Discussion

The species diversity of nanofossils in the study area will be determined by comparing the results from the four selected sections. Data from the selected sections of Ngawi, Bojonegoro, Nganjuk and Jombang were collected for determining genus and species of Pliocene-Pleistocene nanofossils of Kendeng Zone (NN12-NN21). The abundance (number of individuals) and variety and number of species found in samples from Kalibeng and Sonde Formation is presented in the following Table-1.
| No. | N sample | Code sample | Sp. | A g e |
|-----|---------|-------------|-----|-------|
| 1   | 4       | 1           | VW.5 | 0.016 |
| 2   | 2       | 1           | VW.6 | 0.010 |
| 3   | 1       | 1           | VW.8 | 0.013 |
| 4   | 1       | 1           | VW.9 | 0.006 |
| 5   | 1       | 1           | VW.9 | 0.019 |
| 6   | 1       | 1           | VW.10 | 0.003 |
| 7   | 1       | 1           | VW.12 | 0.022 |
| 8   | 1       | 1           | VW.17 | 0.029 |
| 9   | 1       | 1           | VW.22 | 0.013 |
| 10  | 1       | 1           | VW.23 | 0.029 |
| 11  | 1       | 1           | VW.25 | 0.016 |
| 12  | 1       | 1           | VW.33 | 0.026 |
| 13  | 1       | 1           | VW.35 | 0.029 |
| 14  | 1       | 1           | VW.36 | 0.022 |
| 15  | 1       | 1           | VW.38 | 0.026 |
| 16  | 1       | 1           | VW.42 | 0.022 |
| 17  | 1       | 1           | VW.44 | 0.029 |
| 18  | 1       | 1           | VW.45 | 0.022 |
| 19  | 1       | 1           | VW.51 | 0.003 |
| 20  | 1       | 1           | VW.55 | 0.003 |
| 21  | 1       | 1           | VW.57 | 0.010 |
| 22  | 1       | 1           | VW.60 | 0.000 |
| 23  | 1       | 1           | VW.61 | 0.000 |
| 24  | 1       | 1           | VW.62 | 0.013 |
| 25  | 1       | 1           | VW.63 | 0.013 |
| 26  | 1       | 1           | VW.64 | 0.016 |
| 27  | 1       | 1           | VW.65 | 0.055 |
| 28  | 1       | 1           | VW.70 | 0.022 |
| 29  | 1       | 1           | VW.71 | 0.035 |
| 30  | 1       | 1           | VW.72 | 0.029 |
| 31  | 1       | 1           | VW.73 | 0.019 |
| 32  | 1       | 1           | VW.76A  | 1.003 |
| 33  | 1       | 1           | VW.77 | 0.006 |
| 34  | 1       | 1           | VW.79 | 0.000 |
| 35  | 1       | 1           | VW.80 | 0.000 |
| 36  | 1       | 1           | VW.81 | 0.003 |
| 37  | 1       | 1           | VW.82 | 0.000 |
| 38  | 1       | 1           | VW.83 | 0.013 |
| 39  | 1       | 1           | VW.84 | 0.010 |
| 40  | 1       | 1           | VW.85 | 0.003 |
| 41  | 1       | 1           | VW.86 | 0.016 |
| 42  | 1       | 1           | VW.87 | 0.006 |
| 43  | 1       | 1           | VW.89 | 0.006 |
| 44  | 1       | 1           | VW.90 | 0.013 |
| 45  | 1       | 1           | VW.91 | 0.000 |
| 46  | 1       | 1           | VW.92 | 0.013 |
| 47  | 1       | 1           | VW.93 | 0.000 |
| 48  | 1       | 1           | VW.94 | 0.000 |
| 49  | 1       | 1           | VW.95 | 0.000 |
| 50  | 1       | 1           | VW.96 | 0.058 |
| 51  | 1       | 1           | VW.97 | 0.032 |
| 52  | 1       | 1           | VW.98 | 0.035 |
| 53  | 1       | 1           | VW.99 | 0.026 |
| 54  | 1       | 1           | VW.10 | 0.022 |
| 55  | 1       | 1           | VW.10A | 0.022 |
| 56  | 1       | 1           | VW.10B | 0.009 |
| 57  | 1       | 1           | VW.11 | 0.022 |
| 58  | 1       | 1           | VW.12 | 0.022 |
| 59  | 1       | 1           | VW.15 | 0.029 |
| 60  | 1       | 1           | VW.16 | 0.013 |
| 61  | 1       | 1           | VW.17 | 0.013 |

**Table 1.** Number of species from Kalibeng and Klikit /Sonde Formation from Ngawi-Bojonegoro-Nganjuk-Jombang Sections of Kendeng Zone.
Table 2. Distribution of nanofossils species, Diversity Index \((H')\) and Homogeneity \((E)\), From Ngawi-Bojonegoro-Nganjuk-Jombang Sections of Kendeng Zone

| No. | Species                     | JOMBANG |
|-----|-----------------------------|---------|
| 1   | Ammonolithus delicatus      | 0,00    |
| 2   | Ammonolithus tricorniculatus| 0,00    |
| 3   | Calcidiscus leptoporus      | 0,00    |
| 4   | Calcidiscus macrocytherei   | 0,00    |
| 5   | Ceratolithus acutus         | 0,00    |
| 6   | Ceratolithus armatus        | 0,00    |
| 7   | Ceratolithus rugosus        | 0,00    |
| 8   | Ceratolithus telemus        | 0,00    |
| 9   | Coccolithus pelagicus       | 0,00    |
| 10  | Coccocisps piolelagis       | 0,00    |
| 11  | Discoaster sp.              | 0,00    |
| 12  | Discoaster surculus        | 0,00    |
| 13  | Discoaster tamalis          | 0,00    |
| 14  | Discoaster triradiatus      | 0,00    |
| 15  | Discoaster tristifer        | 0,00    |
| 16  | Discoaster variabilis       | 0,00    |
| 17  | Emiliania huxleyi           | 0,00    |
| 18  | Gephyrocapsa caribbeanica   | 0,00    |
| 19  | Gephyrocapsa oceanica       | 0,00    |
| 20  | Helcosphaera carteri        | 0,00    |
| 21  | Helcosphaera kampferi       | 0,00    |
| 22  | Helcosphaera selli          | 0,00    |
| 23  | Photospaera japonica        | 0,00    |
| 24  | Photospaera sp.             | 0,00    |
| 25  | Photospaera mutipora        | 0,00    |
| 26  | Pseudomelania lucasana      | 0,00    |
| 27  | Pseudomelania ovata         | 0,00    |
| 28  | Reticulofenestra huapi      | 0,00    |
| 29  | Reticulofenestra minutia    | 0,00    |
| 30  | Reticulofenestra minuta     | 0,00    |
| 31  | Reticulofenestra pseudomelania| 0,00  |
| 32  | Rhizospherea clavigera      | 0,00    |
| 33  | Scapholithus fossilis       | 0,00    |
| 34  | Scyphosphaera apsteini      | 0,00    |
| 35  | Scyphosphaera aranata       | 0,00    |
| 36  | Scyphosphaera globulata     | 0,00    |
| 37  | Scyphosphaera palcherrima   | 0,00    |
| 38  | Scyphosphaera ventressa     | 0,00    |
| 39  | Sphenolithus abies          | 0,00    |
| 40  | Sphenolithus neobies        | 0,00    |
| 41  | Syracosphaera sp.           | 0,00    |
| 42  | Thoracosphaera albotropica  | 0,00    |
| 43  | Thoracosphaera saxeae       | 0,00    |
| 44  | Umbilicosphaera jafari      | 0,00    |
| 45  | Discoaster sp.              | 0,00    |
| 46  | Discoaster surculus        | 0,00    |
| 47  | Discoaster tamalis          | 0,00    |
| 48  | Discoaster triradiatus      | 0,00    |
| 49  | Discoaster tristifer        | 0,00    |
| 50  | Discoaster variabilis       | 0,00    |
| 51  | Emiliania huxleyi           | 0,00    |
| 52  | Gephyrocapsa caribbeanica   | 0,00    |
| 53  | Gephyrocapsa oceanica       | 0,00    |
| 54  | Helcosphaera carteri        | 0,00    |

Quantitative analysis of nanofossils have been performed on 4 stratigraphic measurement sections. The results of analysis show that Kalibeng and Sonde Formations are deposited in Early Pliocene to Early Pleistocene (NN12-NN21) and there are 18 genus and 54 specieses identified (Table-3). The
diversity models of nannofossil Pliocene-Pleistocene resulted from the four selected sections are summarized as follows and shown in Figure 7.

- Bengawan Solo River section, District of Ngawi: Age NN12-NN20 (Early Pliocene-Middle Pleistocene), 46 specieses identified, average number of species (0.056), Diversity Index ($H'$)=0.053 and Evenness/Homogeneity Index ($E$)=0.009.

- Kedungsumber River section, Soko Area, Distric of Temayang, Bojonegoro: Age NN12-NN20 (Early Pliocene - Early Pleistocene), 26 specieses identified, average number of species (0.196), Diversity Index ($H'$) = 0.035 and Evenness/Homogeneity Index ($E$)= 0.006.

- Kaliasin River section, Pinggir area, Distric of Lengkong, Nganjuk: Age NN12-NN20 (Early Pliocene - Early Pleistocene), 40 specieses identified and average number of species (0.074), Diversity Index ($H'$) = 0.050 and Evenness/Homogeneity Index ($E$)= 0.009.

- Kalibeng River section, Kedungringin Area, Distric of Plandaan, Jombang: Age NN12-NN19 (Early Pliocene- Early Pleistocene), 33 specieses identified, average number of species (0.098), Diversity Index ($H'$) = 0.043 and Evenness/Homogeneity Index ($E$)= 0.007.

From the results shown above, the Diversity Index of nannofossils in the study area is $H'$=0.035-0.050. This values is considered as “Small diversity and low community stability” (where $H'< 2.3026$). This means small diversity and low community stability. The Range of Evenness/Homogeneity is $E=0.006-0.009$, and it can be considered as “small population” (with $E< 0.4$). This means small population. The smaller the index value of diversity ($H'$) then the uniformity index ($E$) will also be smaller, indicating the dominance of a particular species against other species. Based on table 2, a model of diversity model of each section, has been constructed. The model is used to know the pattern of development of species diversity, to performed paleoecological analysis on Pliocene to Pleistocene (Figure 7).

![Graph of Nannofossils Species Diversity & Evenness](image1)

![Graph of Nannofossils Species Diversity & Evenness](image2)

![Graph of Nannofossils Species Diversity & Evenness](image3)

![Graph of Nannofossils Species Diversity & Evenness](image4)

**Figure 7.** Diversity model of nannofossils species Pliocene-Pleistocene from Ngawi-Bojonegoro-Nganjuk-Jombang Sections of Kendeng Zone.
Based on four diversity models of nannofossil shown in Figure 4, shown that there is a decreasing pattern of diversity index from Pliocene to Pleistocene and Jombang section have a different pattern. This means that there is a decrease of species diversity from Pliocene to Pleistocene. This diversity model is expected to determine paleoclimate change in Pliocene-Pleistocene of Kendeng zone. The low diversity index is strongly influenced by changes in paleoecology, climate change and ecosystem stability. The uniformity index (E) is low which means the ecosystem is in a less stable condition. This is probably due to climate change in Pliocene-Pleistocene globally, volcanic or tectonic.

4. Conclusions

Presence of nannofossil is affected by many factors and used as a tool for Cenozoic biostratigraphic analysis and application in paleoecological. Research area that consists of four selected locations (Ngawi, Bojonegoro, Nganjuk and Jombang sections) in the Kendeng Zone, is composed by Kalibeng and Klitik/Sonde Formations with Early Pliocene to Early Pleistocene (NN12-NN21).

Total number species of the Kalibeng Formation more abundance than Klitik/Sonde Formation, this is because Kalibeng Formation composed of lithology dominated by fine-grain clastic sediment (marl), deposited of the open marine (Bathyal), whilst Klitik/Sonde Formation is deposited in shallow marine (neritic) and lithology dominated by limestone.

Diversity Index of nannofossils is $H'=0.035-0.050$, indicating “small diversity and low community stability”. The Range of Evennes/Homogeneity is $E=0.006-0.009$, showing “small population”. The smaller the index value of diversity ($H'$) then the uniformity index (E) will also be smaller, indicating the dominant of a species against other species.

Based on the graphic of diversity model shown in Figure 7, there is a decreasing pattern of Diversity index from Pliocene to Pleistocene in the three selected locations while the Jombang section have a different pattern. With the similar results of the three locations, it means that there is a decrease of species diversity from Pliocene to Pleistocene. This diversity model can be used to determine paleoclimate change in Pliocene-Pleistocene of Kendeng zone. The low diversity index is strongly influenced by changes in paleoecology, climate change and ecosystem stability. The uniformity index (E) is low, this means the ecosystem is in a less stable condition. It is probably due to climate change in Pliocene-Pleistocene globally.

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