ENVIRONMENTAL CONTROL OF NANNOPLANKTON AND FORAMINIFERA ASSEMBLAGES IN MADURA WATERS

by:

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ABSTRACT

Nannoplankton is widely used for determining age of sediments following the other microorganism foraminifera since the late 1960s; and it was started being used for marine geography study in the year of 1984. This topic interests to be done in Indonesia as one of the tropic region.

The research covered a study about environment using nannoplankton and it is compared with the same study using foraminifera. Methods of the study include: (1) collecting secondary data and samples; (2) collecting field data record; (3) laboratory analyses upon sediment samples to determine the content of nannoplankton and foraminifera (micropaleontology analyses), the texture and composition of minerals (by means of grain size, petrology megascopic and microscopic analyses) (4) intergrating all of the analyses result.

Madura waters can be divided into four zones, among all : (I) inner shelf (water depth less than 30 m) in Madura Strait, (II) inner shelf in open marine north of Madura, (III) outer shelf (water depth 30 to 80 m) in Madura Strait, and (IV) outer shelf in open marine north of Madura. Inner shelf in the Madura Strait (Zone I) is characterized by less than 1% sediment of nannoplankton (are made up of Gephyrocapsa oceanica); rare assemblages of benthic foraminifera only (Ammonia spp., arenaceous carbonate test taxa such as : Ammobaculites spp., Textularia agglutinans, Haplophragmoides spp., and milliolidae). Inner shelf open marine north of Madura (Zone II) yielded few nannoplankton assemblages, dominated by Gephyrocapsa oceanica with low number of Emiliania huxleyi, Helicosphaera carteri, H. pavimentum, H. wallichii and Pontosphaera spp; common foraminifera assemblages consist of rare planktic Globigerinoides ruber, G. trilobus sacculiferus, G. conglobatus with one or two dominant benthic (Elphidium spp, Ammonia spp., Pseudorotalia spp., Asterorotalia spp.). Outer shelf of Madura Strait (Zone III) assigned by common nannoplankton assemblages, dominated by Gephyrocapsa oceanica and Emiliania huxleyi with few to common Helicosphaera carteri, H. pavimentum, H. wallichii, Pontosphaera spp., Calcidiscus leptoporus, Umbellosphaera irregularis and Umbilicosphaera spp.; common benthic foraminifera assemblages Elphidium spp, Ammonia spp., Cibicides spp., Pseudorotalia spp., and Asterorotalia spp. with rare planktic Globigerinoides ruber, G. trilobus sacculiferus, and G. conglobatus. In the outer shelf open marine north of Madura (Zone IV), it is recorded abundant of nannoplankton Gephyrocapsa oceanica, Emiliania huxleyi,
Helicosphaera carteri, H. pavimentum, H. wallichii, Pontosphaera spp., Discoaster spp., Calcidiscus leptoporus, Umbellosphaera irregularis, Umbilicosphaera spp.; the presence of moderate divers and abundance of planktic foraminifera Globigerina calida, P. obliquiloculata, Orbulina universa, H. aequilateralis with common abundance benthic Bolivina spp., Bulimina spp., Cibicides spp., Pseudorotalia spp., Asterorotalia spp., Lenticulina spp., Cassidulina spp., Siphonina spp., and the presence of Uvigerina spp.

The most significant physical environment parameter of each zone controlling appearance of marker species and abundancy of microorganism assemblages are bathymetry, salinity, temperature, pH and sediment due to fluvial supply.

**Keywords**: nannoplankton, foraminifera, environment, marker species, Madura Waters

**SARI**

Nannoplankton telah digunakan secara luas untuk penentuan umur sedimen di samping mikroorganisme lain, foraminifera, sejak tahun 1960-an; dan mulai digunakan untuk studi geografi laut pada tahun 1984. Kajian ini menarik untuk dilakukan di Indonesia yang termasuk daerah tropis.

Studi ini mempelajari perubahan lingkungan berdasarkan analisis nannoplankton, dibandingkan dengan foraminifera yang umum dipakai untuk kegunaan sejenis. Metode penelitian mencakup : (1) pengumpulan data sekunder dan sampel; (2) pengambilan data lapangan; (3) pekerjaan laboratorium meliputi analisis mikropaleontologi dan petrologi; serta (4) integrasi seluruh hasil analisis.

Perairan Madura dapat dibedakan menjadi empat zona, yaitu: (I) Paparan dalam (kedalaman muka air laut kurang dari 30 m) di Selat Madura; (II) Paparan dalam pada laut terbuka di Perairan Utara Madura; (III) Paparan luar (kedalaman muka air laut 30 hingga 80 m) di Selat Madura; dan (IV) Paparan luar pada laut terbuka di Perairan Utara Madura.

Paparan dalam di Selat Madura (Zona I) dicirikan oleh kumpulan nannoplankton kurang dari 1% total sedimen (Gephyrocapsa oceanica); foraminifera bentik jarang (Ammonia spp., cangkang gamping pasir seperti Ammobaculites spp., Textularia agglutinans, Haplophragmoides spp., dan miliolid). Paparan dalam di laut terbuka (Zona II) dicirikan oleh nannoplankton kurang melimpah yang didominasi oleh Gephyrocapsa oceanica dengan beberapa Emiliania huxleyi, Helicosphaera carteri, H. pavimentum, H. wallichii, Pontosphaera spp; foraminifera cukup melimpah dengan plankton Globigerinoides ruber, G. trilobus sacculiferus, G. conglobatus dalam jumlah jarang serta satu atau dua jenis bentik yang dominan (Elphidium spp, Ammonia spp., Pseudorotalia spp., Asterorotalia spp.).

Paparan luar di Selat Madura (Zona III) dicirikan oleh nannoplankton dalam jumlah yang umum, didominasi oleh Gephyrocapsa oceanica dan Emiliania huxleyi dengan beberapa Helicosphaera carteri, H. pavimentum, H. wallichii, Pontosphaera spp., Calcidiscus leptoporus, Umbellosphaera irregularis, Umbilicosphaera spp.; foraminifera bentik jumlahnya umum seperti Elphidium spp, Ammonia spp., Cibicides spp., Pseudorotalia spp., dan Asterorotalia spp. dengan foraminifera planktik seperti Globigerinoides ruber, G. trilobus sacculiferus, dan G. conglobatus dalam jumlah jarang. Di paparan luar laut terbuka (Zona IV) teridentifikasi nannoplankton yang melimpah seperti Gephyrocapsa oceanica,
Emiliania huxleyi, Helicosphaera carteri, H. pavimentum, H. wallichii, Pontoosphaera spp., Discoaster spp., Calcidiscus leptoporus, Umbellosphaera irregularis, Umbilicosphaera spp.; dan beragam jenis foraminifera plankton seperti Globigerina calida, Pulleniatina obliquiloculata, Orbulina universa dan Hastigerina aequilateralis serta foraminifera bentik seperti Bolivina spp., Bulimina spp., Cibicides spp., Pseudorotalia spp., Asterorotalia spp., Lenticulina spp., Cassidulina spp., Siphonina spp. dan Uvigerina spp. dalam jumlah yang umum.

Parameter lingkungan fisik yang paling berpengaruh dalam mengontrol kehadiran spesies penunjuk (indikator) dan kelimpahan kumpulan mikroorganisma adalah: batimetri, salinitas, temperatur, pH dan sedimen.

Katakunci: nanoplankton, foraminifera, lingkungan, spesies penunjuk, Perairan Madura

INTRODUCTION

Since the late 1960s, nanoplankton has been used in the geological study particularly to determine the age of sediment. In the last few years, the study of nanoplankton has been developed especially among others in geographical determination. McIntyre, et al., 1970; Winter, et al., 1979; Wang and Samtleben, 1983; Okada, 1984; Okada, 1992; Baumann, et al., 2001; and Gibbs, 2001 recognized lateral oceanographic condition changes based on the qualitative and quantitative analyses (appearance of marker species, amount- and number- of spesies) of nanoplankton assemblages.

In Indonesia, the use of nanoplankton to determine the age of sediment has successful results. However, studies of marine geography and environment in using nanoplankton has never been done.

Madura Waters has been selected as the study area as a lot of secondary data and surface and core- samples can be used; this area is marked by the abundance of both nanoplankton and foraminifera as well.

This research is herein intended to determine the environmental control of nanoplankton and foraminifera assemblages in waters near Madura.

MATERIAL AND METHOD

Nanoplankton and foraminifera assemblages were studied in twenty six shallow marine surface sediment samples from Madura Strait and twenty four samples from open marine water north of Madura. The fifty samples collected by Marine Geological Institute (MGI) were obtained from the area between coordinates 5°48’00” S to 8°00’00” S and 112°24’00” E – 114°30’00” E.

The actual research was done in several stages, namely:
1. collection of secondary data and shallow samples (seabed surface sediment from grab sampler and sediment from the uppermost part of core samples from one metre of gravity corer
2. collecting field data record (physical oceanography factors measurement)
3. laboratory analyses upon sediment samples to determine the content of nanoplankton and foraminifera (micropaleontology analyses), the texture and composition of minerals (by means of grain size, petrology megascopic and microscopic analyses).
The samples were prepared using nannoplankton smear slide and foraminifera residue preparation methods. The nannoplankton slides were examined using a light microscope of 1000 magnification in both cross-polarized and phased light for contrast. Foraminifera examined using a slab microscope of 40 magnification.

4. Integrating all of analyses result

The taxonomy of nannoplankton is referred to Perch-Nielsen (1985), planktic foraminifera is referred to Bolli and Saunders (1985), and benthic foraminifera is referred to van Marle (1991).

RESULT

Twenty-three nannoplankton taxa, sixteen planktic- and thirty-four benthic-foraminifera were identified in the sediment samples. Few reworked occur in each samples. Nannoplankton taxa in the surface sediment samples of Madura Waters are among all: Family Braarudosphaeraceae Deflandre (1947): *Braarudosphaera bigelowii* (Grand and Braarud, 1935) Deflandre (1947); Family Calciosoleniaceae Kamptner (1950); Family Cocolithaceae Poche (1913): *Coccolithus pelagicus* (Wallich, 1877) Schiller (1930), *Calcidiscus leptoporus* (Murray and Blackman, 1989) Loblich and Tappan (1978) and *Umbilicosphaera* spp; Family Discoasteraceae Tan (1927): *Discoaster* spp.; Family Helicosphaeraceae Black (1971): *Helicosphaera carteri* (Wallich, 1877) Kampertn (1950), *Helicosphaera hyalina* Gaarder (1970), *Helicosphaera pavimentum* Okada and Mc Intyre (1977), *Helicosphaera wallichii* (Lohmann, 1902) Boudreaux and Hay (1969), *Helicosphaera* spp.; Family Pontosphaeraceae Lemmermann (1908): *Pontosphaera discopora* Schiller (1925) and *Pontosphaera japonica* (Takayama, 1967) Nishida (1971), Family Princiaceae Hay and Mohler (1967): *Emiliania huxleyi* (Lohmann, 1902) Hay and Mohler in Hay et al. (1967), *Gephyrocapsa oceanica* Kampertn (1943), *Gephyrocapsa* spp., *Pseudoemiliania lacunosa* (Kamptner, 1963) Gartner (1963), and *Reticulofenestra* spp; Family Rabdosphaeraceae Lemmermann (1908): *Rabdosphaera* spp., Family Sphenolithaceae Deflandre in Grasse (1952) *Sphenolithus* spp.; Family Syracosphaeraceae Lemmermann (1908): *Syracosphaera* spp.; Family Thoracosphaeraceae Schiller (1930): *Thoracosphaera* spp; and Insertae sedis: *Umbellosphaera irregularis* Paasche in Markali and Paasche (1955). Planktic foraminifera assemblages in the sediment consist of: *Globigerina bermudezi* Seiglie, *Globigerina calida* Parker, *Globigerina* spp., *Globigerinoides ruber* (d'Orbigny), *Globigerinoides trilobus trilobus* (Reuss), *Globigerinoides trilobus immaturus* LeRoy, *Globigerinoides trilobus sacculifer* Brady, *Globigerinoides* spp., *Globorotalia humerosa* Takayanagi dan Saito, *Globorotalia menardii cultrata* (d'Orbigny), *Globorotalia tumida tumida* (Brady), *Globorotalia ungulata* Bermudez, *Globorotalia* spp., *Hastigerina aequilateralis* (Brady), *Hastigerina siphonifera* (d'Orbigny), *Orbulina* spp. D'Orbigny (1839) and *Pulleniatiina* spp. Cushman (1927). Hyaline benthic foraminifera taxa were identified among all: Family Almaenidae Myatlyuk, 1959: *Ammomalinaella* spp.; Family Amphistiginidae Cushman, 1927: *Amphistegina* spp.; Family Baggnidae Cushman (1927): *Cancri* spp.; Family Bolivinidae Glaessner, 1937: *Bolivina*
spp.; Family Cassidulinidae d’Orbigny, 1839: \textit{Cassidulina} spp.; Family Cibicididae Cushman, 1927: \textit{Cibicides} spp.; Family Elphidinidae Galloway, 1933: \textit{Elphidium crispum} (Linnaeus) and \textit{Elphidium} spp.; Family Eponinidae Hofker, 1951: \textit{Eponides} spp.; Family Lagenidae Reuss, 1862: \textit{Fissurina} spp. and \textit{Lagena} spp.; Family Nodosariidae Ehrenberg, 1838: \textit{Dentalina} spp. and \textit{Nodosaria} spp.; Family Reussella Cushman, 1933: \textit{Reusella} spp.; Family Rotaliidae Ehrenberg, 1839: \textit{Ammonia beccarii} (Linnaeus) s.l., \textit{Asterorotalia} spp. and \textit{Pseudorotalia} spp.; Family Sphaeroidinidae Cushman, 1927: \textit{Sphaeroidina bulloides} d’Orbigny and \textit{Sphaeroidina} spp.; Family Uvigerinidae Haeckel, 1894: \textit{Uvigerina} spp.; Family Vaginulidae Reuss, 1860: \textit{Lenticulina costata} (Fichtel and Moll) and \textit{Lenticulina} spp.

Arenaceous test benthic foraminifera can be identified among all: Family Textulariidae Ehrenberg, 1839: \textit{Textularia} spp.; Family Haplophragmoididae Maync, 1952: \textit{Haplophragmoides} spp.; and Family Lituolidae De Blainville, 1827: \textit{Ammobaculites} spp. Porcelaneous test benthic or Family Miliolidae Ehrenberg, 1839 in the samples are: \textit{Flintina} spp., \textit{Pyrgo} spp., \textit{Quinqueloculina seminulum} (Linnaeus), \textit{Quinqueloculina communis} Cushman and Todd, \textit{Spiroloculina depresa} d’Orbigny, \textit{Spiroloculina} spp., \textit{Triloculina tricarinata} d’Orbigny and \textit{Triloculina} spp.

The distribution and the abundance pattern of nannoplankton & foraminifera assemblages are shown in Table 1.

Megascopically and microscopically, sediment can be classified into: clay, silty clay, sandy clay, clayey silt, silt, sandy silt, clayey sand, silty sand, and fine-, medium-, coarse-grained sand. The shape of material sediment can be differentiated into rounded to well rounded (0.7-0.9), subrounded to rounded (0.5-0.7), subangular to subrounded (0.3-0.5); the sphericity of sediment can be differentiated into high to very high (0.7-0.9), average to high (0.5-0.7) and low to average (0.3-0.5) (shown in Table 2). The sediment textural analyses result is compiled by Masria (1991), Astjario, et al. (1991), Arifin, et al. (1992) and Astjario, et al. (1998), as shown in Figure 1.

According to Ingle (1980), marine biofazies is divided into: inner shelf (0 - 50 m; 0 – 150 ft), outer shelf (50 – 150 m; 150 – 470 ft), upper bathyal (150 – 500 m; 460 – 1560 ft), upper middle bathyal (500 – 1500 m; 1560 – 4700 ft), lower middle bathyal (1500 – 2000 m; 4700 – 6250 ft), and lower bathyal (2000 m + ; 6250 ft+).

Based on bathymetry and physical oceanographic parameters including sediment (type, texture and mineral composition) Madura waters can be divided into four zones, among all: (I) inner shelf (water depth less than 30 m) in strait, (II) inner shelf in open marine, (III) outer shelf in strait, and (IV) outer shelf (water depth 30 - 80 m) in open marine. The difference of condition were signed by the characteristic distribution and the abundance pattern of nannoplankton & foraminifera assemblages in restricted and open marine in Madura Waters. (Table 3 and Figure 2).

In water depth less than 30 meters (inner shelf) in the Madura Strait (Zone I), the zone is being indicated by various grain-size sediment (clay to sand), low salinity, low sea surface temperature (29,3° C) and pH = 6,0-7,3; the assemblages of nannoplankton is less than 1% of sediment, and are made up of the only species, \textit{Gephyrocapsa oceanica}; the benthic foraminifera noted included...
| Outer shelf in open marine north of Mauritius (Zone I) | Outer shelf in Mauritius (Zone II) | Inner shelf in open marine north of Mauritius (Zone III) | Inner shelf in Mauritius (Zone IV) |
|-----------------------------------------------------|----------------------------------|--------------------------------------------------------|-----------------------------------|
| Brachiopods                                          |                                  |                                                        |                                   |
| Bivalves                                            |                                  |                                                        |                                   |
| Worms                                              |                                  |                                                        |                                   |
| Tentaculata                                         |                                  |                                                        |                                   |
| Discorhabditida                                    |                                  |                                                        |                                   |
| Polychaeta                                          |                                  |                                                        |                                   |
| Ostracoda                                          |                                  |                                                        |                                   |
| Foraminifera                                       |                                  |                                                        |                                   |
| Radiolaria                                         |                                  |                                                        |                                   |
| Dinoflagellata                                     |                                  |                                                        |                                   |

Table 1. Distribution of Nannoplankton And Foraminifera Assemblages in The Surface Sediment of Mauritius Waters

| Nannoplankton Assemblages | Outer shelf in open marine north of Mauritius (Zone I) | Outer shelf in Mauritius (Zone II) | Inner shelf in open marine north of Mauritius (Zone III) | Inner shelf in Mauritius (Zone IV) |
|---------------------------|--------------------------------------------------------|----------------------------------|--------------------------------------------------------|-----------------------------------|
| Emiliania huxleyi         |                                                        |                                  |                                                        |                                   |
| Gephyrocapsa oceanica     |                                                        |                                  |                                                        |                                   |
| Umbilicosphaera           |                                                        |                                  |                                                        |                                   |
| Calcidiscus leptoporus    |                                                        |                                  |                                                        |                                   |
| Braarudosphaera bigelowii |                                                        |                                  |                                                        |                                   |
| Thoracosphaera            |                                                        |                                  |                                                        |                                   |
| Spiroloculina             |                                                        |                                  |                                                        |                                   |
| Uvigerina                 |                                                        |                                  |                                                        |                                   |
| Lagena                    |                                                        |                                  |                                                        |                                   |
| Bolivina                  |                                                        |                                  |                                                        |                                   |
| Globorotalia menardii     |                                                        |                                  |                                                        |                                   |

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### Table 2. Megascopic, Microscopic and Grain size Analyses of Sediment in Madura Waters

| Sample Code | Coordinate | Depth (m) | Megascopic | Microscopic | Minerals | Fine grain |
|-------------|------------|-----------|------------|-------------|----------|-----------|
| OM-18       | -5.996     | 115.905   | 69.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-11       | -6.000     | 112.912   | 69.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-21       | -6.000     | 111.016   | 65.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-7        | -6.208     | 112.476   | 63.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-13       | -6.090     | 115.04 25  | 57.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-15       | -6.418     | 115.99 4  | 75.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-10       | -6.552     | 114.00 7  | 77.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-16       | -6.709     | 112.47 6  | 42.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-23       | -6.017     | 112.54 7  | 50.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| OM-14       | -6.096     | 115.92 1  | 27.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 31     | -6.248     | 112.47 6  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 32     | -6.405     | 112.47 6  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 15     | -6.418     | 115.99 4  | 75.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 13     | -6.552     | 114.00 7  | 77.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 16     | -6.017     | 112.54 7  | 50.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 24     | -6.045     | 112.76 4  | 29.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 17     | -6.096     | 112.72 9  | 7.50       | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 18     | -6.000     | 112.76 5  | 60.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 29     | -6.050     | 112.62 4  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 45     | -6.834     | 115.91 1  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 24     | -6.045     | 112.76 4  | 29.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 17     | -6.096     | 112.72 9  | 7.50       | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 18     | -6.000     | 112.76 5  | 60.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 29     | -6.050     | 112.62 4  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |
| GM - 45     | -6.834     | 115.91 1  | 23.00      | Clay, granulogy, feldspar | Clay     | 0.005-0.04 |

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Figure 1. Sea Surface Sediment Map of Madura Waters (modified from Masria, 1991; Arifin et al., 1992 and Astjario et al., 1998)
Table 3. Physical Oceanographic Parameter, Sediment Characteristic and Microorganism Assemblages of Madura Waters

| ZONE                      | SEDIMENT                  | MICROORGANISM ASSEMBLAGES | NANNOPLANKTON FORMATION | FORAMINIFERA |
|---------------------------|---------------------------|---------------------------|-------------------------|--------------|
|                           | TYPE                      | TEXTURE                   | COMPOSITION             | MARKER SPECIES | ABUNDANCE    |
|                           |                           | Sphericity and roundness | Dominated by lithic     | No to very rare | Ammonia spp., |
| Inner shelf               | Clay, silt, sandy silt,   | sand, silt, silt sand,    | Volcanic material >     | Ammonia spp.,  | Astomoceras spp., |
| in Madura Strait          |                           |                           | carbonate               | Asteomoceras spp., | (10 species)  |
| (Zone I)                  |                           |                           |                         | Testitina spp., | & Haplophragmoides spp. |
| Bathymetry = 0 - 3 m      |                           |                           |                         | & Milideridae & Quinqueloculina spp. |               |
| Sea surface temperature = |                           |                           |                         |               |               |
| 29.3 °C                   |                           |                           |                         |               |               |
| Salinity < 30 ‰           |                           |                           |                         |               |               |
| pH = 6.0 - 7.3            |                           |                           |                         |               |               |
|                           | Silty clay                | fine material < 55%       | Gephyrocapsa oceanica  | ≥ 45 individu,  | Elphidium spp., |
| in open marine north of   |                           | percentage of fine grain  | dominant.               | ≥ 8 species,   | Ammonia spp.,  |
| Madura (Zone II)          |                           | proportional with distance | Emiliania huxleyi       | 14 individu,   | Pseudovaccellam spp. |
| Bathymetry = 0 - 3 m      |                           | 76 to 87%                 | Helicosphaera carteri,  | 2 individu,    | and Asterorotalia spp. |
| Sea surface temperature = |                           |                           | H. pavimentum,         | 4 individu,    |               |
| 29.4 °C                   |                           |                           | H. wallichii,           | 9 individu,    |               |
| Salinity = 31 - 34 ‰      |                           |                           | Pontosphaera discopora,| 34 individu,   |               |
| pH = 6.0 - 7.6            |                           |                           | P. multipora,           | 17 species,    |               |
|                           |                           |                           | Cibicides spp.,        | ≥ 10 individu, |               |
| Outer shelf               | Clay, silt, clay, silt,   | fine material < 55%       | Gephyrocapsa oceanica  | ≥ 200 individu,| Elphidium spp., |
| in Madura Strait          |                           | sand, silt, sand sand,    | dominant.               | 25 individu,   | Ammonia spp.,  |
| (Zone III)                |                           |                           | Emiliania huxleyi       | 34 individu,   | Pseudovaccellam spp. |
| Bathymetry = 30 - 200 m   |                           |                           | Helicosphaera carteri,  | 4 individu,    | and Asterorotalia spp. |
| Sea surface temperature = |                           |                           | H. pavimentum,         | 16 individu,   |               |
| 29.6 °C                   |                           |                           | H. wallichii,           | 2 individu,    |               |
| Salinity = 31 - 34 ‰      |                           |                           | Pontosphaera discopora,| 18 individu,   |               |
| pH = 6.0 - 7.8            |                           |                           | P. multipora,           | 2 species,     |               |
|                           |                           |                           | Cibicides spp,          | 3 species,     |               |
| Outer shelf               | Clay, silt, clay, silt,   | fine material < 76%       | Gephyrocapsa oceanica  | ≥ 100 individu,| Elphidium spp., |
| in open marine north of   |                           | sand, silt, sand sand,    | dominant.               | 25 individu,   | Ammonia spp.,  |
| Madura (Zone IV)          |                           |                           | Emiliania huxleyi       | 34 individu,   | Pseudovaccellam spp. |
| Bathymetry = 30 - 200 m   |                           |                           | Helicosphaera carteri,  | 4 individu,    | and Asterorotalia spp. |
| Sea surface temperature = |                           |                           | H. pavimentum,         | 16 individu,   |               |
| 30.3 °C                   |                           |                           | H. wallichii,           | 2 individu,    |               |
| Salinity = 31 - 34 ‰      |                           |                           | Pontosphaera discopora,| 18 individu,   |               |
| pH = 7.4 - 8.2            |                           |                           | P. multipora,           | 2 species,     |               |
|                           |                           |                           | Cibicides spp.,        | 3 species,     |               |

Note: Values and data points are illustrative and may not reflect actual findings or analyses from the study.
Ammonia spp., arenaceous carbonate test taxa (Ammobaculites spp., Textularia agglutinans, Haplophragmoides spp.), milliolidae (Quinqueloculina spp.); none of the planktic foraminifera observed.

In inner shelf open marine north of Madura (Zone II), very fine-grained sediments, low temperature (29.4°C), normal salinity and pH 6.2 to 7.6 yielded the zone; the nannoplankton assemblages are dominated by Gephyrocapsa oceanica together with a few Emiliania huxleyi, Helicosphaera carteri, H. pavimentum, H. wallichii, Pontosphaera spp; the foraminifera assemblages includes Globigerinoides ruber, G. trilobus sacculiferus, G. conglobatus, Elphidium spp, Ammonia spp., Pseudorotalia spp. and Asterorotalia spp.
In Madura Strait, the outer shelf zone (Zone III) is indicated by the accumulation of the relative fine-grained sediment, sea surface temperature = 29.6°C, normal salinity, and pH 6.2 to 7.8; the nannoplankton assemblages are dominated by *Gephyrocapsa oceanica* and *Emiliania huxleyi* which are closely associated with *Helicosphaera carteri*, *H. pavimentum*, *H. wallichii*, *Pontosphaera spp.*, and a few *Calcidiscus leptoporus*, *Umbilicosphaera spp.*; the foraminifera assemblages includes *Globigerinoides ruber*, *G. triobus sacculiferus*, *G. conglobatus*, *Elphidium spp.*, *Ammonia spp.*, *Cibicides spp.*, *Pseudorotalia spp.*, and *Asterorotalia spp.* are common.

In the outer shelf open marine north of Madura (Zone IV), which is indicated by clay, high temperature (30.3°C), normal salinity, normal pH (7.4 to 8.2); the nannoplankton species such as *Gephyrocapsa oceanica*, *Emiliania huxleyi*, *Helicosphaera carteri*, *H. pavimentum*, *H. wallichii*, *Pontosphaera spp.*, *Discoaster spp.*, *Calcidiscus leptoporus*, *Umbellosphaera irregularis*, *Umbilicosphaera spp.* are abundant; the foraminifera assemblages of *Globigerina calida*, *Pulleniatina obliquiloculata*, *Orbulina universa*, *Hastigerina aequilateralis*, *Bolivina spp.*, *Bulimina spp.*, *Cibicides spp.*, *Pseudorotalia spp.*, *Asterorotalia spp.*, *Lenticulina spp.*, *Cassidulina spp.*, *Siphonina spp.*, and *Uvigerina spp.* are common. In open marine, both amount- and number- of species of nannoplankton as well as foraminifera increases with increasing water depth.

The distribution and abundance of both nannoplankton and foraminifera assemblages in both Madura Strait and water north of Madura are closely related to environment.

The most significant physical environment parameter controlling appearance of marker species, amount- and number- of species in microorganism assemblages are bathymetry, salinity, temperature, pH and sediment due to fluvial supply.

This study displayed a good correlation between nannoplankton as well as foraminifera assemblages in the sense of environment interpretation. In open marine region, the abundance of shallow marine taxa reduces with increasing water depth, on the other hand the abundancy and diversity index (number of species) of deeper marine taxa are present in proportional with depth. In strait region, the assemblages is most controlled by the physical and chemical environment parameters.

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