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Original paper

BIODIVERSITY OF BENTHIC DIATOM AND PRIMARY PRODUCTIVITY OF BENTHIC MICRO-FLORA IN MANGROVE FORESTS ON CENTRAL JAVA

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ABSTRACT

A study to determine biodiversity related to ecological function of secondary mangrove forests at central Java had been carried out in three different locations viz. Rembang, Demak and Pemalang coasts. Location of sampling was selected systematically in three levels of inundation within both lower and higher densities of mangrove. Sediment samples were collected randomly with four replications. A lens tissue trapping method was applied to collect living benthic diatoms. Primary productivity was measured in-situ in the locations as production of carbon per unit area per unit time. It was determined by dissolved oxygen content measured by the bell jar method. Data were then analyzed using α biodiversity index (Shannon-Wiener index), ANOVA, regression and cluster multivariate analysis for β biodiversity. Totally, 86 benthic diatom species had been found and the benthic diatom community assemblage was dominated by Amphora coffeaeformis, Diploneis crabro, Diploneis smithi, Navicula elliptica, Pleurosigma sp., Stauropsis majuscula and Surirella gemma. Benthic diatom abundance was 8.6750 x 10^4 to 18.9626 x 10^4 cell/m^2, where the highest was found in Demak and the lowest was in Pemalang. Abundance of the diatom does not always have significant relation ($P > 0.05$) to both inundation levels and mangrove density; however, this was more depended on location. The assemblage of benthic diatom community was more similar in Rembang and Pemalang compared to that in Demak, however the α biodiversity index tended to be higher in the lower mangrove density. The benthic micro-flora primary productivity was 120 to 342 mg C/m^2/hour and had no significant relation ($P > 0.05$) to abundance of benthic diatom. It was revealed that the optimum density of mangrove to have the highest benthic micro-flora primary productivity was between 8000 to 10000 trees/ha.

Keyword : Benthic diatoms; primary productivity ; mangrove

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INTRODUCTION.

Benthic diatom is one of the most important micro-flora living in the sediment of tropical mangrove forest. The important of benthic diatom has been recognized as indicator of mud stability (Sylvestre, *et al.*, 2004), water pollution, effect of diesel oil and heavy metal Cu (Silva, 2006). Furthermore, the diatom can be used as a food of many organisms living in mangrove sediment, including mollusks, bivalves, polychaetes (Hendrarto, 1995; Alongi, 1998), and juvenile fishes (Underwood and Chapman, 1995). Furthermore, as a member of benthic micro-algae the diatom supports various communities of small benthic animals such as polychaetes, nematode worms, cumacean, copepods and soldier crab (Hollaway and Tibbets, 1995).

Considering Indonesia is one of the best potency of mangrove in the world, however studies of benthic micro-flora, inparticular benthic diatoms are still very limited. Some studies has been recorded including distribution and abundance of soil fungi at Demak (Hendrarto, 1984), and benthic diatom at Sulawesi (Horton, *et.al.*, 2007). Some other studies of benthic diatom in mangrove forests however, had been carried out in North Queensland, Australia (Hendrarto, 1995),

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Mexico (Beltrones and Castrejón, 2006) and French Guiana (Sylvestre, *et al.*, 2004). These authors concluded different benthic diatom community assemblages and recorded a significant number of species contributed in the ecosystems. Therefore, more studies would improved the record of benthic diatom in Indonesia.

In the last decade, there were significant efforts to rehabilitate degraded mangrove forests at central Java. Several years ago, the local communities and related government institutions have replanted some areas especially at Rembang, Demak and Pemalang coast. The mangrove has grown and green belt of secondary forest has been established. On the other hand, ecological function of the forests has not fully recognized yet. One of the methods that may be used to determine the ecological function is by measuring benthic diatom community assemblages and ability of benthic micro-flora to improve the ecosystem quality by its primary productivity. This approach has been applied in some mangrove forests in North Queensland, Australia (Hendrarto, 1995). Therefore, this recent study aimed to determine benthic diatom community assemblage and benthic micro-flora primary productivity of mangrove forests of central Java, using areas of Rembang, Demak and Pemalang as the study case.

MATERIALS AND METHODS

The study was conducted in the secondary mangrove forests at north coast of central Java, that was in the areas of Rembang (6028'45"S, 111022'36"E), Demak (6052'33"S, 110030'33"E) and Pemalang (6046'30''S, 109030'29"E). The areas are bordered by sea at the north most and brackish water ponds (**Fig. 1**). The forests of Rembang and Demak are dominated by *Rhizophora*, whereas that in Pemalang is dominated by *Rhizophora* and *Avicennia*. All areas have permanent fresh water input from small rivers. Consequently, the salinity of water is below the open sea.

Two stations were located in each area encompassed two different density of mangrove and sampling was conducted in three different levels of inundation with five randomly selected sub-areas as replications. Sampling was carried out within three months in dry season *i.e.* during July to August 2009. Blocks of sediment (4 x 4 cm; 2 cm depth) were removed into sealed polyethylene bags and transported to the laboratory. After stored in the dark for 6 to 8 hours (Eaton & Moss, 1966; Hendrarto 1995). Whole sample was poured into a container, wetted by sterile, clean seawater and shaken. It was then poured into a 90 mm diameter Petri dish. Using forceps a piece of lens tissue was layed onto the sediment surface in the petri dish. It should be large enough to cover the entire surface, and a 2 cm square piece of lens tissue was placed on top of the first piece. The samples then placed in sunlight and never exposed to artificial light, even at night and experienced the natural cycle of light and darkness for one full 24-hour cycle. Lens tissues were harvested in the next morning between 08:00 and 11:00 (Eaton and Moss, 1966; Hendrarto 1995). Each lens tissue was then placed in a vial and preserved with 3 ml of 5% formaldehyde and 1.5% sodium hypochlorite solutions (1 : 1 by volume). The diatoms were released by macerating the tissue and transferred to a counting chamber, and then identified under a phase contrast light microscope (Hendrarto, 1995).

The primary productivity of benthic algae was measured on a sediment surface basis *i.e.* on measurement of the changes in dissolved oxygen concentration over sediments per unit of time, in both light and dark conditions (Hargrave *et.al.*, 1983). The oxygen production by benthic microflora was measured *in situ* using bell-shape jars. Dark jars were made by covering with a black "scotch tape" and aluminum foil (Hendrarto, 1995). Measurements were carried out between 09.00 and 12.00 md. After period of 15 min. oxygen content was measured using an oxygen meter. Estimation of oxygen production then were converted into carbon units (Sastry, 2009). Mangrove densities were measured by applying a Point Centered Quarter Method (Dahdouh-Guebas and Koedam, 2006). Distances and Diameter at Breast Height (DBH) of trees were measured in each of 20 sample points distributed systematically along 100 m transects.

Accordingly, data were analyzed using α biodiversity index (Shannon-Wiener index), ANOVA, regression and cluster multivariate analysis for β biodiversity.

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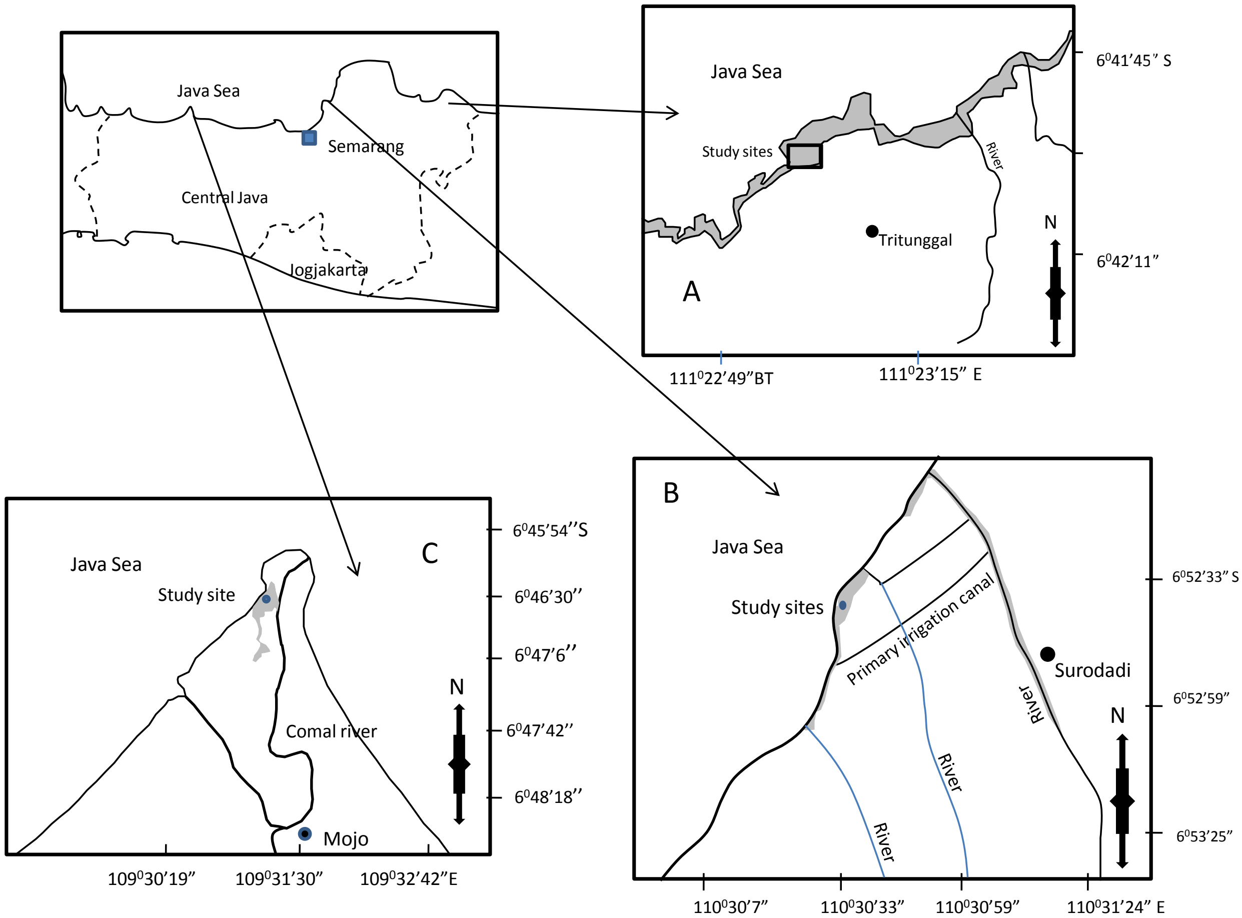

Fig. 1. Maps show the Location of study in the north coast of central Java. (A) Rembang, (B) Demak and (C) Pemalang.

RESULTHS AND DISCUSSION

Results

Mangrove Forest

Based on mangrove density, the mangrove forests showed different characteristic. *Rhizophora* dominated the secondary mangrove forest of Rembang. The lower density forest had average distance between trees 1.34 m (*viz.* 7.462 trees/ha) and circle size at breast height 21.96 cm, whereas the higher density had trees distance 0.70 m (*viz.*14.285 trees/ha) with circle size 23.2 cm. Therefore, the denser the forests the older they are. However, in Demak *Rhizophora* dominated the lower density forest, and combination of *Rhizophora* and *Avicennia* dominated the higher density forest. The average tree distance in the lower density forest is 5.18 m (or 1930 tree/ha) with circle size 17.95 cm, whereas the higher density has trees distance 2.57 (*viz.* 3891 trees/ha) with circle size 18.45 cm. The mangrove forest in Pemalang has different domination pattern, in which *Avicennia* dominated the lower density site with tree distance 3.22 m (*viz.* 3105 trees/ha) and circle size 30.65 cm. *Rhizophora* dominated the higher density with tree distance 2.05 m (*viz.* 4878 trees/ha) and circle size 18.30 cm. This suggested that the lower density forest might older than the higher density forest.

Benthic diatom

A total of 86 species of benthic diatom had been recorded from three mangrove forests of central Java. Some species has the best distribution including *Amphora coffeaeformis, Diploneis crabro, Diploneis smithi, Navicula elliptica, Pleurosigma sp., Stauropsis majuscula,* and *Surirella gemma.* These species always occur in all sampling locations. Particular species dominated Rembang forest

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i.e. Pleurosigma sp., P. elongatum, A. coffeaeformis and C. *placentula.* In Demak forest some species was dominant *i.e. A.brevipes, A. delicatum, A.oblongella, A. longipes,* and A. *coffeaeformis.* However, dominant species in Pemalang forest was *Pleurosigma* sp. *A. turgid, A. brevipes, N. eliptica, C. scutellum, D. smithi. Amphiprora* sp. The highest number of cell was found in Demak and followed by Rembang and Pemalang. The similar pattern was also found in the species richness (**Table 1**).

The benthic diatom assemblages in Rembang and Pemalang mangrove forest was likely more similar compared to that found in Demak. Multivariate cluster analysis using Bray-Curtis distance (Beals, 1984) explained this phenomenon (**Fig. 2**). Therefore, benthic diatom community structure tended to have a significant dependency with location.

Table 1. Abundance of benthic diatom species (cell/m^2) in three mangrove forests of central Java

Spesies	Rembang	Demak	Pemalang
Achnantes brevipes		1500	125
Achnantes delicatum		3625	
Achnantes oblongella		750	
Achnanthes longipes	2625	125	
Amphiprora formosa			3125
Amphiprora sp			2750
Amphora coffeaeformis	19250	9375	3250
Amphora ovalis	5125		
Amphora turgida		17500	25250
Amphora veneta		10125	
Asterionella japanica	125		
Bacillaria paradoxa	125	3875	
Caloneis platycephala	6625		
Cocconeis placentula	13250	2375	
Cocconeis scutellum		11750	4750
Cymbella affinis	125	125	
Cymbella amphicephala		875	
Denticula elegans	2125		
Diatoma messodon		125	
Diploneis bambus			625
Diploneis crabro	1875	1125	4125
Diploneis oblongela			625
Diploneis oculata		1125	
Diploneis ovalis		10500	
Diploneis smithi	1250	500	16500
Ephitemia adnata	125		
Epithemia arcus	1500		
Gomphoneis clevei		9250	
Gomphonema gracile		5125	
Grammatophora serpentina	625		
Gyrosigma acumninatum	4500	5500	
Licmophora anglica	125		

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Spesies	Rembang	Demak	Pemalang
Licmophora lyngbya	625		125
Mastogloia grevillei		1250	
Monoraphidium subclavatum		6875	
Navicula cuspidata		1875	
Navicula elliptica	2375	1000	26250
Navicula gracilis		2625	
Navicula menisculus	125	2500	
Navicula subadnata	375		
Navicula tripunctata	4625	2750	
Navicula viridula	4000		
Navicula vulpine	1625		
Nitszchia filiformis	125	1750	
Nitszchia obtusa	125	11125	
Nitzschia agustata		12375	
Nitzschia amphiboides		6625	
Nitzschia angularis		625	
Nitzschia gracilis		1625	
Nitzschia heufleriana		4375	
Nitzschia kariana		500	
Nitzschia longissima	2500	1625	
Nitzschia longissima			
Nitzschia minuscula		1125	
Nitzschia obtusa		5250	
Nitzschia palea	125		
Nitzschia sp	2250		125
Nitzschia spectabilis	250	3250	
Nitzschia terrestris		875	
Nitzschiella longissima		875	
Pinnularia gibba		1750	
Pleurosigma angulatum		16500	
Pleurosigma balticum	9250	11000	
Pleurosigma decorum	125		
Pleurosigma elogatum	56750	22000	
Pleurosigma fasciola		21125	
Pleurosigma hippocampus	3000	4750	
Pleurosigma naculaceum		750	
Pleurosigma sp	75750	27375	92125
Pleurosigma speciosum	8500	1250	
Pleurosigma vitreum	500	5875	
Raphoneis amphiceros	2250	1125	
Raphoneis belgica	625		
Raphoneis surirella	125		

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Spesies	Rembang	Demak	Pemalang
Schizonema mucosa		9750	
Scolippleura latestriala		1000	
Stauroneis anceps		1125	
Stauropsis majuscula	125	7875	1625
Stauropsis membranacea	2875		
Stauropsis membranacea		5750	
Striatella unpuncata		3125	
Surirella gemma	9000	3625	250
Synedra afinis		1625	
Synedra nitszchioides	375		
Tabullaria fasciculata		2625	
Thalassiothrix longissima		1750	
Taxa_S	43	62	16
Individuals	247750	317875	181625
Dominance_D	0.1618	0.03717	0.3079
Shannon_H	2.433	3.6	1.608
Simpson_1-D	0.8382	0.9628	0.6921
Evenness_e^H/S	0.265	0.59	0.3121
Equitability_J	0.6469	0.8722	0.58

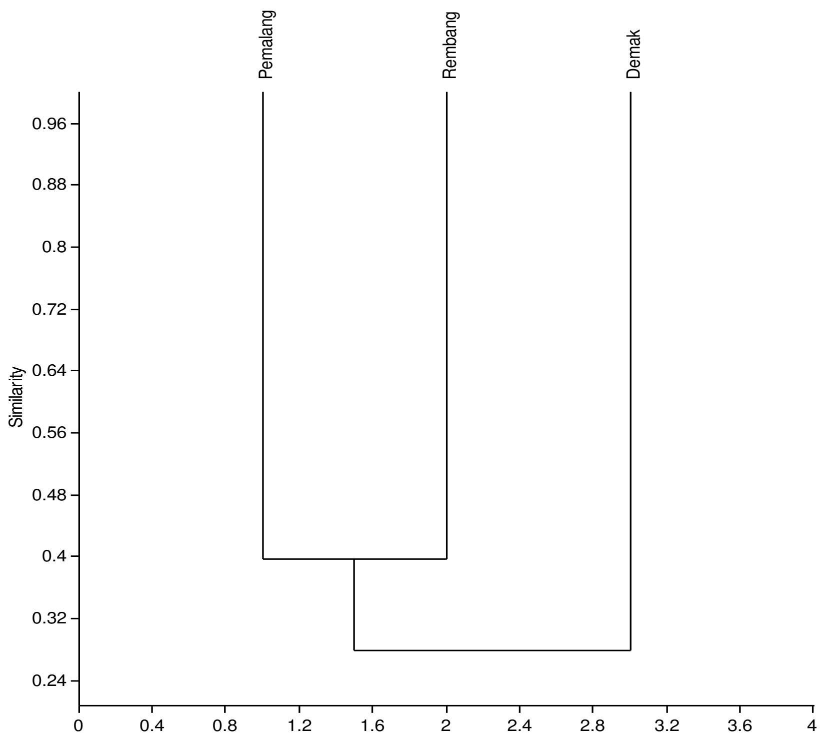

Fig. 2. Dendrogram of cluster analysis of benthic community assemblages living in mangrove forests of north coast of central Java.

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Primary productivity

Benthic micro-flora primary productivity in the three locations was in the range of 70.90 – 342 mg/C/m^2. Primary productivity of benthic micro-flora in general was apparently following the pattern of mangrove density. However, the pattern sometimes may obscure where the denser mangrove forest would decrease benthic micro-flora productivity. This has been proven by regression and correlation tests between the primary productivity versus mangrove density. It was found that the most significant model was a cubic regression line (ANOVA P = 0.010), and around 54 % of the model could be explained by these two factors, whereas correlation coefficient appeared to be high *i.e.* 74 % (**Table 2**). The pattern of the best fit regression line is shown in **Fig. 3.** This figure explains that primary productivity may optimum when mangrove density was around 8000 to 10000 trees/ha and decreased afterward.

Table 2. Model summary and parameter estimates of cubic equation in regression test between benthic micro-flora primary productivity vs. mangrove density.

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Cubic	.542	5.526	3	14	.010	331.567	-.120	2.418E-5	-1.164E-9

Dependent Variable: primary productivity, and the independent variable is mangrove density.

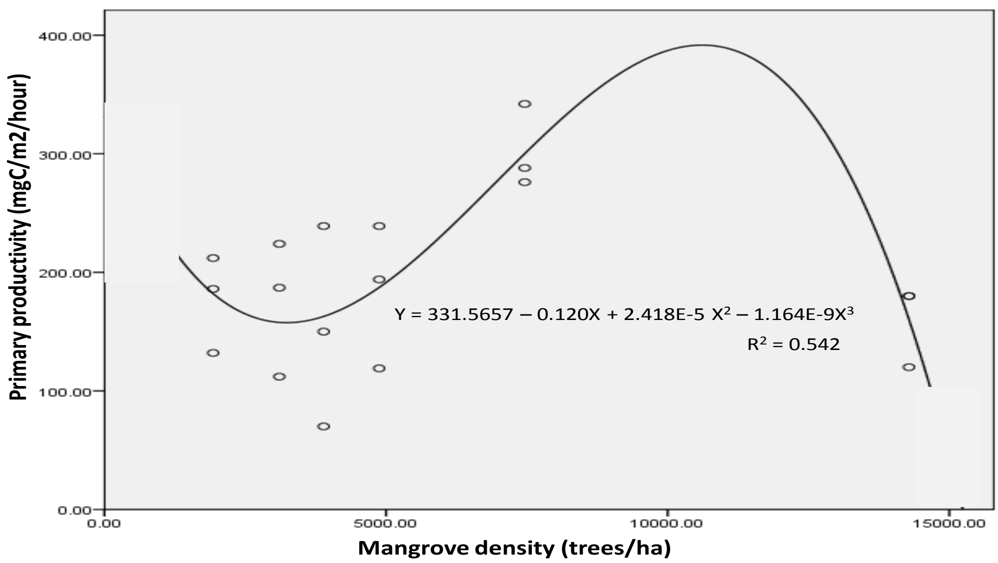

Fig. 3. The pattern of regression line between benthic micro-flora primary productivity and mangrove density.

Discussion

Several dominant species found in this study were general species living in estuarine. *A. coffeaeformis* (Agh) Kütz was found in tropical mangrove forests of north Queensland, Australia (Crosby and Wood, 1959 and Hendrarto, 1995), also in Florida (Navarro, 1989), Papua New Guinea (Vyverman, 1991, and Malaysia (Zong and Kamaludin, 2004). It was classified as marine species living in coastal environment (Hustedt and Jensen, 1985). Hustedt (1938) also recognized it in rivers of Java and Sumatra. It was also recognized as a dominant species in Sulawesi mangrove forest. Therefore, this species is a common mesohalobous diatom living in mangrove forests of Indonesia. *Diploneis crabro* (Ehrenberg) Ehrenberg ex

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Cleve (syn. *Navicula crabro* Grunow) and *Diploneis smithii* (Breb.) Cleve were discovered in Australian mangrove forests (Crosby and Wood, 1959 and Hendrarto, 1995), categorized as polyhalobous diatoms and living in estuarine environment. *D. smithii* has also found in mangrove forests in Cuba, Malaysia and Sulawesi (Foged, 1984; Zong and Kamaludin, 2004; Horton, *et.al.,* 2007, respectively).

Navicula elliptica may a synonym of *Diploneis elliptica* (Kutz.) Cleve that commonly occurs as marine phytoplankton (Hällfors, 2004). This diatom maybe was collected from waters inside the samples. However, *Pleurosigma sp.* was the most dominant diatom in Paripe river, Brazil ((Moura, *et.al*., 2007). Genus *Pleurosigma* is one of the most dominant diatoms in mangrove forest sediments (Hendrarto, 1995). *Surirella gemma* (Ehrenberg) Kützing is common diatom living in estuarine as mesohaline benthic and epiphytic, often also living in fresh water environments (Crosby and Wood, 1959). Hendrarto (1995) recognized this species would dominant in wet summer season, and it was correlated with the availability of fresh water. This may suggested that north Java mangrove forests were influenced by fresh water inflow from rivers even in dry season.

The species richness in this study was 86 species consisted of mesohalobous, oligohalobous and halophilous types, which was lower than that found by (Horton, *et.al.,* 2007) in other mangrove forests in Sulawesi, Indonesia. This might be because only living benthic diatoms were collected, whereas the previous study used all diatom cells collected from the sediments. Wilson and Holmes (1981) revealed that the dead diatom cells could significantly higher than the living one in collection of total cell diatom in sediments. However, Hendrarto (1995) recorded even higher species richness *i.e.* 223 species of benthic diatom in an primary Australian mangrove forest. This difference is likely because the previous study was more intensive as the author carried out his study in the whole year with more sampling replications. Season would affect benthic diatom community assemblages (Hendrarto, 1995; Oppenheim, 1991; Admiral *et al.*, 1984 and Colijn and Dijkema, 1981).

Value of α biodiversity index of benthic diatom in the secondary forest in this study was 0.75 – 2.65. This was almost similar to that found by Wilson & Holmes (1981) in Ventura County, California, that was 0.97 – 2.60. However, Hendrarto (1995) found higher value in Australian mangrove forest *i.e.* 2.55 – 2.85. The higher value of α biodiversity index of benthic diatom might indicated the less level of forest disturbance (Beltrones and Castrejón, 2006). Therefore, mangrove forest in Demak possibly has more natural environment than that in Rembang and Pemalang. Another factor, that likely affected the index was mangrove density that closely related to quality and intensity of light received by benthic micro-flora. Some authors (Wilson and Holmes, 1981; Admiral *at.al.,* and Round, 1987) explained the correlation between benthic diatom communities with light. In this recent study, the primary productivity has not significant correlation to abundance of benthic diatom; however, it was more related to mangrove density. The primary production was 70.90 – 342 mg C/m^2/hour, appeared to be lower than that found by Hendrarto (1995) in mangrove forest at north Queensland viz. 58.29 – 322.1 mg C/m^2/hour. However, using chlorophyll method in Ao Nam Bor, Vietnam, Hargrave *et.al.,* (1983) had found the production was 0.75 – 1.28 mg C/mg chl-a/hour.

CONCLUSION

Benthic diatom in studied areas was low in species richness; however abundance of diatom did not highly correlate to both inundation levels and mangrove density. Biological diversity of benthic diatom was higher in the lower mangrove density forests. Primary productivity of benthic flora in mangrove sediment did not significantly correlate to the abundance of benthic diatom.

REFERENCES

Admiral, W., H. Peletier and T. Brouwer. 1984. The seasonal succession paterns of diatom species on an intertidal mudflat: an experimental analysis. *Oikos*, 42: 30 – 40.

Alongi, D.M. 1998. *Coastal Ecosystem Processes*. Australia Institute of Marine Science, Townsville, Queensland, Australia

ISSN : 1410-5217
Acrredited : 83/Dikti/Kep/2009

Beals, E.W. 1984. Bray-Curtis ordination: an effective strategy for analusis of multivariate ecological data. *Adv. Ecol. Res*. 14: 1-55

Beltrones D. A. S. and E.S. Castrejón. 2006. Structure of Benthic Diatom Assemblages from a Mangrove Environment in a Mexican Subtropical Lagoon. *Biotropica* 31: 148 – 170

Colijn, F. and S. Dijkema, 1981. Species composition of benthic diatoms and distribution of chlorophyll a on an intertidal flat in the Dutch Wadden sea. *Mar. Ecol. Prog. Serr*, 14: 185 – 196.

Crosby, L.H. and E.J. F. Wood. 1959. Studies on Australian and New Zealand diatoms. II-Normaly epontik and benthic genera. *Trans. Royal. Soc. of New Zealand*, 86: 1 – 58.

Eaton, J.W. and B. Moss. 1966. The estimation of numbers and pigment content in epipelic algal populations. *Limn. and Ocean*., 11: 585 – 595.

Dahdouh-Guebas, F. and N. Koedam. 2006. Empirical estimate of the reliability of the use of the pointcentred quarter method (PCQM): Solutions to ambiguous field situations and description of the PCQM+ protocol. *For. Ecol. Manag.*, 228:1-18

Foged, N. 1984. Freshwater and littoral diatoms from Cuba. *Bibl. Diat.* 5, 1–243

Hällfors, G. 2004. Checklist of Baltic Sea Phytoplankton Species (including some heterotrophic protistan groups). *Baltic Sea Environment Proceedings* No. 95: 210 pp.

Hargrave, B.T., N.J. Prouse, G.A. Phillips and P.A. Neame. 1983. Primary production and respiration in pelagic and benthic communities at two intertidal sites in the upper bay of Fundy. *Can. J. Fis. Aq. Sci*, 40: 229 – 243

Hendrarto, I.B. 1984. Aspects of ecology of soli mycoflora in mangrove and salt marsh ecosystems. M.Sc. thesis. Newcastle Upon-Tyne University, Newcastle Upon-Tyne, England.

Hendrarto, I.B. 1995. *Distribution and abundance of benthic diatoms in a tropical mangrove forest and effect of grazing on them by* ***Telescopium telescopium*** *(Linnaeus, 1758).* Thesis for the degree of Doctor Philosophy, Dept.of Marine Biology, James Cook University of North Queensland, Townsville, Australia.

Hollaway, M and I.Tibbetts. 1995. *Meiobenthos of the Brisbane River and Moreton Bay: evidence of mullet as potential consumers*. International Larval Fish Conference and Australian Society for Fish Biology Abstracts. University of Sydney.

Horton, B.P., Y. Zong, and S. Engelhart. 2007. Diatoms from Indonesian mangroves and their suitability as sea-level indicators for tropical environments. *Marine Micropaleontology* 63 : 155–168

Hustedt, F. 1938. *Systematische und ökologische untersuchungen über die diatomen-flora von Java, Bali und Sumatra*. Stutgart: E. Schweizerbart'sche Verlagsbuchhandlung.

Hustedt, F. and N.G. Jensen. 1985. *The pennate diatoms. A Translation of Hustedt's "Die kielselalgen, 2 Teil"*. Koenigstein: Koeltz Scientific Books, 918 pp.

Navarro, J.N. 1982. Benthic marine diatoms of Caja de Muertos Island, Puerto Rico. *Nova Hedwigia* 49, 333–367.

Oppenheim, D.R. 1991. Seasonal changes in epipelic diatoms along an intertidal shore, Berrow Flats, Sommerset. *J. Mar. Biol Ass. U.K*., 71: 579 – 596.

Round, F.E. 1987. *The Biology of Algae*. Edward Arnold. New York.

Sastry, M. 2009. Dissolved oxygen. http://www.phschool.com/science/biology_place/labbench/

Silva, S. 2006. Effects of diesel-fuel and copper contaminants on benthic microalgae. A

ISSN : 1410-5217
Acrredited : 83/Dikti/Kep/2009

Disertation of Doctor of Philosophy. The Graduate Faculty of the Louisiana State University and Agricultural and Mechanical College.

Sylvestre, F., D. Guiral and J. P. Debenay. 2004. Modern diatom distribution in mangrove swamps from the Kaw Estuary (French Guiana). *Mar. Geol.,* 208 (2-4): 281-293.

Underwood, A.J. and M.G. Chapman. 1995. *Coast. Mar. Ecol. of Temperate. Australia. Institute of Marine Ecology*, University of Sydney. UNSW Press.

Vyverman, W. 1991. *Diatoms from Papua New Guinea. Bibliotheca Diatomologica, vol. 22*. J. Cramer, Berlin. 223 pp.

Wilson C.J. and R.W. Holmes. 1981. The ecological importance of Distinguishing between living and dead diatoms in estuarine sediments. *Br. Phycol. Jour.* 16:345-349.

Zong, Y. and B.H. Kamaludin. 2004. Diatom assemblages from two mangrove tidal flats in Peninsular Malaysia. *Diat. Res.,* 19, 329–344.