

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 8.6750×10^4 to 18.9626×10^4 cell/m², 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/m²/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, in particular 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),

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.

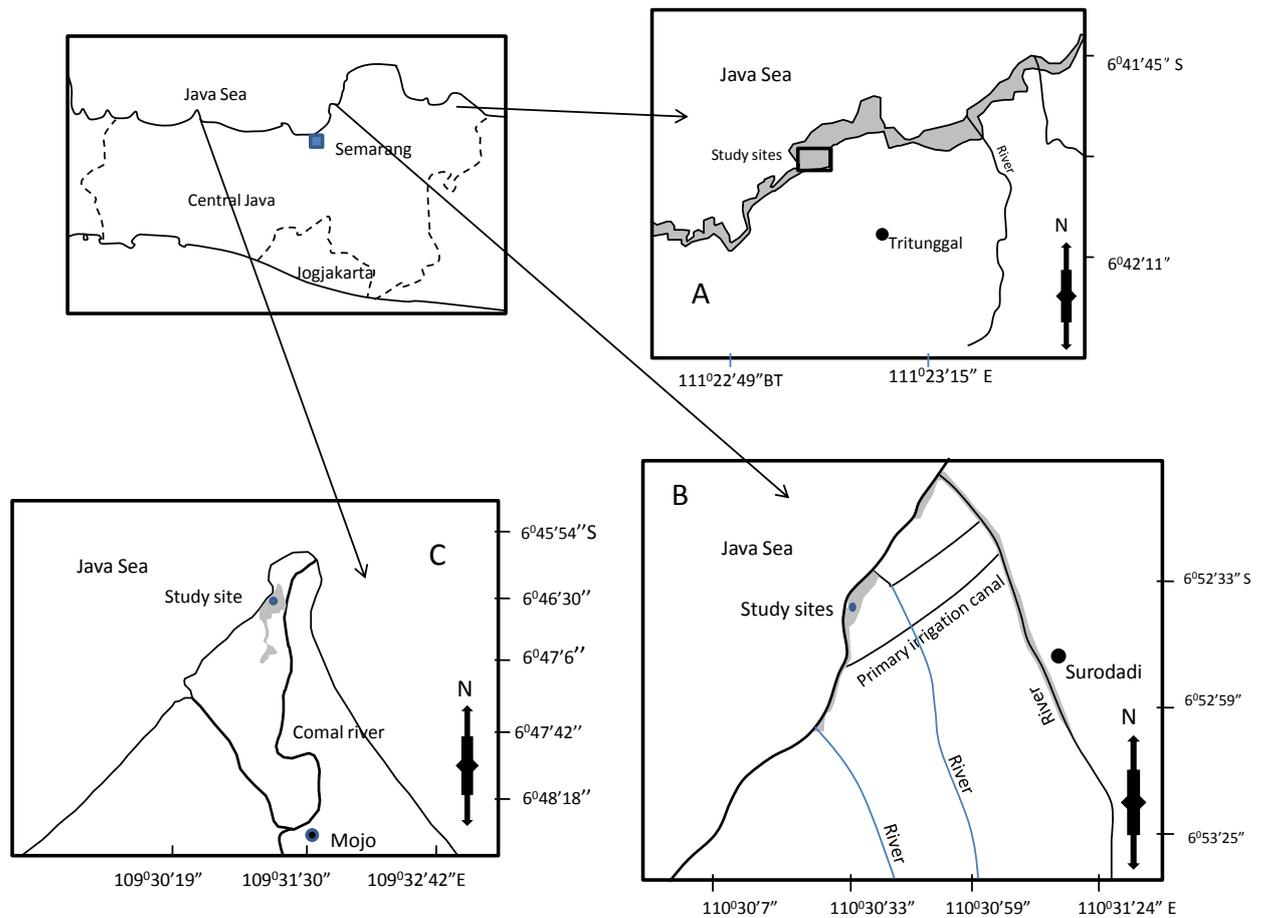


Fig. 1. Maps show the Location of study in the north coast of central Java. (A) Rembang, (B) Demak and (C) Pemalang.

RESULTS 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

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/m²) in three mangrove forests of central Java

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

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

Spesies	Rembang	Demak	Pemalang
<i>Schizonema mucosa</i>		9750	
<i>Scolippleura latestriala</i>		1000	
<i>Stauroneis anceps</i>		1125	
<i>Stauropsis majuscula</i>	125	7875	1625
<i>Stauropsis membranacea</i>	2875		
<i>Stauropsis membranacea</i>		5750	
<i>Striatella unpuncata</i>		3125	
<i>Surirella gemma</i>	9000	3625	250
<i>Synedra afinis</i>		1625	
<i>Synedra nitzschoides</i>	375		
<i>Tabullaria fasciculata</i>		2625	
<i>Thalassiothrix longissima</i>		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

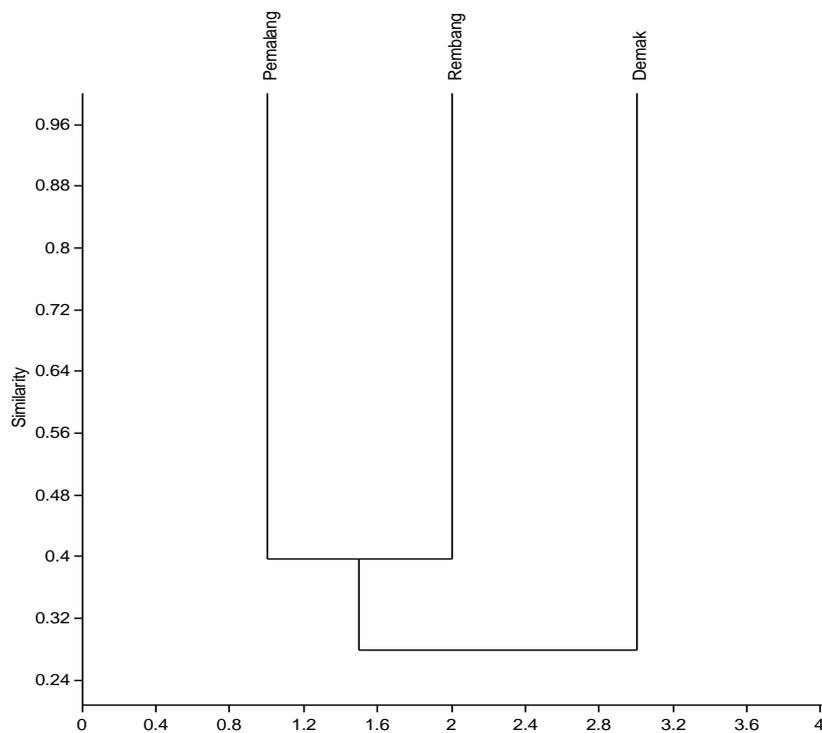


Fig. 2. Dendrogram of cluster analysis of benthic community assemblages living in mangrove forests of north coast of central Java.

Primary productivity

Benthic micro-flora primary productivity in the three locations was in the range of 70.90 – 342 mg/C/m². 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.

Equation	Model Summary					Parameter Estimates			
	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.

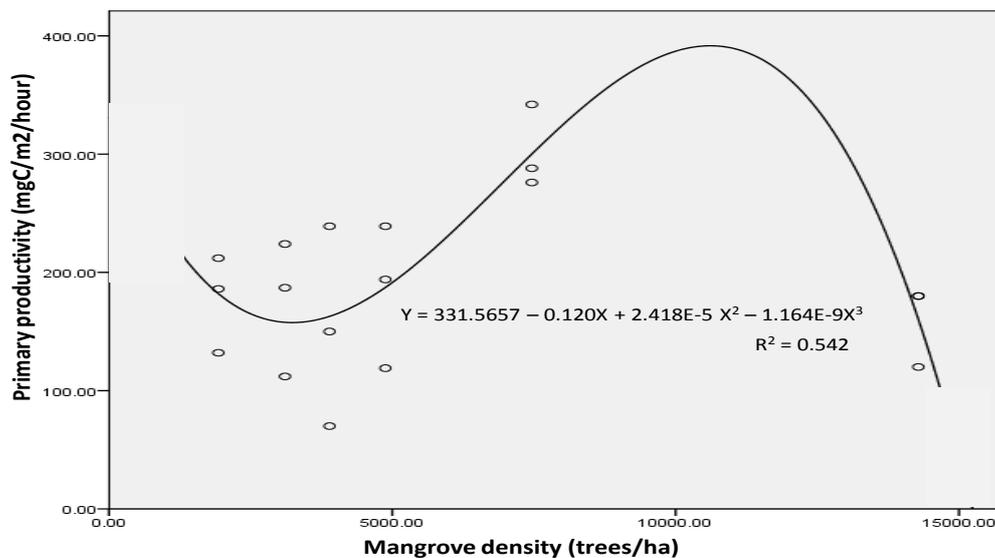


Fig. 3. The pattern of regression line between benthic micro-flora primary productivity and mangrove density.

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

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/m²/hour, appeared to be lower than that found by Hendrarto (1995) in mangrove forest at north Queensland *viz.* 58.29 – 322.1 mg C/m²/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 patterns 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

- Beals, E.W. 1984. Bray-Curtis ordination: an effective strategy for analysis 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-Normally epontic 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 epipelagic 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*. Stuttgart: 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 epipelagic diatoms along an intertidal shore, Berrow Flats, Somerset. *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

- 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.