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SEASONAL VARIATIONS OF NUTRIENT BUDGETS IN JAKARTA BAY, INDONESIA

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ABSTRACT

This study aims to quantify the fluxes of carbon, nitrogen, phosphorus, and silicate in Jakarta Bay and use these flux data to gain an initial understanding of the biogeochemical processes occurring in the system. We investigated water, suspended matter and sediments fluxes from estuarine, coastal water and outside of the bay. Water samples were analyzed for dissolved nutrients, chlorophyll-*phytoplankton* abundance, and their composition. Suspended matter and sediment were analyzed for carbon and nitrogen. Nutrient concentrations were high in the rivers or estuaries and then decreased rapidly seaward. Calculation budget results showed that Jakarta Bay is a sink for DIP, DIN and DSi during dry season and rainy season. In the dry season, the system is in the slightly fixation condition ([nfix-denit] = 0.03 mmol N $m^{-2}d^{-1}$). In contrast, denitrification exceed nitrogen fixation ([nfix-denit] = -9.74 mmol N $m^{-2}d^{-1}$) in the rainy season. Moreover, the bay produced net carbon about 2.6-32 mmol C $m^{-2}d^{-1}$.

Keywords: Nutrient budget, Biogeochemistry, Jakarta Bay

INTRODUCTION

Jakarta Bay is a semi enclosed bay located on the northern coast of Jakarta Metropolitan City, extending from 5.9° to 6.176° S and 106.6° to 107.03° E. Two capes, Tanjung Karawang, border the bay at the east and Tanjung Pasir at the west. Topographical pattern follows the shape of the bay. It is shallow and flat in the middle of the bay, and steep at both capes (Figure 1). Locality of tides in Jakarta Bay is diurnal with mean neap to spring tidal range is 27 cm–97 cm (Illahude, 1980).

Hydrologically, there are 13 rivers across the Jakarta region, of which three big rivers with significant discharge to Jakarta Bay, those are Citarum River, Ciliwung River, and Cisadane River. The catchment area of Jakarta Bay is about 650 km^2. Citarum River has the biggest drainage area and the longest river length. However, this river keeps the water discharge in the three cascade dams upstream to the middle part of the stream. This river flows to the eastern part of Jakarta Bay where not all of discharge goes to Jakarta Bay. The most significant river is Ciliwung River from the complex volcanic area of Mount Pangrango and Mount Gede, and this river runs across the central part of Jakarta city and always causes heavy flooding as well as nutrients. During the flood, the river discharge can exceed 500 m^3s^{-1} and brings debris of trees and housing material. The other one is Cisadane River that flows downstream to the western part of Jakarta Bay with the maximum discharge of 973 m^3s^{-1}.

There are two monsoonal seasons at Jakarta Bay, called as west monsoon that is related to the rainy season from October to March, and the east monsoon that is related to the dry season from April to September. The yearly rainfall amount varies from 1800 mm/year in the coastal area to 4000 mm/year in Bogor and mountainous area (Figure 2). Such high yearly rainfall in the upstream of mountainous or highland region in the southern part of Greater Jakarta indicates higher rainfall intensity up to 80% in the rainy season. Therefore, the water and sediment flux from the river to the coastal water of Jakarta Bay would be much more transported significantly during this season.

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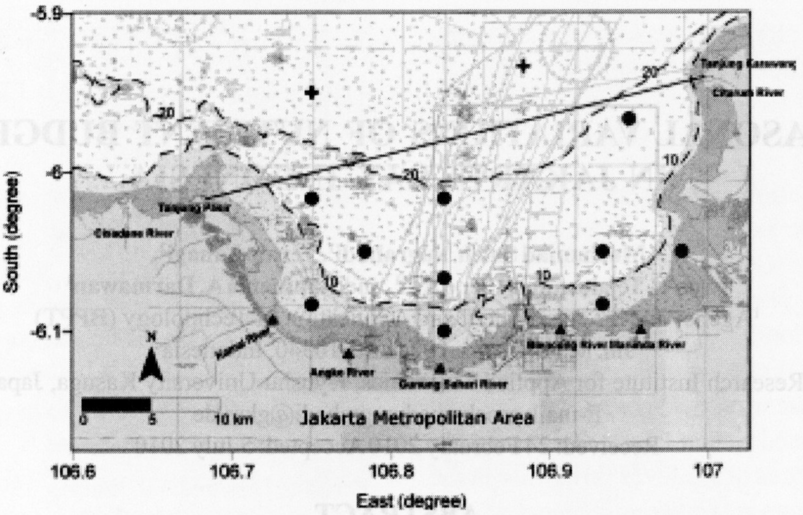

Figure 1. Jakarta Bay. Solid triangles, dots, and plus denote sampling stations in estuaries, inner bay and outer bay, respectively. Solid line shows the boundary of the budgeted system. Broken lines show the depth in meter.

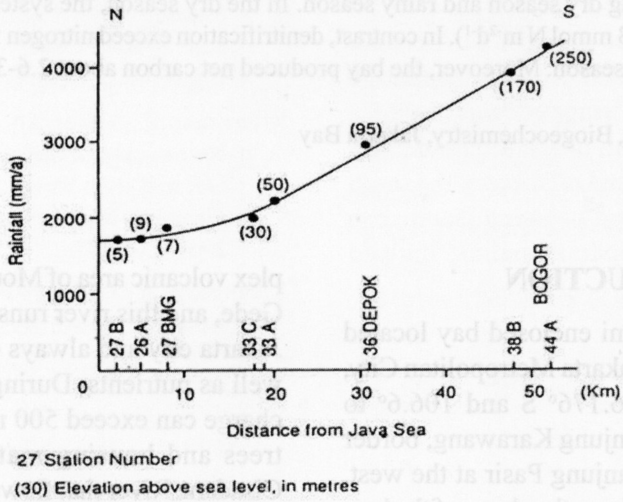

Figure 2. Rainfall distribution from the coast of Jakarta to Bogor (after Maimun, F., 1985)

Jakarta, as Indonesian capital city with the population of 8,522,589 inhabitants and other 15 million people in the surrounded suburban of Jakarta (Anonymous, 2010), has a strategic role of regional socio-economic development. The urbanization in the greater Jakarta (called Jabodetabek) creates a significant anthropogenic impact to the environmental system. It is reported that the green area has been changing into impervious area in the range between 20%–78% in the period 1973 to 2002 (*Kompas*, 3 February 2007). The threat to environmental degradation in the Jakarta Bay from anthropogenic source is greater than from natural source (Zaenal, 2004). The role of coastal system as net carbon sources or as sinks remains debatable because the systems vary in response to external change. However, it is difficult to calculate carbon and nutrient budgets through direct observations. LOICZ (Land-Ocean Interaction in the Coastal Zone) has developed the well-tested and widely used Biogeochemical Modeling Guidelines (Gordon *et al.*, 1996) to implemented carbon and nutrient budgets

(Buranatheprat *et al*., 2002; Crossland *et al*., 1999; Hung and Kuo, 2002; Smith *et al*., 2000). The study aims to estimate carbon (C), nitrogen (N), phosphorus (P), and silicate (Si) fluxes and to infer *from* these fluxes into the biogeochemical processes occurring in the system of Jakarta Bay.

MATERIAL AND METHODS

Material

Present study summarizes data from biogeochemical surveys in the Jakarta Bay. We conducted two samplings representing dry and rainy seasons in August 2006 and February 2007. There were seventeen sampling stations in this study, of which five were in the estuaries (shown by solid triangles in Figure1) and ten in the bay (shown by solid circles in Figure1) and two out of the bay (shown by plus signs in Figure1). The riverine discharges were estimated from the cross section areas that were measured using echo sounder and mean water velocity measured with flow meter. The water samples were taken with a 5-litre van Dorn water sampler. For each station, two water samples were taken to form a composite water sample for the analysis. Orthophosphate, nitrate, nitrite, ammonium, and silicate were analyzed according to standard method of American Public Health Agency (APHA, 1998). Salinity was measured in-situ using CTD. Precipitation and evaporation data were from supplied by the Meteorological, Climatological and Geophysical Agency, Jakarta, Indonesia.

Biogeochemical Budget

We followed budgeting procedure from LOICZ (Gordon *et al*., 1996). Since the mixed layer exists for the whole water column throughout the year (Damar, 2003), one layer box model was adopted for estimating the budgets. The budgets in this study involve only dissolved material, e.g. DIP, DIN, and DSi. We discussed the dissolved and particulate carbon data separately in Nugrahadi *et al*. (2009). Information on sediment and chlorophyll-a are presented in Tejakusuma *et al*. (2007).

The LOICZ biogeochemical budget model is a steady-state box model. We construct nutrient budgets from non-conservative distributions of nutrients and water budgets. The model assumed that either water volume remains constant or that change of volume through time is known, then the net water outflow of the system can be estimated by difference. Oceanographer considers salt as conservative because the system does not either produce or consume salt. The seawater outflow delivers salt advectively. The change of salinity in the systems results in inward mixing of salt. The salinity at the boundary of the systems is taken as the average of salinity of the system (here is in the bay, denote with the subscript BAY) and adjacent systems (denote with the subscript OCN). Briefly, under steady-state condition, the water mass balance can be estimated by:

$$V_R = V_{in} - V_{out} = \frac{dV_{BAY}}{dt} - V_Q - V_P - V_G - V_o + V_E \qquad (1)$$

Where V_R is residual current that is equal to the net input of freshwater; V_Q, V_P, V_E, V_G, V_O, V_{in}, V_{out} are mean flow of river discharge, precipitation, evaporation, groundwater, waster water, advective inflow and advective outflow from the bay. Taking salinity from the river as zero psu, therefore the salt balance in the bay can be derived:

$$V_X = \frac{1}{(S_{BAY} - S_{OCN})}\left[V_{BAY}\frac{dS_{BAY}}{dt} + V_R S_R\right] \qquad (2)$$

Where $S_R = (S_{BAY} + S_{OCN})/2$, and S_{BAY} and S_{OCN} are the mean salinity in the bay and ocean. V_X is the water exchange flow or mixing flow between the bay and the adjacent ocean. Assuming the constant volume of the bay, the total water exchange time is calculated as

$$\tau(day) = \frac{V_{Bay}}{(|V_R| + V_X)} \qquad (3)$$

Table 1. Variation of physical properties, water budget and residence time of the Jakarta

Sampling period	Freshwater input (10^3 m^3 d^{-1})			Residual flow (V_R)	Salinity (PSU)		$V_R S_R$	Exchange (V_X)	Residence Time (?)
	River	Precipitation	Evaporation	(10^3 m^3 d^{-1})	S_{OCN}	S_{BAY}	(10^3 m^3 d^{-1})	(10^3 m^3 d^{-1})	day
Aug-06	3017	0	2232	-785	32.90	32.05	-25506	30007	135
Feb-07	12261	3770	1091	-14940	30.37	27.44	-431830	147382	26

The processes leading to the non-conservative fluxes are examined from the stoichiometric linkage between the fluxes. There are two assumptions underlying behind these fluxes. Firstly, is small number of process enumerated which are likely dominate these non-conservative fluxes, and secondly approximation of the processes using stoichiometric. These non-conservative fluxes are here noted with Δ symbol. Non-conservative budgets are estimated from water budgets and nutrient concentrations. The first calculated budget is phosphorus budget because it has no degassing phase and it becomes the first priority of ecosystem nutrient budgeting. The non-conservative budget is generally expressed with the equation below:

$$\Delta Y = V\frac{dV}{dt} + Y\frac{dV}{dt} - \sum V_{in}Y_{in} + \sum V_{out}Y_{out} \qquad (4)$$

Y, V, and ΔY are concentration of nutrients, meaning flow rate and non-conservative budget, respectively. Subscription "in" and "out" are inflow and outflow, respectively. The unit of ΔY in this budget is concentration (in mol) per unit time (day). It is also useful to use ΔY per unit area by dividing this number with the area of the system, so the unit will be mol $m^{-1}d^{-1}$.

RESULTS

Water and Salt Budget

Owing to its medium size, hydrological condition of Jakarta Bay varied with time as a function of freshwater input. Due to the unavailability of the groundwater and sewerage data, the freshwater input from land that is taken into consideration in this calculation is only river discharge. Precipitations and evaporation data were calculated from one week measurement prior to the survey date. The budget area was projected of approximately 496 km^2 using software ArcGIS (Geographic Information Systems). With a mean depth of 8.4 m (Damar, 2003), volume of the system was estimated to be $2.17x10^9$ m^3. Table 1 shows that the freshwater input in the rainy season ($12{,}261x10^3$ m^3 d^{-1}) from the land to the bay folds four times of that in the dry season (3,017 $x10^3$ m^3 d^{-1}). Even though the seasonal horizontal distribution of salinity is not presented here, the difference between salinity in the system (estuary plus the bay) and that in ocean (out of the bay) is greater in the rainy season than that in the dry season. Freshwater discharge strongly influences Jakarta Bay, resulting in large horizontal and temporal salinity variation.

The net freshwater input (V_R) from the rivers, precipitation, and evaporation are $-785x10^3$ and -14.940 $x10^3$ m^3 d^{-1} in dry and rainy seasons, respectively. Following LOICZ convention, inflow to the system is taken to be positive and outflow negative, thus there were outflow from the bay to the ocean in dry as well as rainy seasons (Figure 3).

These require mixing volume (V_X) or exchange volume of approximately $30{,}007x10^3$ and $147{,}382x10^3$ m^3d^{-1} in dry and rainy seasons, respectively. Apparently, the mixing flux dominated the water budgets, resulting in mean bay salinity approaching oceanic salinity when river discharge was low during the dry season (Figure 4).

Total water exchange time in dry and rainy season are 135 days and 26 days, respectively. The total water exchange of our study was much longer than that reported by Damar (2003) which mentioned the water residence time in the bay was 5 days. It might be caused by the different size of study area between Damar (285 km^2) and ours (495 km^2).

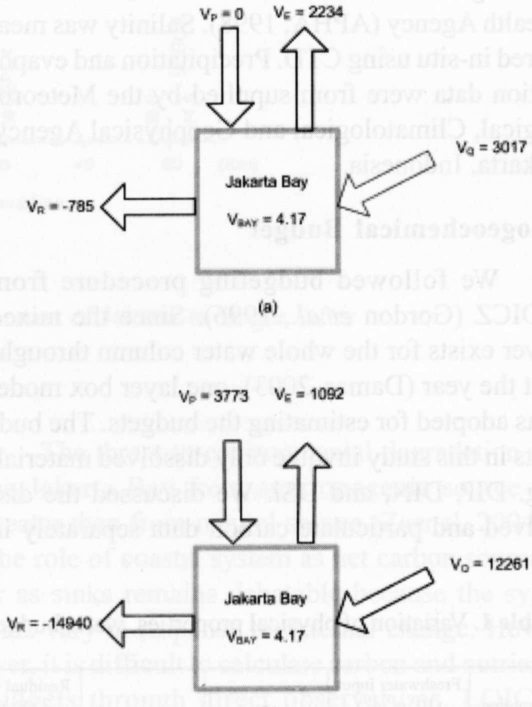

Figure 3. Water budget in dry (upper) and rainy season (lower). System volume (V_{bay}) is expressed in unit m^3, water fluxes in 10^3 m^3d^{-1}.

Additionally, the rivers which were taken into account in our study were only five and the discharges were measured once without considering the tide. However, seasonal water budget of the system is obviously controlled by the freshwater input and water exchange. Thus, nutrient and carbon budget are expected to vary seasonally in response to such variation of residence time.

Non-Conservative Material Budget

Variations of nutrient concentrations in the freshwater (river), in the bay (estuary and the bay) and in the ocean, are presented in Table 2. In general, nutrient concentration decreases seaward, except dissolved inorganic phosphorus (PO_4, hereafter DIP) concentration in the dry seasons, which has similar concentration between in the bay and in the ocean. DIP concentration in the freshwater in dry season is lower than that in rainy season. In contrast to the freshwater, DIP concentration in the bay and in the ocean in the dry season is higher than that in the rainy season. It may be depleted by the large photosynthesis in wet seasons which will be discussed later. Table 3 presents DIP budget for Jakarta Bay. Assuming all nutrient loads were accounted by the river runoff, the bay seems to be a sink for DIP for both seasons; ΔDIP is -12.09×10^3 mol day^{-1} in the dry season and -150 $\times 10^3$ mol day^{-1} in the rainy season (Figure 5).

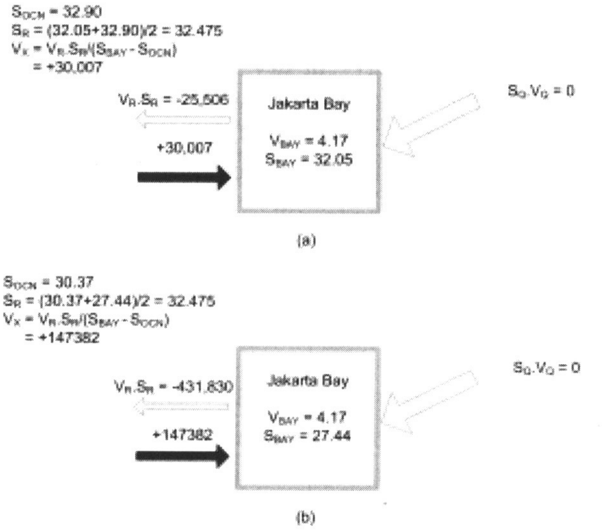

Figure 4. Salinity budget in dry (upper) and rainy season (lower). System volume (V_{bay}) is expressed in unit m^3, water fluxes in 10^3 m^3 d^{-1}, and salt fluxes in 10^3 psu.m^3 d^{-1}.

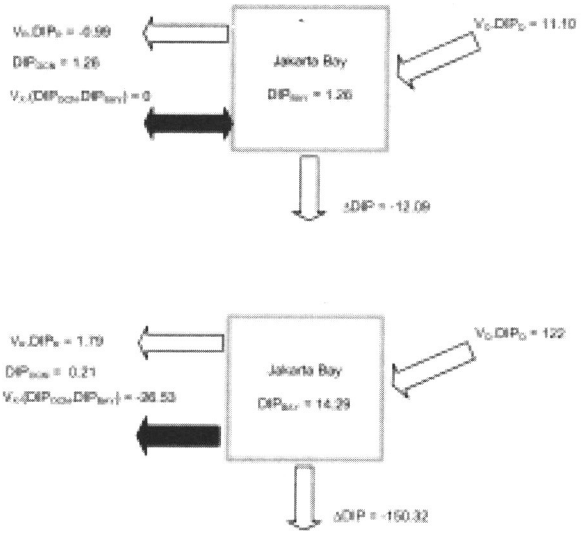

Figure 5. Phosphorus budget in dry (upper) and rainy season (lower). Nutrient fluxes in 10^3 mol d^{-1}

Table 2. Variation of nutrient concentration in the freshwater, in the Jakarta Bay and in the ocean

Sampling Period	DIP (μM)			DIN (μM)			DSi (μM)		
	Freshwater	Bay	Ocean	Freshwater	Bay	Ocean	Freshwater	Bay	Ocean
Aug-06	3.94	1.26	1.26	522.40	26.41	61.21	507.90	35.20	33.65
Feb-07	14.29	0.21	0.03	295.19	41.46	14.28	119.09	7.82	4.85

Table 3. Temporal variability of nutrients fluxes in the Jakarta Bay

Sampling Period	River flux (+) (10^3 mol d^{-1})			Residual flux(-)(10^3 mol d^{-1})			Mixing flux (10^3 mol d^{-1})		
	DIP	DIN	DSi	DIP	DIN	DSi	DIP	DIN	DSi
Aug-06	11.10	1186.00	1464.00	0.99	34.41	27.04	0.00	1044.26	-46.51
Feb-07	122.00	2815.00	1667.00	1.79	416.37	94.64	-26.53	-4005.85	-437.73

Land supplied nitrogen in large amount during both investigation periods. NO_3^- and NH_4^+ and NO_2 are lumped into dissolved inorganic nitrogen (hereafter DIN). Although DIN concentration in freshwater during dry season (522.40 M) was higher than that in the rainy season (295.19 µM), the flux of DIN from land to the bay during rainy season (2,815x10^3 mol day^{-1}) doubled than that during dry season (1,186 x10^3 mol day^{-1}) due to large river discharge. DIN concentration decreases rapidly seaward, except that in the dry season that shows higher concentration in the ocean than that in the bay. It may be possible that the Citarum discharge in the eastern part of the bay supplied more nitrogen to the ocean and conveyed westward by the residual current. For long period, the residual current plays more important for material transport in the coastal sea (Yanagi, 1999). The monsoon winds control the circulation in the bay. Simulation result indicated strong residual current flows westward during South East Monsoon or dry season (Koropitan *et al.*, 2009). Residual outflow removes about 34.41 x10^3 mol day^{-1} and 416.37 x10^3 mol day^{-1} DIN in dry and rainy season, respectively. Mixing adds 1,044 x10^3 mol day^{-1} and removes 4,006 x10^3 mol day^{-1} DIN in dry and rainy seasons, respectively. Jakarta Bay acts as a sink for 176x10^3 mol day^{-1} and 7237 x10^3 mol day^{-1} of DIN in dry and rainy season, respectively (Figure 6).

Silicate concentrations in both dry and rainy seasons were high (Table 2). However, it reveals that dissolved silicate (hereafter, DSi) concentration in the dry season was higher than that in the rainy season. Despite the origin of silicate from the river, it was possible that high river discharge dilute the concentration in the bay during the rainy season. Low DIN concentration in the river during rainy season may be the same reason. Riverine supply of silicate were about 1,464 x10^3 mol day^{-1} and 1,667 x10^3 mol day^{-1} in dry and rainy seasons, respectively. Residual outflow in dry and rainy seasons remove 27.04 and 94.64 x10^3 mol day^{-1} DSi, respectively, and mixing removed 47x10^3 mol

Table 4. Non-conservative fluxes and budgets of the NPSi in the Jakarta Bay

Sampling Period	□DIP	□DIN	□DSi	(p-r)	(nfix - denit)
	(10^3 mol d^{-1})	(10^3 mol d^{-1})	(10^3 mol d^{-1})	(10^3 mol d^{-1})	(10^3 mol d^{-1})
Aug-06	-12.09	-176.15	-1537.55	1281.50	17.28
Feb-07	-150.32	-7237.22	-2199.37	15934.09	-4832.07

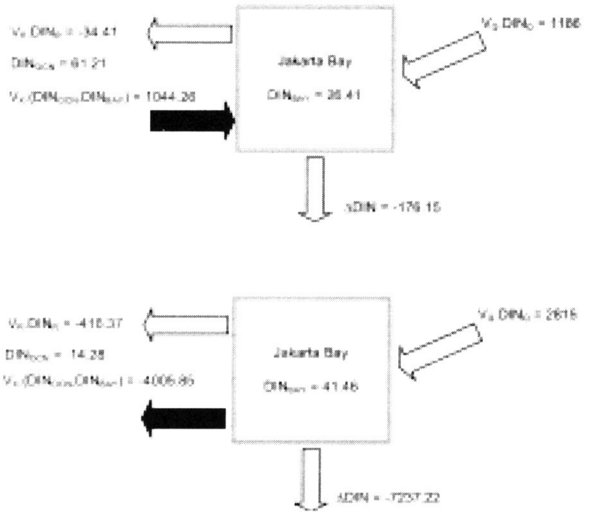

Figure 6. Nitrogen budget in dry (upper) and rainy season (lower). Nutrient fluxes in 10^3 mol d^{-1}

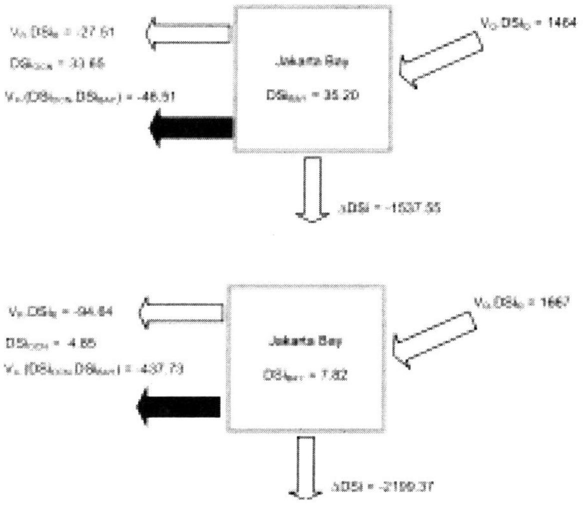

Figure 7. Silicate budget in dry (upper) and rainy season (lower). Nutrient fluxes in 10^3 mol d$_{-1}$

day^{-1} and 438 x10^3 mol day^{-1} in both seasons. The budget would be balanced if there was removal 1,537 x10^3 and 2,199 x10^3 mol day^{-1} of DSi in dry and rainy season, respectively (Figure 7).

Stoichiometric Linkage between Non-Conservative NP Fluxes, Carbon and Nitrogen Budgets

The net ecosystem metabolism production (NEP = difference between primary production (p) and respiration(r) [*p–r*]) can be estimated stoichiometrically from ΔDIP and C: P ratio of organic matter being produced or consumed in the bay. Therefore,

$$[p - r] = -\Delta DIC_o = \Delta DIP \times (C:P)_{Particulate} \quad (5)$$

The particulate C : P ratio in the bay was not measured, and then the Redfield ratio (Redfield *et al.*,1963) was adopted for stoichiometry calculation because phytoplankton is the primary producer in Jakarta Bay (Damar, 2003). Following the equation above, the NEP in both seasons were estimated as 1,281 x10^3 and 15,934 x10^3 mol day^{-1}. Notably, a system with a negative ΔDIP is a CO_2 consuming system via a net production of organic matter (p>r). In contrast, the system would be a net producer of CO_2 (p<r) if ΔDIP is positive. Thus, the positive value of NEP indicates that Jakarta Bay can be considered as a net autotrophy system. Over the budgeting area, the net carbon productions in dry and rainy seasons are 2.58 and 31.13 mmol m^{-2}d^{-1}, respectively or 31 and 385 mg C m^{-2}d^{-1}.

The dissolved nitrogen flux associated with production (*nfix*) and decomposition of organic particulate material (*denit*) is the dissolved phosphorus flux (ΔP = ΔDIP) multiplied by (N : P) particulate. It follows, that (*nfix - denit*) is the difference between the measured dissolved nitrogen flux in the absence of the dissolved organic nitrogen (DON) and that expected value from production and decomposition of organic matter:

$$(nfix - denit) = \Delta DIN - \Delta DIP \times (N:P)_{Particulate} \quad (6)$$

Using this formula, net nitrogen fluxes in Jakarta Bay in the dry and rainy seasons found to be +17 x 10^3 and -4832 x10^3 mol N day^{-1}, respectively. Over the budgeting area, the system seems to be fixating 0.03 mmol m^{-2}d^{-1} in dry season and denitrifying 9.74 mmol m^{-2}d^{-1}.

DISCUSSION

Using one layer box model we illustrated the nutrient budget and its seasonal variability in anthropogenic heavily coastal water such as Jakarta Bay. To examine the reliability of data and budgeting procedure, we compare the result with the primary productivities in Jakarta Bay from previous studies (Table 5). Susanna and Yanagi (2002) stated that higher productivity during rainy season was also investigated by using a numerical box ecosystem model and by Damar (2003) using ^{14}C isotope measurement. It is believed that the nutrient supplied from land, transported through the river with high discharge due to high precipitation enriches the coastal water and increases the primary productivity in the rainy season. The annual averaged primary production estimated from this study is 76 g C m^{-2}yr^{-1}, therefore Jakarta Bay can be considered as oligothophic level (Nixon, 1995 in Damar 2003; Hinga, 1995 in Susanna, 2002). This figure is far below the primary production range estimated by previous studies although this number is still in the Boynton's primary production range for all marine planktonic systems worldwide, which is from around 12 g C m^{-2}yr^{-1} to 520 g C m^{2}yr^{-1} (Damar, 2003). Based on the primary production, Susanna and Yanagi (2002) stated that Jakarta Bay was mesotrophic, while Damar (2003) stated that Jakarta Bay was divided into three tropic levels, those were oligotrophic in the open sea, mesotrophic in the inner bay, and hypereutrophic in the coastal area (Figure 8).

Table 5. Comparison of primary production in the Jakarta Bay from different methods

Source	Method	Primary production (mg C m^{-2} d^{-1})	
		Rainy	Dry
Aryo Damar (2003)	^{14}C isotope measurement	520	350
Susanna (2002)	Box ecosystem model	830	410
This study	LOICZ box model	385 (p-r)	31 (p-r)

However, Damar (2003) and Susanna and Yanagi (2002) only estimated primary production, whereas the respiration is not included. In addition, the large discrepancy may be due to time-averaged concentrations of nutrients and water budgets that cause large errors, particularly from dry and rainy season observation.

Quantitative study of nitrogen cycle is important in order to understand the basic processes of production in sea. The significance of nitrification and denitrification on geochemical and ecological process has received considerable attention in the recent years. In a system that received a lot of nutrient from hinterland area such as Jakarta Bay, denitrification regulates the amount of primary production in the system, control degree of eutrophication, becomes as sink of nitrogen in the bay, and decreases amount of derived nitrogen continentally transported to the bay (Seitzinger, 1988). The nitrogen budget in this study is in the range values between maximum nitrogen fixation (20 mmol $m^{-2}d^{-1}$, 8 mol $m^{-2}yr^{-1}$) and (minus) maximum denitrification (-10 mmol $m^{-2}d^{-1}$, -5 mol $m^{-2}yr^{-1}$) in the world-wide coastal seas (Crossland *et al*., 2005). The nitrogen fixation in Jakarta Bay maybe occurred due to low nutrient load and low concentration in the dry season and the presence of Cyanophyceae plankton that act as nitrogen absorber that was revealed from our field investigations (Tejakusuma *et al*., 2007). During rainy season, nutrient and organic material load from land is high. The denitrification rate of Jakarta Bay is similar to that investigated in Chiku Lagoon, Taiwan (-9 mmol $m^{-2}d^{-1}$) (Hung J.J. and Kuo, F, 2002), but higher than Mirs Bay in China (-0.05 mmol $m^{-2}d^{-1}$), Sorgoson Bay (-1.06 mmol $m^{-2}d^{-1}$), Sogod Bay (-0.07 mmol $m^{-2}d^{-1}$), and Davao Gulf (-0.08 mmol $m^{-2}d^{-1}$) in Philipines (Smith *et al*., 2000). This result indicated that the net primary production in the system provide organic matter which drives denitrification in the Jakarta Bay. Low oxygen (1–1 to 3.4 mg/l in estuaries and 5–7 mg/l in the bay) measured during our observation in rainy season supported this fact.

This study represents a simple budget calculation using measurement data to investigate biogeochemical dynamic of Jakarta Bay. Mixed layer occupies whole water column throughout the year, therefore we used one layer box model. We also discussed the comparison of the result with the previous studies.

The budgeting approach showed that nutrients and carbon budgets are subjected to seasonal variability in Jakarta Bay. The temporal variability of CNPSi budgets is derived from high variable inputs and exchanges of nutrients between the bay and the outer ocean. Water residence time in this system varies seasonally. It is shorter in the rainy season than that in the dry season. Net Ecosystem Production (NEP) of this system is positive for both seasons, indicating that the bay can be considered as a net autotrophic system. It is a sink

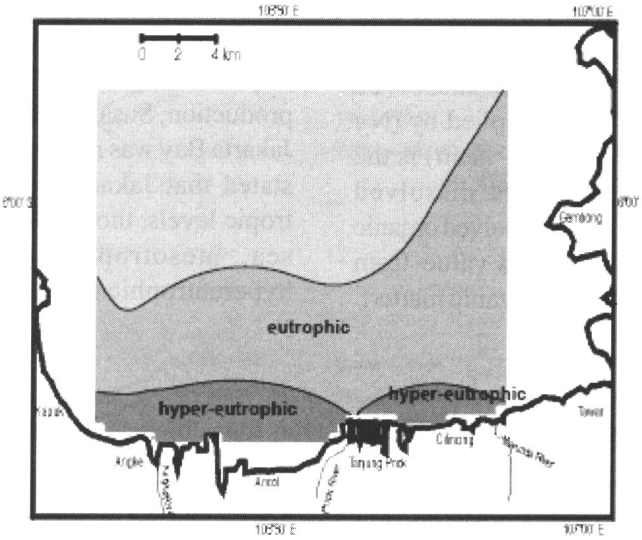

Figure 8. Projection map of spatial trophic states of Jakarta Bay waters calculated based on Trophical Marine Index (after Damar, 2003)

for phosphorus, nitrogen, and silicate in both seasons, and the system is in the states of slightly nitrogen fixation in dry season, but denitrification in rainy season.

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REFERENCES

Anonymous. 2010. http://id.wikipedia.org/wiki/Daerah_Khusus_Ibukota_Jakarta.

American Public Health Association (APHA). 1998. *Standard Methods for the Examination of Water and Wastewater, 20th ed.* Washington, DC.

Arifin, Zainal. 2004. Local Millenium Ecosystem Assessment: Condition and Trend of the Greater Jakarta Bay Ecosystem. Report to Ministry of Environment Republic Indonesia. Jakarta.

Buranatheprat, A., T. Yanagi, B. Thanomsak, and S. Pichan. 2002. Seasonal Variations in Inorganic Nutrient Budgets of the Bangpakong Estuary, Thailand. *J. of Oceanography*, Vol. 58, pp. 557–564.

Crossland, J.C., Kremer H. H., H.J. Lindeboom, J.M. Crossland, and M. D. Le Tissier. 2005. Coastal fluxes in the anthropogenic. Springer, Berlin.

Damar, A. 2003. *Effects of Enrichment on Nutrient Dynamics, Phytoplankton Dynamics and Productivity in Indonesian Tropical Waters: A Comparison between Jakarta Bay, Lampung Bay and Semangka Bay*. Dissertation, Kiel University, Kiel.

Gordon, D.C. Jr, P.R. Boudreau, K.H. Mann, K.H. Ong, W.L. Silvert, S.V. Smith, G. Watayakorn, Wulff F., and T. Yanagi. 1996. LOICZ Biogeochemical Modeling Guideline. LOICZ, Texel, the Netherlands, 96pp.

Hung, J.J, and F. Kuo. 2002. Temporal Variability of Carbon and Nutrients Budget in the Chiku Lagoon, Southwestern Taiwan. Estuary, Coastal and Shelf Science 54, 887–900.

Illahude, G. 1980. The Oceanogaphic Features of the Coastal Region between Jakarta & Cirebon. Proceeding of the Jakarta Workshop on Coastal Resources Management, LIPI, Jakarta.

Kompas Daily News, 3rd February 2007.

Koropitan, A.F., M. Ikeda, A. Damar, Y. Yamanaka. 2009. Influences of Physical Processes on the Ecosystem of Jakarta Bay: A Coupled Physical-Ecosystem Model Experiment. *ICES Journal of Marine Science*, 66: 336–348.

Maimun, F. 1985. Jakarta Groundwater study, Groundwater Table Fluctuation in the Jakarta Area and Its Surrounding 1983–1985. Directorate of Environmental Geology, Bandung.

Nugrahadi, M.S. T. Yanagi, Tejakusuma I.G.., Adi S., Darmawan R-A. 2009. Dissolved and Particulate Carbon in Jakarta Bay, Indonesia. MRI Vol. 34–1: 11–17.

Redfield, A.C., B.H. Ketchum, and Richard F.A. 1963. The Influence of Organism on the Composition on Sea-water, Chapter-2, In the Sea, Vol. 2, Edited by M.N. Hill, Inter Science Publisher. P26-77, New York and London.

Seitzinger, P. Sybil. 1988. Denitrication in Freshwater and Coastal Marine Ecosystems: Ecological and Geochemical Significance. Limnol. Oceaonogr. 33:702–724.

Smith, S.V., V. Dupra, J.I. Marshall Crossland, and C.J. Crossland. 2000. Estuarine System of the South China Sea Region: Carbon, Nitrogen and Phosphorus Fluxes. LOICZ Report & Studies No. 14, ii+156 pages, LOICZ IPO, Texel, the Netherlands.

Susanna, N., Yanagi, T. 2002. Lower Tropic Level Ecosystem in Jakarta Bay, Indonesia. La Mer, Vol. 40, pp 161–170, Tokyo.

Tejakusuma, I.G., Senoadi, M.S. Nugrahadi, R. Darmawan. 2007. Current Natural and Anthropogenic Carbon Flux in the Jakarta Bay, Indonesia. SARCS Report Project, Chung-li, Taiwan.

Yanagi, Tetsuo. 1999. *Coastal Oceanography*. Terrapub, Tokyo, p172.