La mer 40 : 161–170, 2002
Société franco-japonaise d'océanographie, Tokyo

Lower Trophic Level Ecosystem in Jakarta Bay, Indonesia

Nurdjaman SUSANNA* and Tetsuo YANAGI**

Abstract : The lower trophic level ecosystem of Jakarta Bay, Indonesia in wet and dry seasons is studied by using observed data and a box ecosystem model. The observed values of chlorophyll-*a* and Dissolved Inorganic Nitrogen (DIN) concentration are well reproduced by a vertical one-dimensional ecosystem model except in wet season 1976. Chlorophyll-*a* and DIN concentrations are higher in wet season than in dry season. Generally, concentrations of ecosystem compartments are higher in wet season than in dry season. Rainfall directly affects on the growth of phytoplankton in Jakarta Bay and the primary production in Jakarta Bay (416–830 mgC/m^2/day) is larger than in Banten Bay (84–122 mgC/m^2/day; SUSANNA and YANAGI, 2002). According to primary production Jakarta Bay is classified under mesotrophic and Banten Bay is oligotrophic. In Banten Bay, the regenerated production is higher than the new production and plays an important role, while in Jakarta Bay the ratio of new production to regenerated production is almost one. Both nutrient load and recycling DIN play an important role in the increasing of chlorophyll-*a* concentration in Jakarta Bay.

Keywords : *Jakarta Bay, DIN, chlorophyll-a, box ecosystem model, primary production, Banten Bay.*

1. Introduction

Jakarta Bay is a semi-enclosed bay, and is connected to the Java Sea. This area is directly affected by human activities because it is close to the large city, Jakarta, which is one of the fast growing Asian mega-cities that have sprung up during the past few decades. As the urbanization and industrial activities extend, the nutrient supply has increased. The waters of Jakarta Bay are fed by several major coastal rivers, which transport sediments and sewage water, as well as agricultural and industrial effluents (Fig.1). This has resulted in high levels of nutrients concentration and in the contamination of coastal waters extending for a considerable distance into the Java Sea. In recent years, a severe water pollution accompanied with red tides and oxygen-depleted water mass has been frequently observed in Jakarta Bay. These phenomena are said to be related to the increase in the coastal nutrient supply. High nutrients level can lead to enhanced phytoplankton growth and potentially to eutrophication. Repeated observations in Jakarta Bay revealed that the bay water is very productive. The averaged chlorophyll-*a* concentration ranged from 0.9 to 5.41 mg/m^3 with a maximum value of 17.96 mg/m^3 (PRASENO *et al.,* 1978). The highest chlorophyll-*a* concentration was found in the sample taken in front of the river mouth. Blooming of a single species was observed in Jakarta Bay by Praseno and ADNAN (1978). The plankton *Noctiluca* was often found blooming in waters influenced by river discharge, appearing in great numbers after the heavy rainfall.

There are many studies concerning the coastal marine ecosystem and many attempts to estimate the environmental management strategy (SOHMA *et al.*, 2001). Simulation by numerical model is one of tools that can be used to predict the management effect quantitatively.

FASHAM *et al.* (1990) presented a model of the annual cycle of plankton dynamics and

* Interdisiplinary Graduate School of Engineering Sciences, Kyushu University, Kasuga 816-8580, Japan
** Research Institute for Applied Mechanics, Kyushu University, Kasuga 816-8580, Japan

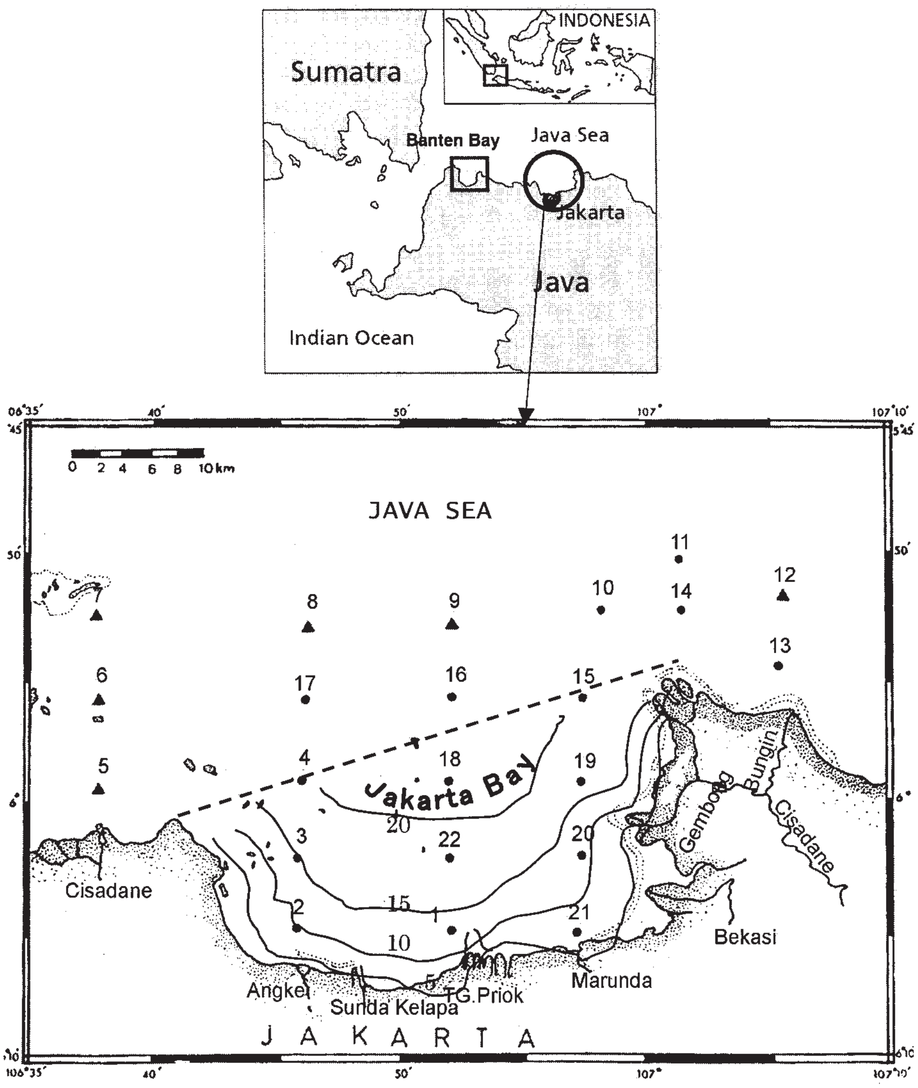

Fig. 1 Jakarta Bay and observation stations. Numbers with contour show the depth in meters. Broken line shows the model boundary.

nitrogen cycling in the oceanic mixed layer at Station "S" near Bermuda. KAWAMIYA *et al.* (1995) also developed a model which has constructed a vertical one-dimensional ecosystem and applied to Station Papa.

In this paper, a box ecosystem model has been described that reproduces the observation field, using the best available parameters. An application of the model has been a calculation of detailed budget of bioelement through the coastal ecosystem. The results are compared with the previous estimate of nutrient fluxes in Banten Bay (SUSANNA and YANAGI, 2002), which is located next to Jakarta Bay (Fig.1) to assess the performance of the model and to identify which process requires a detailed study.

2. Observation

Research and Development Center for Oceanology of the Indonesia carried out field observations at 22 stations shown in Fig. 1

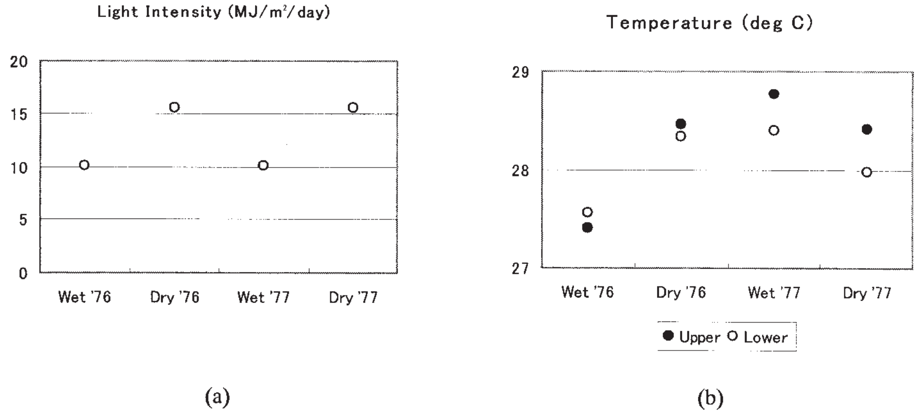

Fig. 2 Seasonal variation of light intensity at Jakarta (a) and average water temperatures in the upper and lower layers of Jakarta Bay (b).

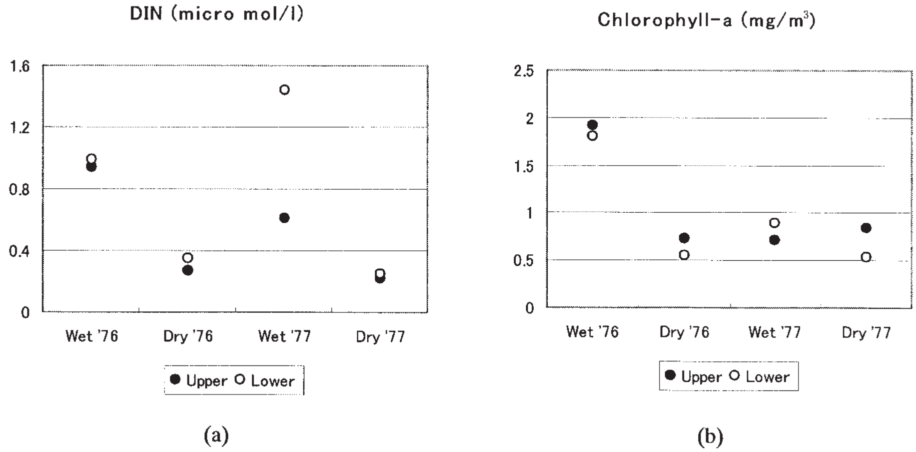

Fig. 3 Seasonal variation of DIN concentration (a) and chlorophyll-*a* concentration (b) at outer bay.

during 1976 to 1977. Samplings were carried out during both wet and dry seasons, and they were 21–23 January 1976 (wet season), 10–12 August 1976 (dry season), 26–29 January 1977 (wet season) , and 10–13 August 1977 (dry season). The field observations of water temperature, dissolved inorganic nitrogen (DIN) and chlorophyll-*a* concentrations were taken at the depths of 0, 5, 10, 15, 20... meters. The data of stations 5 to 14, 16 and 17 are used as outer values (boundary condition of the model) and those of stations 1 to 4, 15, 18, 19, 20, 21 and 22 as inner values (for verification). Seasonal variation of solar radiation (I) at Jakarta was observed by Geophysics and Meteorology Agency, Indonesia (Fig. 2 (a)). The thickness of the euphotic layer (H_u) is taken to be 7.0 m in wet season and 10.0 m in dry season, on the basis of the sechi disk depth data in the bay (ANONYMOUS, 1976 a, b, 1977 a, b). Euphotic depth is 2.8 times the Sechi disk depth (PARSONS *et al.*, 1984). Variation of water temperature in the upper (euphotic) and lower (aphotic) layers are shown in Fig. 2(b). Estimation of land effect on water temperature in Jakarta Bay showed that there was convection of heat energy from land to sea water (ILAHUDE and SIANIPAR, 1977). Besides, water temperature near river mouth was higher than other sites in Jakarta Bay in January 1977 (wet season) (ILAHUDE and SOEPANGAT, 1977). Concentrations of DIN and chlorophyll-a at outer bay are used for the boundary conditions of the model calculation (Fig. 3).

The average load of DIN from rivers, industrial and sewage treatment plants, which flow into Jakarta Bay, is estimated to be 305.8 g/sec in wet season and 235.8 g/sec in dry season (ANONYMOUS, 1997c).

3. Model Description

We consider that the simplest model capable of capturing the essence of nitrogen cycling requires five compartments. These compartments are: Phytoplankton (PHY), Zooplankton (ZOO), Particulate Organic Nitrogen (PON), Dissolved Organic Nitrogen (DON) and DIN. The structure of nitrogen based material flows are described by SUSANNA and YANAGI (2002). All compartments of ecosystem are applied in the upper (euphotic) and lower (aphotic) layers. Major flows include nitrogen uptake by phytoplankton, excretion, ingestion, grazing, mortality and decomposition of particulate materials. While bacteria plankton is not modeled explicitly, their effects are modeled indirectly through the decomposition and cycling of organic substances from the senescent cells of phytoplankton and zooplankton. The dynamics of each compartment are described with differential equations, which are composed of biological source and sink terms, and diffusion terms. Details are given below (based on KAWAMIYA *et al*,. 1995) :

$$\frac{d\mathrm{PHY}}{dt} = -w_p\mathrm{PHY} + \mathit{Diffusion}(\mathrm{PHY}) + (A_1\mathrm{PHY} - B_1\mathrm{ZOO} - A_2\mathrm{PHY} - A_3\mathrm{PHY}^2) \tag{1}$$

$$\frac{d\mathrm{ZOO}}{dt} = \mathit{Diffusion}(\mathrm{ZOO}) + (B_1\mathrm{ZOO} - B_2\mathrm{ZOO} - B_3\mathrm{ZOO} - B_4\mathrm{ZOO}^2) \tag{2}$$

$$\frac{d\mathrm{PON}}{dt} = -w_D\,\mathrm{PON} + \mathit{Diffusion}(\mathrm{PON}) + (A_3\mathrm{PHY}^2 + B_3\mathrm{ZOO} + B_4\mathrm{ZOO}^2 - C_1\mathrm{PON} - C_2\mathrm{PON}) \tag{3}$$

$$\frac{d\mathrm{DON}}{dt} = \mathit{Diffusion}(\mathrm{DON}) + (A_2\mathrm{PHY} + C_2\mathrm{PON} - D_1\mathrm{DON}) \tag{4}$$

$$\frac{d\mathrm{DIN}}{dt} = \mathit{Diffusion}(\mathrm{DIN}) + (-\mathrm{A}_1\mathrm{PHY} + B_2\mathrm{ZOO} + C_1\mathrm{PON} + D_1\mathrm{DON}) \tag{5}$$

where $\mathit{Diffusion}(C_i)$ is vertical and horizontal diffusion of C_i (one of the compartment concentration in this model). Vertical diffusion is $\frac{\partial}{\partial z}\left(K_v\frac{\partial C_i}{\partial z}\right)$ and horizontal diffusion is $\frac{\partial}{\partial x}\left(K_h\frac{\partial C_i}{\partial x}\right)$, where K_v and K_h denote the vertical and horizontal eddy diffusivities. Horizontal diffusivity (K_h) is 13 m^2/sec and vertical diffusivity (K_v) = 2.0×10^{-4} m^2/sec are decided based on SUSANNA and YANAGI (2002). w_P and w_D denote the sinking velocity of phytoplankton and PON, respectively.

The following are explanation of biochemical formulations.

a. Photosynthesis (A_1)

Photosynthesis is assumed to be a function of temperature, nutrient concentration and light intensity. The Michaelis-Menten equation is used to define the nutrient limited growth rate (FASHAM *et al.*, 1983). As for the dependence on light intensity, the formula used by STEELE (1962), by which light inhibition can be expressed, is employed.

$$A_1 = V_{max}\left(\frac{DIN_u}{DIN_u + K_N}\right).exp(kT_u).\ \frac{I_a}{I_{opt}}exp\left(1-\frac{I_a}{I_{opt}}\right), \tag{6}$$

where V_{max} is the maximum nitrogen uptake rate, K_N is a half saturation constant for DIN, k denotes the temperature dependency of photosynthesis, T_u is temperature in the upper layer, I_{opt} is optimum light intensity for photosynthesis and I_a is average light intensity in the upper layer :

$$I_a = \frac{1}{H_u}\int_0^{H_u} 0.5Iexp(-k_e z)\,dz, \tag{7}$$

where 0.5 is the conversion factor for the fraction of photosynthetically active radiation in the total radiation (PARSONS *et al.*, 1984), I is the total surface radiation observed at Jakarta (shown in Fig. 2a) and k_e is the extinction coefficient as estimated by $k_e = 4.6/H_u$, where H_u is the thickness of the euphotic layer (PARSONS *et al.*, 1984).

b. Extracellular Excretion (A_2)

Table 1 Parameter values used in this model. Values in parentheses are those used by KAWAMIYA *et al.* (1995).

V_{max}	Maximum photosynthesis rate at 0℃	1.3(1.0)	/day
K	Temperature coefficient for Photosynthesis rate	0.063	/℃
K_N	Half Saturation constant for dissolve inorganic nitrogen	0.98(3.0)	μmol/l
I_{opt}	Optimum Light Intensity	18.0(4.21)	MJ/m²/day
γ	Ratio of Extra cellular Excretion to Photosynthesis	0.135	
M_{PO}	Phytoplankton Mortality Rate at 0℃	0.0281	1/μmolN day
k_{MP}	Temperature Coefficient fot Phytoplankton Mortality rate	0.069	/℃
α	Assimilation Efficiency of Zooplankton	0.7	
β	Growth Efficiency of Zooplankton	0.3	
GR_{max}	Maximum Grazing Rate at 0℃	0.3	/day
k_g	Temperature Coefficient for Grazing	0.0693	/℃
λ	Ivlev Constant	1.4	1/μmolN
PHY	Threshold Value for Grazing	0.043	μmolN/l
M_{ZO}	Zooplankton Mortality Rate at 0℃	0.0585	1/μmolN day
k_{MZ}	Temperature Coefficient for Zooplankton Mortality rate	0.0693	/℃
V_{PIO}	PON Decomposition Rate at 0℃(to DIN)	0.03	/day
V_{PIT}	Temperature Coefficient for PON Decomposition(to DIN)	0.0693	/℃
V_{PDO}	PON Decomposition Rate at 0℃(to DIN)	0.03	/day
V_{PDT}	Temperature Coefficient for PON Decomposition(to DIN)	0.0693	/℃
V_{DIO}	DON Decomposition Rate at 0℃	0.03	/day
V_{DIT}	Temperature Coefficient for DON Decomposition	0.0693	/℃
w_p	Sinking speed of phytoplankton	0.037(0.05)	m/day
w_D	Sinking speed of detritus	0.38 (0.5)	m/day

Extracellular excretion is the fraction of net primary production exuded by phytoplankton as DON (GIN *et al.*, 1998), which is assumed to be proportional to photosynthesis (KAWAMIYA *et al.*, 1995).

$$A_2 = \gamma A_1 \tag{8}$$

where γ r is phytoplankton exudation rate.

c. Mortality (A_3, B_4)

Following STEELE and HENDERSON (1992), mortality of phytoplankton and zooplankton is assumed to be proportional to the second power of plankton concentration and dependent on temperature.

Mortality of phytoplankton(A_3) =

$$M_{PO}\, exp\, (k_{MP}T) \tag{9}$$

Mortality of zooplankton(B_4) =

$$M_{ZO}\, exp\, (k_{MZ}T) \tag{10}$$

where M_{po} *and* M_{zo} are mortality rates of phytoplankton and zooplankton at 0℃, respectively. The dead plankton forms the organic nitrogen pools (PON, DON) and are subject to mineralization by bacteria to form DIN. In order to keep the model simple, a linear decay function is used, instead of introducing a separate bacterial compartment.

d. Grazing (B_1)

Grazing process is assumed to be as a function of temperature, phytoplankton concentration and zooplankton concentration.

$$B_1 = G_{max}(1 - exp(\lambda(PHY^* - PHY))) \cdot exp(k_g T) \tag{11}$$

where G_{max} refers to maximum grazing rate, λ is Ivlev's constant, PHY^* is a threshold value for grazing, k_g is temperature coefficient for grazing, and T is water temperature. Grazing rate is saturated when phytoplankton concentration is sufficiently large, while no grazing occurs when phytoplankton concentration is lower than the critical value PHY^*.

e. Excretion and Egestion (B_2, B_3)

Excretion and egestion are assumed to be proportional to grazing rate.

$$\text{Excretion}(B_2) = (\alpha - \beta) B_1 \tag{12}$$

$$\text{Egestion}(B_3) = (1 - \alpha)\, B_1 \tag{13}$$

where α and β are assimilation efficiency

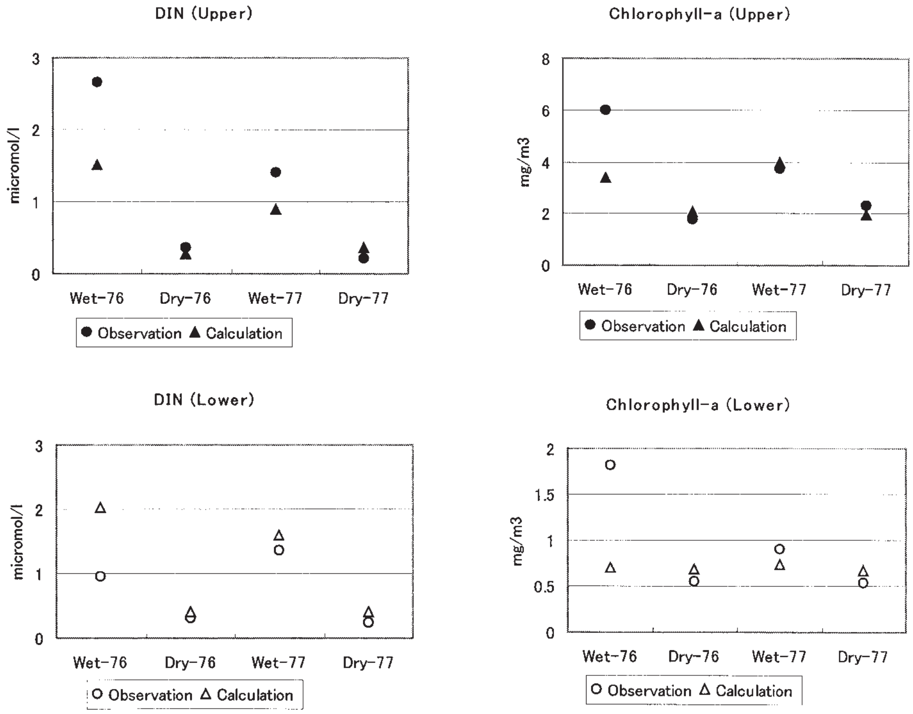

Fig. 4 Comparison between calculated and observed values for DIN and chlorophyll-*a* concentrations in Jakarta Bay.

and growth efficiency of zooplankton, respectively.

f. Decomposition of Organic Matters (C_1, C_2, D_1)

Decomposition of PON into DIN(C_1) =
$V_{PI0}\ exp\ (V_{PIT}T)$ (14)

Decomposition of PON into DON(C_2) =
$V_{PD0}\ exp\ (V_{PDT}T)$ (15)

Decomposition of DON into DIN(D_1) =
$V_{DI0}\ exp\ (V_{DIT}T)$ (16)

where V_{PI0}, V_{PD0}, V_{DI0} are decomposition rates at 0℃, V_{PIT}, V_{PDT}, V_{DIT} are temperature coefficients.

Parameters used in this box model analysis are shown in Table 1.

According to Parsons *et al.* (1984), the range of photosynthetic rate (V_{max}) is 0.05 /day − 8.1/day, and 1.3 /day (at 0℃) is adopted in this model. Larger V_{max} than by KAWAMIYA *et al.*, (1995) may be due to that their model was applied to Station Papa which is in the open ocean or oligotrophic condition. For the half saturation constant of DIN (KN), PARSONS *et al.* (1984) shows that the range is 0.01 − 4.21 mmol/l, and 0.98 mmol/l was reported for eutrophic tropical Pacific (PARSONS *et al.*, 1984). Such small K_N in tropics is considered to be due to that DIN concentration in tropics is much lower than that in mid-latitude.

The initial condition is given as the same values as those at outer bay (Fig. 3). The quasi-steady state is obtained 50 days after the beginning of the calculation. As the horizontal gradient terms are much larger than the temporal changing terms in equations (1) to (5), we consider the quasi-steady state is established in each observation time.

4. Results and Discussion

a. Comparison with observed data

Fig. 4 shows the seasonal variations of calculated and observed DIN and chlorophyll-*a* in Jakarta Bay. Calculated chlorophyll-*a* and DIN concentrations well reproduces the observed values in the upper and lower layers of Jakarta Bay except in wet season 1976. Concentration

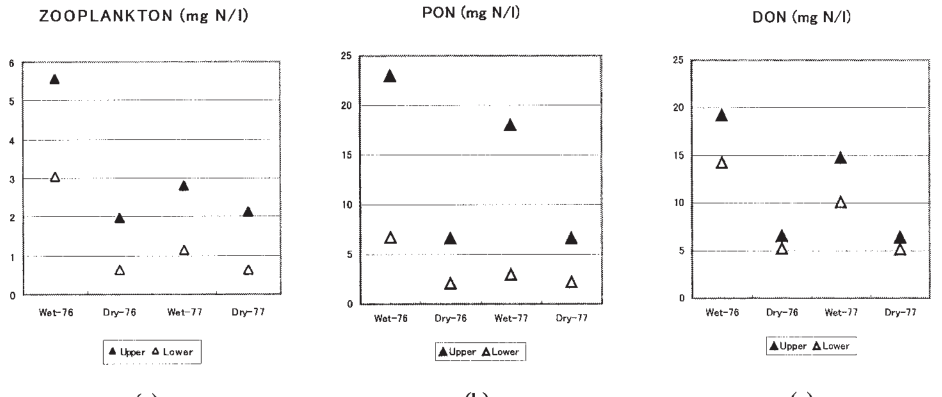

Fig. 5 Results of calculated zooplankton, PON and DON concentrations in Jakarta Bay.

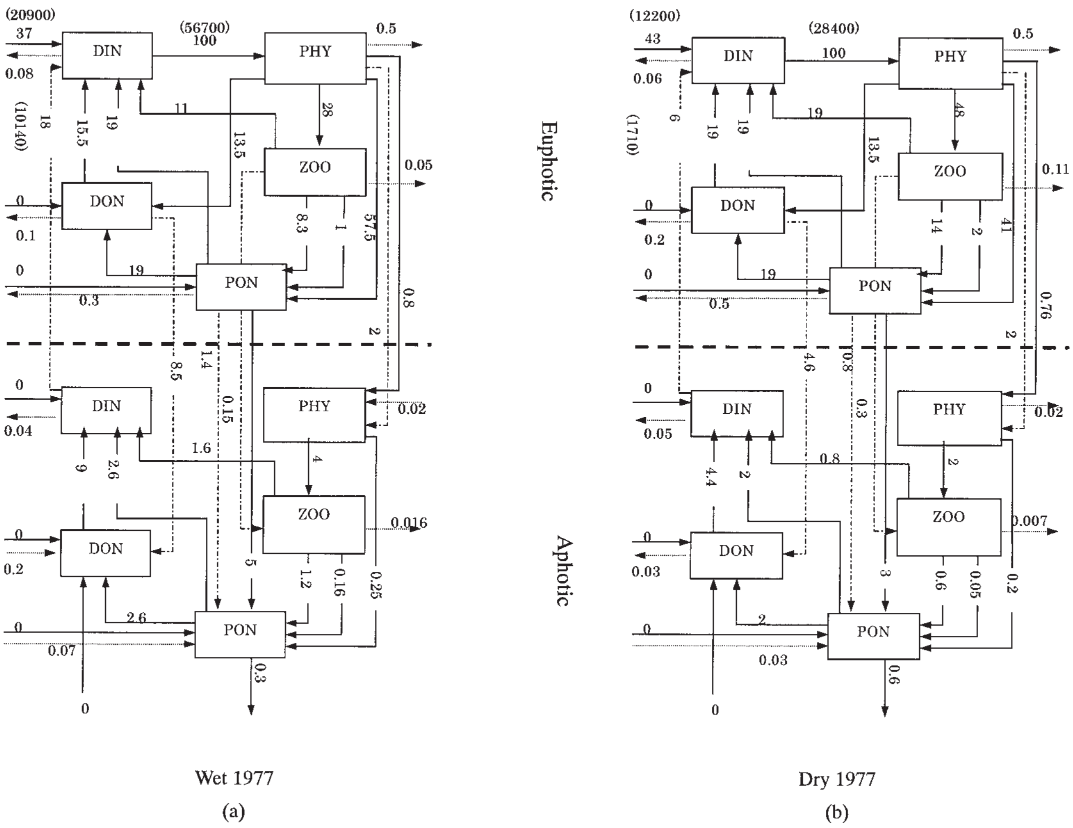

Fig. 6 Normalized nitrogen flux based on the photosynthesis flux in January 1977 (wet season) (a) and August 1977 (dry season) (b) in Jakarta Bay (unit in kg/day)

of chlorophyll-*a* in Jakarta Bay is higher in wet season than in dry season. From model results, chlorophyll-*a* concentration in the lower layer seems to show little seasonal variation. The discrepancy in wet season 1976 in DIN concentration is due to the insufficiency of data for DIN load each year, that is, only averaged DIN load data are given in this model.

Table 2 Comparison of average ecosystem conditions between Jakarta Bay and Banten Bay during wet and dry seasons.

		Jakarta Bay		Banten Bay	
		Way 1977	Dry 1977	Wet 1979	Dry 1980
DIN (microg/l)	upper	1.40	0.20	1.19	0.23
	lower	1.44	0.23	1.25	0.30
Chl-a (mg/m^3)	upper	3.93	2.29	0.79	0.95
	lower	0.89	0.53	0.65	0.86
Nitrogen Flux					
DIN-Phy(kg/day)		56700	28400	2220	3220
Load(kg/day)		20900	12200	63	21
New Production (kg/day)		31100	14000	460	430
Regenerated Prod. (kg/day)		25800	16300	1770	2730
Ratio new production /regenerated prod.		1:0.8 (1.25)	1:1.2 (0.80)	1:3.9 (0.26)	1:6.3 (0.15)
Primary production (mg C/m^2/day)		830	416	83.9	122
Secondary production (mg C/m^2/day)		231	199	15.4	25.3
Transfer Efficiency(%)		28	48	18	21

Calculated DIN concentration is higher in wet season than in dry season, because the load from river is larger in wet season than in dry season. Rainfall played an important role on the growth of phytoplankton and nutrient concentration, which is higher during the northwest monsoon (wet season) (ARINARDI, 1978).

Fig. 5 shows the variation in zooplankton, PON and DON. Generally, all the concentrations are higher in wet season than in dry season. This pattern is related to chlorophyll-*a* and DIN concentrations, being higher in wet season than in dry season.

b. Nitrogen Cycling

Nitrogen flux (Fig. 6) from DIN to phytoplankton is higher in wet season (56,700 kgN/day) than in dry season (28,400 kg N/day). Such a flux difference is caused by higher chlorophyll-*a* concentration in wet season than in dry season. The inflowed DIN flux from land in wet season (20,900 kg/day) is higher than in dry season (12,200 kg/day). It means that large DIN load from land causes high chlorophyll-*a* concentration in Jakarta Bay. The ratio of inflowed DIN flux to photosynthesis-DIN flux is 2.7 in wet season and 2.3 in dry season.

From model results, seasonal variation of new production and regenerated production can be estimated. New production, which is defined as DIN flux in the upper layer from rivers or rain (load) and from the lower layer by diffusion, is larger in wet season (31,100 kgN/day) than in dry season (14,000 kgN/day) due to higher river load. Besides the vertical diffusion is also larger in wet season than in dry season. Regenerated production, which is defined as DIN flux in the upper layer by decomposition of PON and DON and excretion of zooplankton, is larger in wet season (25,800 kgN/day), when the primary production is large, than in dry season (16,300 kgN/day). The ratio of new production to regenerated production is 1: 0.8 in wet season and 1:1.2 in dry season. It means that new production is higher than regenerated production in wet season. The higher new production in wet season is due to the increasing of load from river and the diffusion from the lower layer, while in dry season, the nutrient load is small and regenerated production plays more important role. The transfer efficiency from the primary production to the secondary production is 28 % in wet season and 48 % in dry season.

c. Comparison with Banten Bay.

DIN and chlorophyll-*a* concentrations in Jakarta Bay during wet season are higher than in Banten Bay (SUSANNA and YANAGI, 2002) (Table 2). In both bays, the values of DIN concentrations in the upper and lower layers do not have great differences. They are 1.19–1.44 μg/l in wet season and 0.20–0.30 μg/l in dry season. On the other hand, the values of chlorophyll-*a* concentration in both bays are not the same especially in the upper layer. The range of chlorophyll-*a* concentration in the upper layer is 2.29 3.93 mg/m^3 in Jakarta Bay, while in Banten Bay it has low concentration with the range of 0.79–0.95 mg/m^3. In Jakarta Bay chlorophyll-*a* concentration is higher in wet season than in dry season while in Banten Bay it is higher in dry season than in wet season. In Jakarta Bay, the rise of chlorophyll–*a* concentration in wet season is due to high rainfall and large nutrient load, but in Banten Bay, the nutrient load from river is so small that the chlorophyll-*a* concentration does not rise in wet season. Ratio of new production to regenerated production in Jakarta Bay is higher than in Banten Bay, which is over 0.8 in Jakarta Bay and under 0.26 in Banten Bay. In Jakarta Bay, high nutrient load makes the ratio of new production to regenerated production to balance, however, in Banten Bay, regenerated production is dominant due to small nutrient load and high water temperature. The primary production ranges from 416 to 830 mgC/m^2/day in Jakarta Bay and 84 to 122 mgC/m^2/day in Banten Bay. R YTHER (1969) estimates that the primary production is 137 mgC/m^2/day for the open ocean and 822 mgC/m^2/day for the coastal upwelling area and HINGA *et al.* (1995) classified the waters by the rate of organic carbon production: oligotrophic (< 274 mgC/m^2/day), mesotrophic (275–824 mgC/m^2/day), eutrophic (825–1370 mg C/m^2/day) and hyperthropic (>1370 mg C/m^2/day). According to RYTHER (1969) and HINGA *et al.* (1995), Banten Bay is oligotrophic condition (similar to the open ocean) and Jakarta Bay is mesotrophic condition.

5. Conclusion

The model calculation in Jakarta Bay shows good agreement with the observed ones except in wet season 1976. Chlorophyll-*a* concentration is higher in wet season than in dry season. The variation pattern of chlorophyll-*a* concentration coincides with that DIN concentration. High load of nutrient from industry, domestic and rainfall causes DIN concentration higher in wet season than in dry season. Generally, concentrations of lower trophic level ecosystem compartments are higher in wet season than in dry season in Jakarta Bay. This study shows that Jakarta Bay water is strongly affected by the seasonal variation.

Rainfall and recycling DIN play an important role in the increase of chlorophyll-*a* concentration. The primary production in Banten Bay is smaller than that in Jakarta Bay. According to the primary production level, Banten Bay is oligotrophic and Jakarta Bay is mesotrophic.

The box ecosystem model presented here still has limits. One of these is that the deposit materials at the bottom and release from the sediment have not been taken into account. However, as a whole, we find that a relatively simple box ecosystem model can reproduce the biochemical data at both sites.

References

ANONYMOUS (1976 a): Laporan Pelayaran II KM. Samudra di Teluk Jakarta 21–23 Januari 1976. Proyek Penelitian Masalah Pengembangan Sumber Daya Laut dan Pencemaran Laut LON LIPI, Jakarta. 1–42.

ANONYMOUS (1976 b): Laporan Pelayaran IV KM Samudera di Teluk Jakarta 10–12 Agustus 1976. Proyek Penelitian Masalah Pengembangan Sumber Daya Laut dan Pencemaran Laut LON LIPI, Jakarta. 1–40.

ANONYMOUS (1977 a): Monitoring Teluk Jakarta Laporan No. 6 Pelayaran KM. Samudera 26–29 Januari 1977. Proyek Penelitian Masalah Pengembangan Sumber Daya Laut dan Pencemaran Laut LON– LIPI, Jakarta. 1–49.

ANONYMOUS (1977 b): Pemonitoran Teluk Jakarta Laporan No. 8 Pelayaran KM. Samudra 10–13 Agustus 1977. Proyek Penelitian Masalah

Pengembangan Sumber Daya Laut dan Pencemaran Laut LON– LIPI, Jakarta. 1–57.

ANONYMOUS (1997c) : Pemantauan Kimiawi Air Sungai 1996/1997, Laporan Prokasih DKI Jakarta.

ARINARDI, O.H. (1978) : Rainfall impact on the growth of phytoplankton in Jakarta Bay 1978, Oseanologi di Indonesia, 103–120.

FASHAM, M.J.R., H.W. DUCLOW, and S.M. MCKERVIE (1990) : A Nitrogen–based model of plankton dynamics in the oceanic mixed layer, Journal of Marine Research, **48**, 591–639.

GIN, K.Y.H., J. GUO, and H. CHEONG (1998): A size based ecosystem model for pelagic waters, Ecological Modelling, **112**, 53–72.

HINGA, K.R., H. JEON, N.F. LEWIS (1995): Quantifying the effects of Nitrogen Enrichment on Phytoplankton in Coastal Ecosystems, Marine Eutrophication Review, US Dept. of Commerce, Coastal Ocean Office.

ILAHUDE, A.G., and P. SIANIPER (1977): Pengamatan hidrologi di Teluk Jakarta, Monitoring Teluk Jakarta. Laporan No. 7 Pelayaran KM 'Samudera' 11–14Mei 1977. LON–LIPI, Jakarta: 9–47.

ILAHUDE, A.G., and I. SOEPANGAT (1977): Pengamatan hidrologi di Teluk Jakarta, Monitoring Teluk Jakarta. Laporan No. 6 Pelayaran KM 'Samudera' 26–29 Januari 1977. LON–LIPI, Jakarta: 8–41.

KAWAMIYA, M., M. Kishi, Y. YAMANAKA and N. SUGINOHARA (1995) : An ecological–physical coupled model applied to Station Papa. J. Oceanography, **51**, 635–664.

PARSONS, T., M. TAKAHASHI and B. HARGRAVE (1984): Biological Oceanographic Process. Pergamon Press. 3rd edition. Oxford, 330 pp.

PRASENO, D.P., and Q. ADNAN (1978): Noctiluca miliaris Suriray in Jakarta Bay, Oseanologi di Indonesia, **11**, 1–25 (in Indonesian).

PRASENO, D.P., Z. SOEJOETI, and DIJARDJANA (1978): The application of remote semsing in marine research in Indonesia.Proc. 12th Intern. Symp. Rem. Son. Environ., **3**, 2071–2079.

RYTHER, J.H., (1969) : Photosynthesis and fish production in the sea, Science, 166, 72–76.

SOHMA, A., Y. SEKIGUCHI, H. YAMADA, T. SATO, and K. NAKATA (2001): A new coastal marine ecosystem model study coupled with hydrodynamic and tidal flat ecosystem effect, *Mar. Pollution. Bull.*, **43**, 187–208.

SUSANNA, N. and T. YANAGI (2002): Ecosystem condition in wet and dry seasons of Banten Bay, Indonesia, La mer, **40**, 1–10.

STEELE, J.H., (1962): Environmental control of photosyuthesis in sea, Limnol. Oceanogr., **7**, 137–150.

STEELE, J.H., and HENDERSON, E.W. (1992): The significance of internanuall variability. *In*: Evans, G.T., Fasham, M.J.R (Eds.), Towards a Model of Ocean Biogeochemical Processess. Springer Verlag, Heidelberg, 227–260.

Received June 17, 2002
Accepted October 15, 2002