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Ecosystem conditions in wet and dry seasons of Banten Bay, Indonesia

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Abstract : The ecosystem conditions in wet and dry seasons of Banten Bay, Indonesia are studied by using observed data and a box ecosystem model. The observed values of chlorophyll *a* concentration are well reproduced by the calculation. Chlorophyll *a* was higher in dry season than in wet season. Generally, concentrations of ecosystem compartment are higher in dry season than in wet season. As a whole, Banten Bay water is strongly affected by seasonal variation (wet and dry seasons). Recycling of DIN plays the important role in the increase of chlorophyll *a* concentration, transfer efficiency is almost the same with that in Hakata Bay, Japan, which is located in mid–latitude and hyper–eutrophic. The ratio of new production to regenerated production is smaller in Banten Bay than in Hakata Bay. Banten Bay is under the transition condition between oligotrophic and eutrophic condition.

Key words : *Banten Bay, wet and dry seasons, box ecosystem model, new production, regenerated production, transfer efficiency, Hakata Bay.*

1. Introduction

Banten Bay is a semi–enclosed bay located at the northwest coast of Java, 60 km west of Jakarta, and is connected to the Java Sea, and its surface area is 150 km^2 (Fig. 1). It is shallow with averaged depth of 7 m. The area accommodates a valuable marine ecosystem such as seagrass field, coral reefs and a bird sanctuary of international importance at a peninsula near the town of Banten. The coastal zone, particularly the western part, is rapidly industrializing and is to become one of the major growth centers near Jakarta. Impact of inland pollution, though not yet severe, are expected to become important threats.

NONTJI (1974) compiled all chlorophyll *a* data of the Indonesian waters and obtained an average value of 0.19 mg/m^3. A higher average (0.24 mg/m^3) was obtained in the southeast monsoon (dry season), while during the northwest monsoon (wet season) the average value was 0.16 mg/m^3. However no one tried an ecosystem modeling in coastal seas around Indonesia.

In this study, we investigate the lower trophic level ecosystem and nitrogen budget of Banten Bay in wet and dry seasons using a box ecosystem model and the results are compared to their field observation data. Also we compare our result with the ecosystem condition in Hakata Bay, Japan, which is located in mid–latitude and hyper–eutrophic condition.

2. Observation

Research and Development Center for Oceanology of the Indonesia carried out field observations at 4 stations shown in Fig. 1 four times from 1979 to 1981. Each time corresponds to wet season (northwest monsoon) or dry season (southeast monsoon), they were 18–31 December 1979 (wet season), 18–30 June 1980 (dry season), 29 January – 20 February 1981 (wet season), and 16 August – 12 September 1981 (dry season). The field observations of water temperature, DIN (Dissolved Inorganic Nitrogen) and chlorophyll *a* concentrations were taken at the depth of 0, 5, 10, 15, 20 meters. Station 5 is used as outer value (boundary

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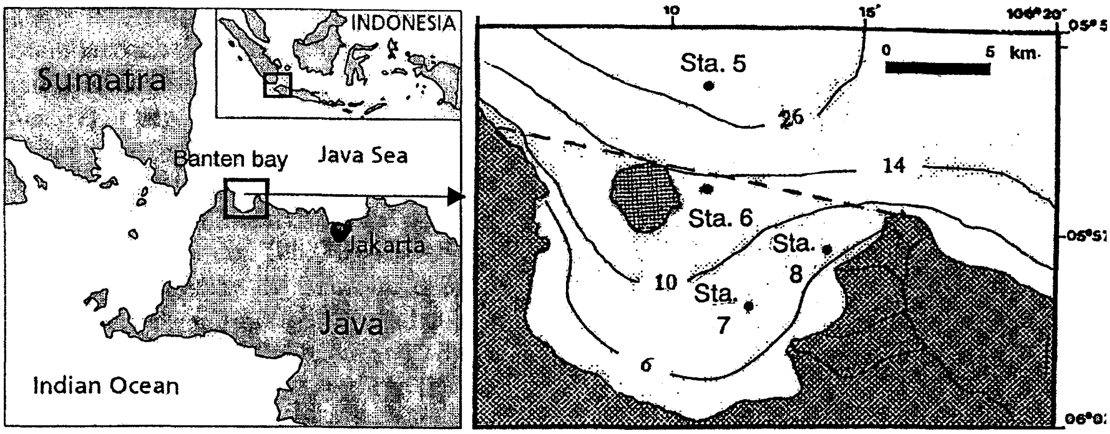

Fig. 1. Banten Bay and observation stations. Numbers show the depth in meters. Broken line shows the model boundary.

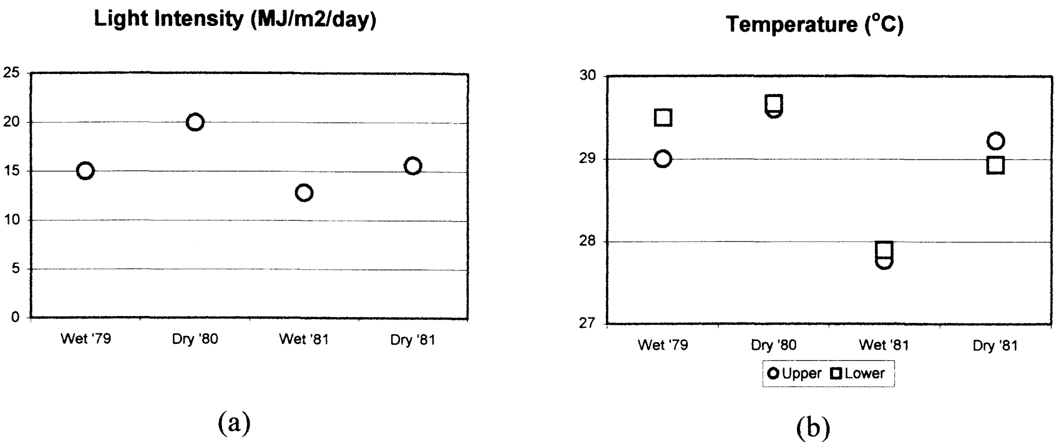

Fig. 2. Light intensity at Jakarta (a). Average water temperatures in the upper and lower layers of Banten Bay (b).

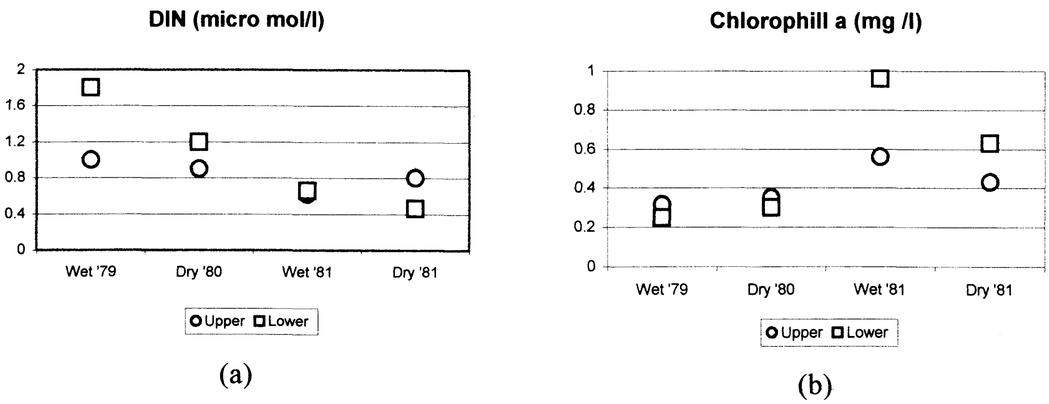

Fig. 3. DIN concentration (a) and chlorophyll *a* concentration at station 5 (b)

condition of the model) and stations 6, 7 and 8 as inner values (for verification). Seasonal variation of solar radiation, I, at Jakarta was observed by Geophysics and Meteorology Agency, Indonesia and is shown in Fig. 2 (a). The thickness of the euphotic layer (H_u) is taken to be 5.5 m in wet season and 6.0 m in dry season, based on the transparency data in the bay (Anonymous, 1980 a, b, 1981 a,b). Variation of water temperature in the upper (euphotic) and lower (aphotic) layers are shown in Fig. 2(b). From Fig. 2 a, light intensity was higher in dry season than in wet season, therefore water temperature was also higher in dry season.

Concentrations of DIN and chlorophyll *a* at outer bay are shown in Fig. 3 that are used for the boundary conditions of the model calculation.

The load of DIN from rivers, industrial and sewage treatment plants, which flow into Banten Bay, has been investigated by Dutch Team (LINDEBOOM *et al.*, 2001), and it is 4.5 kmol N/day in wet season and 1.5 kmol N/day in dry season.

From Dutch team data (LINDEBOOM *et al.*, 2001), Dissolved Inorganic Phosphorus (DIP) in the bay was 0.07 mmol and DIN in the bay was 0.12 mmol and the mole ratio between DIN and DIP was 1.7. This value is much smaller than the Redfield ratio of 16, so DIN becomes a limited nutrient for photosynthesis, and therefore we investigate only nitrogen cycle in this study.

3. Model Description

We consider five compartments (Phytoplankton (PHY), zooplankton (ZOO), Particulate Organic Nitrogen (PON), Dissolved Organic Nitrogen (DON) and Dissolved Imorganic Nitrogen (DIN), shown in Fig. 4, as compartments of ecosystem in the upper (euphotic) and lower (aphotic) layers. Time evolution of those constituents is 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) :

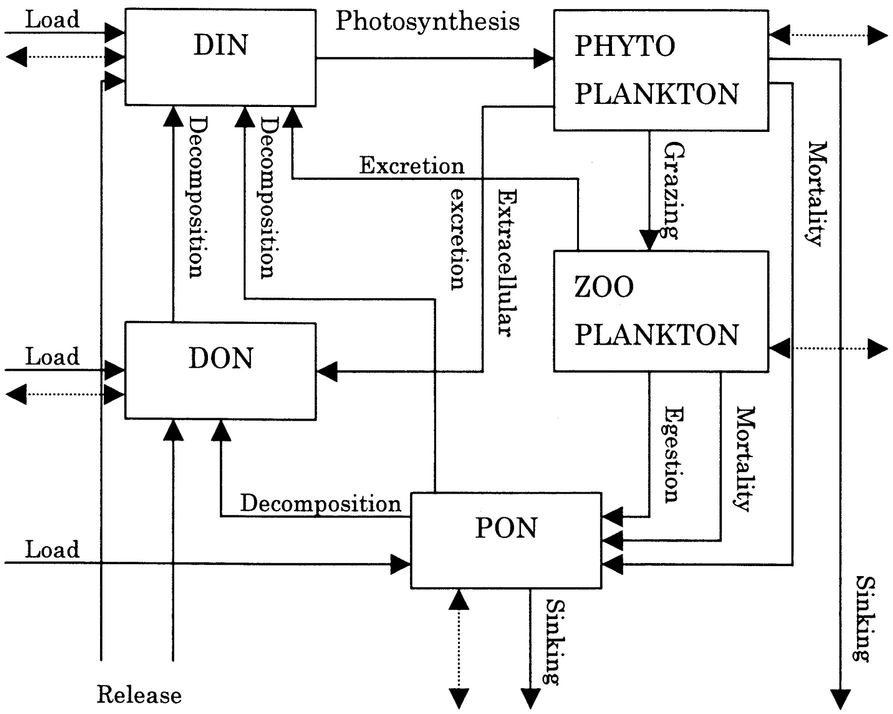

Fig. 4. Interaction among the compartments of numerical ecosystem model. Dashed arrow represents the exchange by diffusion.

$$V_u \frac{dDIN_{iu}}{dt} = DIN_{LA} - V_u(A_1PHY_{iu} - B_2ZOO_{iu} - D_1DON) - S_u\frac{K_h}{L}(DIN_{in} - DIN_{ou}) - A\frac{K_{vD}}{H}(DIN_{iu} - DIN_{il}), \quad (1)$$

$$V_u \frac{dPHY_{iu}}{dt} = V_u(A_1PHY_{iu} - B_1ZOO_{iu} - A_2PHY_{iu} - A_1PHY_{iu}) - Aw_pPHY_{iu} - S_u\frac{K_h}{L}(PHY_{iu} - PHY_{ou}) - A\frac{K_{vP}}{H}(PHY_{iu} - PHY_{il}), \quad (2)$$

$$V_u \frac{dZOO_{iu}}{dt} = V_u(B_1ZOO_{iu} - B_2ZOO_{iu} - B_3ZOO_{iu} - B_4ZOO_{iu}^2) - S_u\frac{K_h}{L}(ZOO_{iu} - ZOO_{ou}) - A\frac{K_{vP}}{H}(ZOO_{iu} - ZOO_{il}), \quad (3)$$

$$V_u \frac{dPON_{iu}}{dt} = PON_{LA} + V_u(A_3PHY_{iu}^2 + B_3ZOO_{iu} + B_4ZOO_{iu}^2 - C_1PON_{iu} - C_2PON_{iu}) - Aw_DPON_{iu} - S_u\frac{K_h}{L}(PON_{iu} - PON_{ou}) - A\frac{K_{vP}}{H}(PON_{iu} - PON_{il}), \quad (4)$$

$$V_u \frac{dDON_{iu}}{dt} = DON_{LA} + V_u(A_2PHY_{iu} + C_2PON_{iu} - D_1DON_{iu}) - S_u\frac{K_h}{L}(DON_{iu} - DON_{ou}) - A\frac{K_{vD}}{H}(DON_{iu} - DON_{il}), \quad (5)$$

$$V_u \frac{dDIN_{il}}{dt} = DIN_{ER} + V_l(B_2ZOO_{il} + C_1PON_{il} + D_1DON_{il}) - S_u\frac{K_h}{L}(DIN_{il} - DIN_{ol}) - A\frac{K_{vD}}{H}(DIN_{iu} - DIN_{il}), \quad (6)$$

$$V_l \frac{dPHY_{il}}{dt} = V_l(-B_1ZOO_{il} - A_3PHY_{il}^2) - Aw_pPHY_{iu} - S_u\frac{K_h}{L}(PHY_{il} - PHY_{ol}) + A\frac{K_{vP}}{H}(PHY_{iu} - PHY_{il}), \quad (7)$$

$$V_l \frac{dZOO_{il}}{dt} = V_l(B_1ZOO_{il} - B_2ZOO_{il} - B_3ZOO_{il} - B_4ZOO_{il}^2) - S_l\frac{K_h}{L}(ZOO_{il} - ZOO_{ol}) - A\frac{K_{vP}}{H}(ZOO_{il} - ZOO_{il}), \quad (8)$$

$$V_l \frac{dPON_{il}}{dt} = PON_{RE} + V_l(A_3PHY_{il}^2 + B_3ZOO_{il} + B_4ZOO_{il}^2 - C_1PON_{il} - C_2PON_{il}) - Aw_DPON_{iu} - PON_{SINK} - S_l\frac{K_h}{L}(PON_{il} - PON_{ol}) + A\frac{K_{vP}}{H}(PON_{iu} - PON_{il}), \quad (9)$$

$$V_l \frac{dPON_{iu}}{dt} = DON_{RE} + V_l(C_2PON_{il} - D_1DON_{il}) - S_u\frac{K_h}{L}(DON_{il} - DON_{ou}) + A\frac{K_{vD}}{H}(DON_{iu} - DON_{il}), \quad (10)$$

where subscript u, l, i, o denote upper layer, lower layer, inner bay, and outer bay, respectively. Subscript LA refers to the load from river, RE to release from the bottom. V denotes volume of the box, S is the sectional area between the inner and outer areas of the bay. A is the sectional area between the upper and lower layers.

Formulation of each biological processes are written below:

a. Photosynthesis (A_1), Photosynthesis is assumed to be a function of temperature, nutrient concentration and intensity of light.

$$A_1 = V_{max}\left[\frac{DIN_{iu}}{DIN_{iu} + K_N}\right].\exp(kT_u).\frac{I_a}{I_{opt}}\exp\left[1 - \frac{I_a}{I_{opt}}\right] \quad (11)$$

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, I_{opt} is optimum light intensity for photosynthesis and I_a is average light intensity in the upper layer :

$$I_a = \frac{1}{H_u}\int_0^{Hu} 0.5I\exp(-k_ex)dz \quad (12)$$

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 Climatological Data for Jakarta Observatory (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 euphotic layer (PARSONS *et al.*, 1984).

b. Extra cellular Excretion (A_2)

$$A_2 = \gamma A_1 \quad (13)$$

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

K_h	Horizontal diffusivity	13	m^2/sec
K_{vD}	Vertical diffusivity of dissolved material	0.0002	m^2/sec
K_{vP}	Vertical diffusivity of particulate material	0.00001	m^2/sec
V_{max}	Maximum photosynthesis rate at 0℃	0.65(1.0)	/day
k	Temperature coefficient for Photosynthesis rate	0.03(0.063)	/℃
K_N	Half Saturation constant for dissolve inorganic nitrogen	0.02(3.0)	μmol/l
I_{opt}	Optimum Light Intensity	18.0(4.21)	MJ/m^2/day
γ	Ratio of Extra cellular Excretion to Photosynthesis	0.135	
M_{PO}	Phytoplankton Mortality Rate at0℃	0.05(0.0281)	1/μmolN day
k_{MP}	Temperature Coefficient for 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℃	0.12(0.3)	/day
k_g	Temperature Coefficient for Grazing	0.0693	/℃
λ	Ivlev Constant	0.93(1.4)	1/μmolN
PHY^*	Threshold Value for Grazing	0.043	μmolN/l
M_{ZO}	Zooplankton Mortality Rate at0℃	0.0585	1/μmolN day
k_{MZ}	Temperature Coefficient for Zooplankton Mortality rate	0.0693	/℃
V_{PIO}	PON Decomposition Rate at0℃(to DIN)	0.03	/day
V_{PIT}	Temperature Coefficient for PON Decomposition(to DIN)	0.0693	/℃
V_{PDO}	PON Decomposition Rate at0℃(to DON)	0.03	/day
V_{PDT}	Temperature Coefficient for PON Decomposition(to DON)	0.0693	/℃
V_{DIO}	DON Decomposition Rate at0℃	0.03	/day
V_{DIT}	Temperature Coefficient for DON Decomposition	0.0693	/℃
w_p	Sinking speed of phytoplankton	0.04(0.05)	m/day
w_D	Sinking speed of detritus	0.4(0.5)	m/day

c. Mortality

Mortality of phytoplankton (A_3)

$$=M_{PO}\exp(k_{MP}T) \quad (14)$$

Mortality of zooplankton (B_4)

$$=M_{ZO}\exp(k_{MZ}T) \quad (15)$$

d. Grazing (B_1)

$$B_1=G_{max}(1-\exp(\lambda(PHY^*-PHY))\exp(k_gT) \quad (16)$$

e. Excretion and Egestion

Excretion (B_2) $=(\alpha-\beta)B_1$ (17)

Egestion (B_3) $=(1-\alpha)B_1$ (18)

f. Decomposition of Organic Matters

Decomposition of PON into DIN (C_1)

$$=V_{PIO}\exp(V_{PIT}T) \quad (19)$$

Decomposition of PON into DON (C_2)

$$=V_{PDO}\exp(V_{PDT}T) \quad (20)$$

Decomposition of DON into DIN (D_1)

$$=V_{DIO}\exp(V_{DIT}T) \quad (21)$$

Coefficient of horizontal diffusivity, vertical diffusivity of dissolved material and vertical diffusivity of particulate material, K_h, K_{vD}, and K_{vp} respectively, are taken to be constant for both seasons (Table 1). Horizontal diffusivity (K_h) is 13 m^2/sec (LINDEBOOM *et al.*, 2001). Other parameters are based on KAWAMIYA *et al.* (1995). We change the values of V_{max}, k, K_N, I_{opt}, M_{PO}, GR_{max}, λ, w_p, and w_D due to tuning. Because parameters by KAWAMIYA *et al.* (1995) are applied in high latitude, so those parameters may be changed in the tropics.

According to Parson *et al.* (1984), the range of photosynthetic rate (V_{max}) is 0.05 /day − 8.1 /day, in this model 0.65 /day (at 0℃) was adopted. Small V_{max} and k than by KAWAMIYA *et al.* (1995) may be due to the small sensitivity of tropical phytoplankton compared to that in mid-latitude. For the half saturation constant (K_N), PARSONS *et al.* (1984) shows that the range is 0.01 − 4.21 mmol/l. In this model 0.02 mmol/l was used. Such small K_N in tropics may be due to that DIN concentration in tropics is much smaller than that in the mid-latitude. As

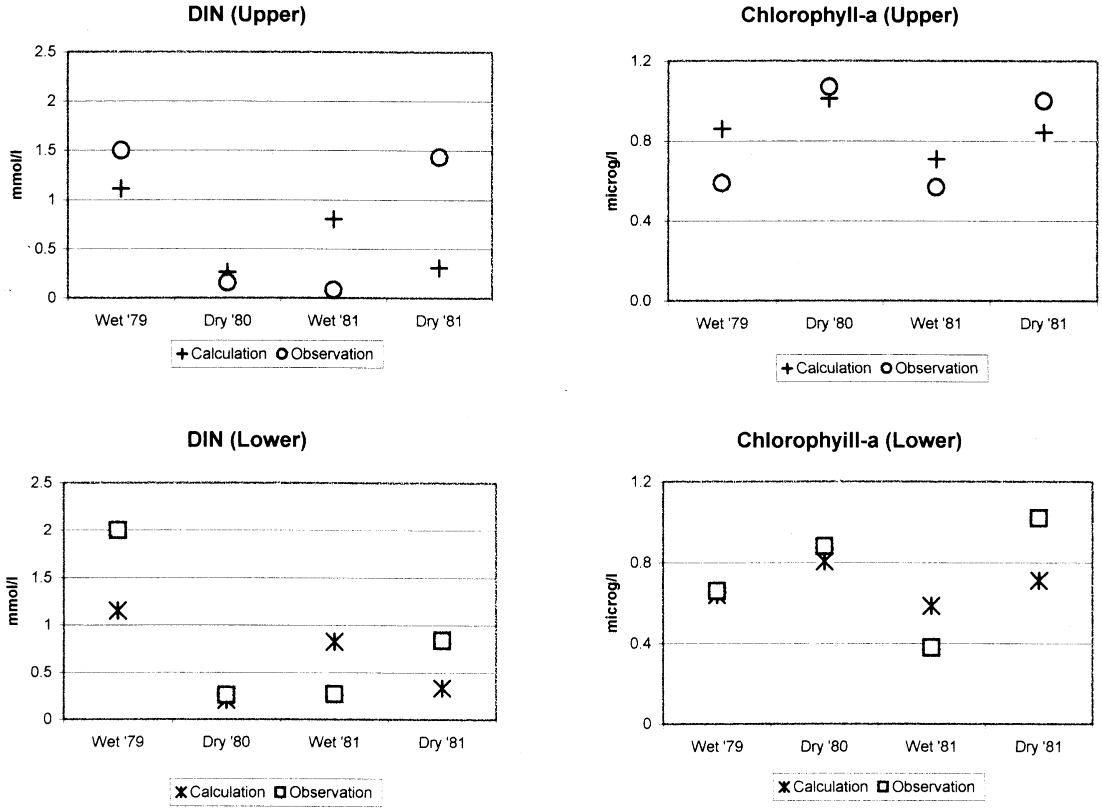

Fig. 5. Comparison between calculated results and observed data in Banten Bay.

for the grazing parameter (GR_{max}), KREMER and NIXON (1978)'s review shows that maximum grazing rate lie in the range of 0.1 – 2.5 /day, and 0.12 /day was used in this model. For Ivlev constant, KREMER and NIXON (1978) reported the range of 0.4 – 25.1/mg:C. In this model, 10.1/mg:C was adopted and this value was set to be 0.93 1/mmol/l by an assuming C:N ratio to be 106:16. Almost all parameters, which are tuned, are smaller than those in KAWAMIYA *et al.* (1995) because the small sensitivity of tropical biota compared with those in mid-latitude area.

The initial condition is given as the same values as those at Sta. 5. 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 (10), we may consider the quasi-steady state is established in each observation time.

4. Results and Discussion

Comparisons of calculations with observations are shown in Fig 5. Calculated chlorophyll *a* concentrations reproduce well the observed ones for the upper and lower layers. Calculation results show good agreement with the observations as to higher chlorophyll *a* in dry season than in wet season. This chlorophyll *a* variation is strongly associated with the variation of light intensity and water temperature, which are higher in dry season than in wet season. The variation of chlorophyll *a* concentration is not affected by DIN concentration variation.

On the other hand, observed DIN concentration is rather well reproduced by the calculation, except in 1981. This discrepancy may be caused by the insufficiency of data for load of DIN each year, that is, only averaged DIN load

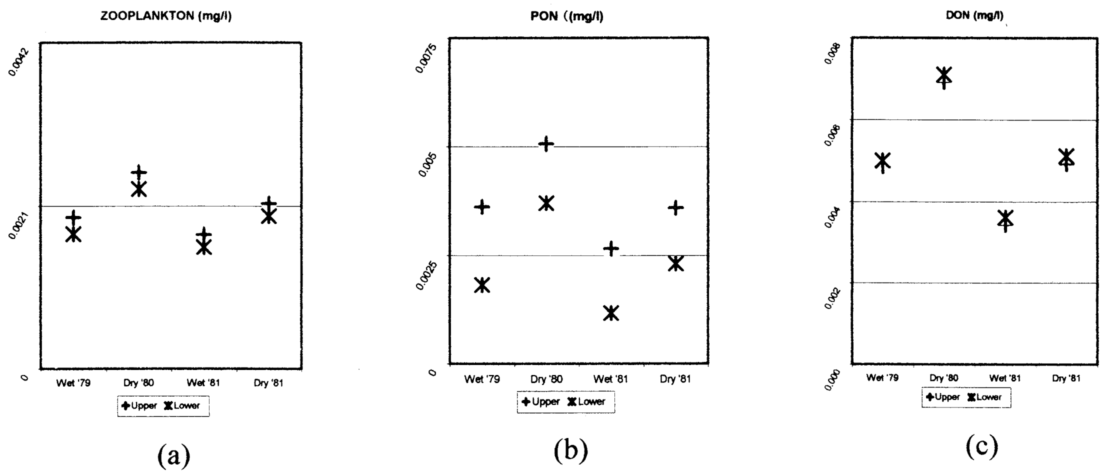

Fig. 6. Results of calculated Zooplankton, PON and DON concentrations in Banten Bay.

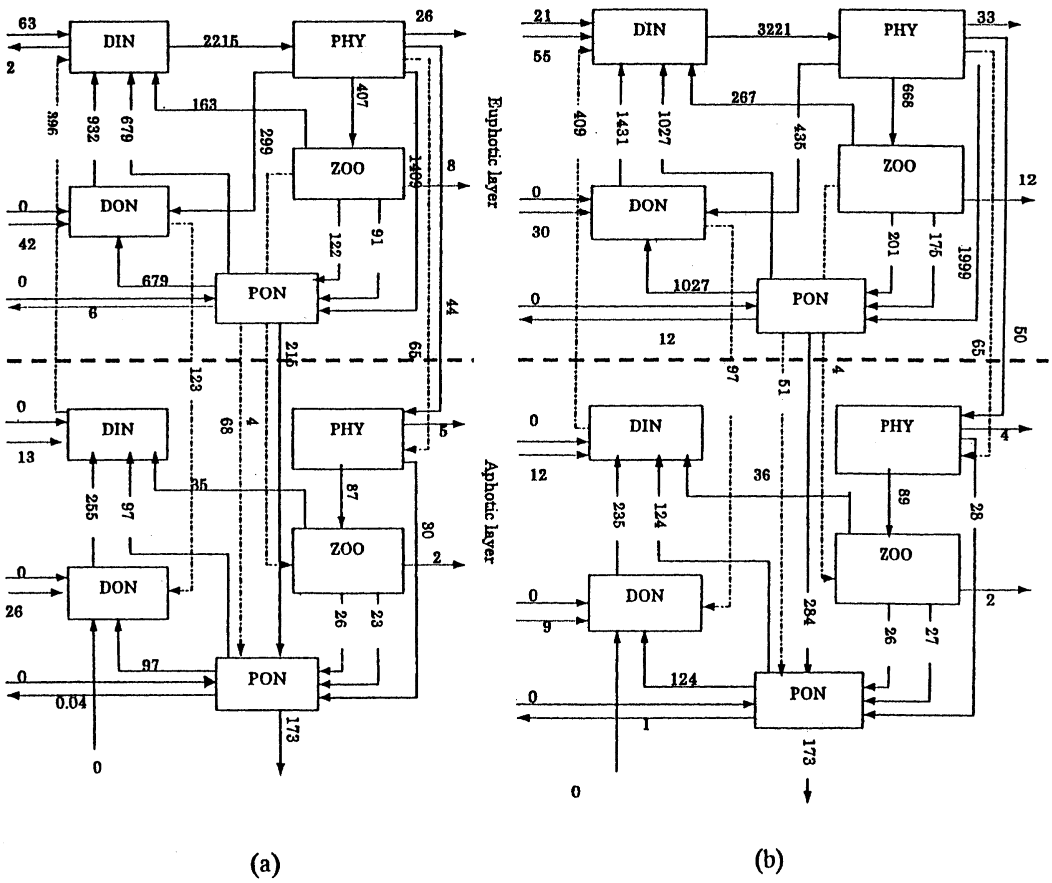

Fig. 7. Nitrogen cycling in December 1979 (wet season) (a) and June 1980 (dry season) (b) in Banten Bay (unit in kg/day)

Table 2. Comparison of average ecosystem conditions between Banten Bay and Hakata Bay.

	Central North Pacific	**Banten Bay**	**Hakata Bay (Yanagi *et al*, 1999)**
DIN (μg/l)	1.90 (Eppley *et al*, 1973)	1.68	243
DIP(μg/l)	1.57 (Eppley *et al*, 1973)	2.17	8.00
Chlorophyl-*a*(μg/l)	0.097 (Eppley *et al*, 1973)	0.808	2.32
New Prod. / Regenerated prod.	0.0475 (Eppley *et al*, 1979)	0.196	1.07
Transfer Efficiency	10.0 %(open ocean) Ryther, 1969	19.6 %	20.0 %

data are given in this model though it has a year-to-year variation. Calculated DIN concentration is higher in wet season than in dry season, because we assume the load from river is much more in wet season than in dry season.

Figure 6 shows the variation in zooplankton, PON and DON. Generally, the concentrations of these parameters are higher in dry season than in wet season. This pattern is related to chlorophyll *a* concentration, that is, chlorophyll *a* concentration is higher in dry season than in wet season.

Beside concentration of compartments, this model can calculate nitrogen cycling. Ntrogen cycling in Banten Bay in wet season (Dec. 1979) and in dry season (June 1980) are shown in Fig. 7.(a) and (b), respectively. Nitrogen flux from DIN to phytoplankton is lower in wet season than in dry season, which is 2,215 kgN /day in wet season and 3,221 kg N/day in dry season. Such difference of fluxes is caused by higher chlorophyll *a* concentration in dry season than in wet season. And the nitrogen flux is 35 times as the inflowed DIN flux from land in wet season and 153 times in dry season. It means that the large DIN load from land does not cause directly high chlorophyll *a* concentration in Banten Bay but the recycling DIN in the bay plays the most important role for high concentration of chlorophyll *a*. From model results, we can calculate new production and regenerated production. New production, which is defined as DIN flux in the upper layer from river or rain (load) and from the lower layer by diffusion, is a little bit larger (almost the same) in wet season due to higher load 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 smaller in wet season, when the primary production is smaller, than in dry season. The ratio of new production to regenerated production is (63+396): (932+679+163) = 1: 2.6 in wet season and (21+409): (1431+1027+267) = 1:6.3, in dry season. It means that new production is smaller than regenerated production for both seasons, and ratio of regenerated production to new production is higher in dry season than in wet season. The transfer efficiency from the primary production to the secondary production is 18 % in wet season and 20 % in dry season. Transfer efficiency becomes larger in dry season than in wet season because the increase of chlorophyll *a* concentration results in an increase of grazing speed by zooplankton.

Table 2 shows the comparison of average ecosystem condition between Banten Bay and Hakata Bay (Yanagi and Onitsuka, 2000), Japan. Hakata Bay is located in mid-latitude and hyper-eutrophicated condition. DIN, DIP and chlorophyll *a* concentration in Hakata Bay are higher than in Banten Bay. The mole ratio between DIN and DIP is higher in Hakata Bay than in Banten Bay, so limiting factor in Hakata Bay is phosphate, while in Banten Bay it is nitrogen. Ratio of new production to regenerated production in Banten Bay is lower than in Hakata Bay. In Ha kata Bay, the new production is larger than regenerated production. It means load of DIN and diffusion from lower layer is large and plays the most important role in Hakata Bay, while in Banten Bay, regenerated production plays the most important role. Transfer efficiency is almost the same in both bays, because in Hakata Bay, which is under hyper-eutrophic, transfer efficiency becomes small due to that much phytoplankton remains without being grazed and the increase of phytoplankton density does not results in an increase of grazing speed by zooplankton. While in Banten Bay, chlorophyll *a* concentration is not so high compared with Hakata Bay, therefore transfer efficiency becomes small too. These results show that Banten Bay is under transition condition between oligotrophic and hyper-eutrophic (Hakata Bay) condition.

5. Conclusion

The model calculations in Banten Bay show good agreement with the observed ones as for high chlorophyll *a* concentration in dry season and low one in wet season.

Chlorophyll *a* concentration in dry season is higher than that in wet season, because water temperature and light intensity become higher in dry season than in wet season. And observed DIN concentration is also reproduced by the model calculation except in 1981. Generally, concentrations of lower trophic ecosystem compartments are higher in dry season than in wet season. From this study, we can say that Banten Bay water is strongly affected by seasonal variation.

Recycling of DIN plays the important role in the increase of chlorophyll *a* concentration. Compared with Hakata Bay, Japan which is located in mid-latitute and hyper-eutrophic, Banten Bay, which is located in tropics, is under transition condition between oligotrophic and hyper-eutrophic condition, that in, DIN, DIP and chlorophyll *a* concentrations are smaller than those in Hakata Bay and ratio of new production to regenerated production is smaller than that in Hakata Bay. Beside that, transfer efficiency is almost the same in both bays.

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