Evaluation of the Nutrient Cycle in the Seagrass Bed

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Abstract Seagrass bed plays an important role in the marine ecosystem in the estuarine area. For the purpose of conservation and management of these seagrass beds, it is necessary to know the system and the role of the seagrass. A three dimensional physical-biological model (MK-3) was modified in order to include seagrass bed and then applied to the Akkeshi Lake, which is situated at a Pacific coast of Hokkaido, in the northern part of Japan. Nitrogen and phosphorus fluxes were evaluated to investigate the role of the seagrass on the nutrient cycle. At first a simple box model was developed. We divided the lake into three boxes to estimate roughly the characteristics of the nutrient cycle based on the observed data. The box model revealed that nitrate is supplied into the lake through the physical processes i.e., river discharge, advection from outer region, and is consumed biologically inside the lake. On the other hand, phosphate is supplied from inside the lake and flows out. Second, in order to explain this different behavior of nitrate and phosphate, three dimensional physical-biological coupled model was applied to the Akkeshi Lake. The model was run under the average meteorological conditions of April for 10 days, then calcuration was continued using real time condition (wind, precipitation etc.) during 16-27th April 1996. The calcuration was carried out for two cases, one was with eelgrass and the other was without eelgrass. The case without eelgrass, nitrate and phosphate were both decreased by biological and chemical processes inside the lake. The case with eelgrass, nitrate was decreased but phosphate was produced inside the lake which was estimated by the box model. Furthermore, the eelgrass was important than phytoplankton to produce the particulate organic matter. The daily variation of chlorophyll a. and nitrate which were observed during 16-27th April 1996 couldn't be appeared in the model results although the averaged values coincided with the observed values. This may be because the effect of melting of the snow in the river discharge, its data is not included.

1. Introduction

Seagrasses have been recognized to play an important role in the nutrient budget in the coastal marine ecosystem. They usually form the dense and highly productive meadows in shallow regions in Japan. They act as a primary producer, a provider of spawning, hiding, and feeding fields for fishes and a habitat for epiphyte, and a resister for water current. For example, *Zostera marina L.* (eelgrass), which is characterized as a wide eelgrass bed over shallow sandy areas, can reach the same order of production as grasslands (Aioi,1981; Mann,1982). It can take up nutrients by leaves and by roots (Iizumi and Hattori, 1982).

Recentry, many seagrass beds are destroyed by either reclamation or coastal-protecting construction. The degree of these influence, however, has not been well-estimated because the quantitative contribution of seagrasses to the nutrient budget still remains unknown in the coastal zone of Japan.

There have been made some numerical models including seagrass ecosystem. For example, Bach(1993) made a one-dimensional general eutrophication model for coastal marine areas that had been extended to include the seasonal variations in growth of eelgrass. The model had been developed and calibrated based on data from a shallow area in the southern part of Denmark. The basic model described the growth of phytoplankton and zooplankton and nutrient dynamics. The eelgrass submodel described seasonal and regional variations in production and biomass of above and below ground parts. This model was seen to be able to describe the seasonal variations in the data material, however, we cannot see the nutrient budget in these area with this model.

A three-dimensional numerical ecosystem model was developed by Kishi and Uchiyama (1993,1995) for the quantitative management of mariculture which includes seagrass uptake of nitrogen. This model focused on the dissolved oxygen budget of bay area where the mariculture of fish, shellfish, seagrass and seaweed is carried out. Their models include seagrass and seweed as a external forcing function the biomass of which is given following the observation, and which consume nutrient from ambient water. Their models give an averaged features of ecosystem in the bay area.

Here we developed a new concept model which can follow the daily variation of the ecosystem. For this purpose, a three dimensional physical-ecological model has been developed and applied to the Akkeshi Lake, which is situated at pacific coast of Hokkaido, in the northern part of Japan(Figure 1). The nitrogen and phosphorus fluxes are evaluated based on the simulated results to investigate the role of seagrass in the nutrient budget quantitatively.

2. Model Description

This ecosystem model is developed by coupling a three-dimensional physical submodel with a biological submodel that based on nitrogen and phosphorous. The physical model is a three-dimensional free surface model (MK-3) developed as a physical submodel(Kawamiya *et al.*,1996). The biological model is ten-compartment nitrogen and phosphorous-based model. This model is

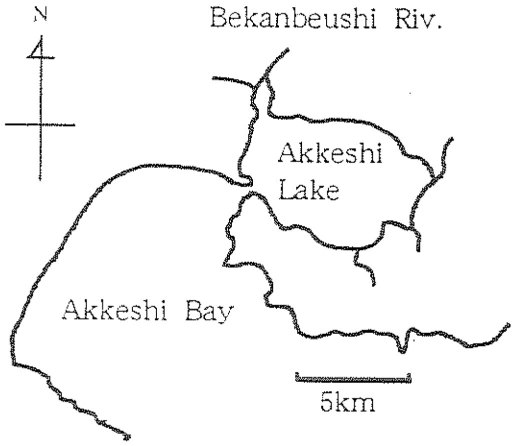

Figure 1: Schematic view of Akkeshi Bay and Akkeshi Lake, Hokkaido Prefecture, Japan.

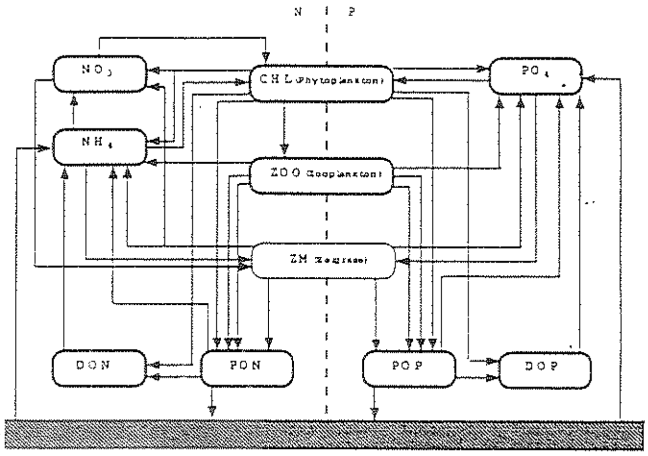

Figure 2: The material flows based on nitrogen and phosphorous.

expanded after the KKYS model(Kawamiya *et al.*,1995) which is seven-compartment nitrogen-based model, and we have been added the biological processes of eelgrass. The detailed formula of these two models were given by Kawamiya *et al.*(1996) and Kawamiya *et al.*(1995), and a brief description is given here.

2.1 Physical model

The governing equations are as follows:

$$\frac{\partial v}{\partial t} + fk \times v - g\nabla_h \zeta - \frac{g}{\rho}\int_z^0 \nabla_h \rho dz = -v\nabla_h v + \nabla_h(A_h \nabla_h v) + \frac{\partial}{\partial z}\left(A_v \frac{\partial v}{\partial z}\right) \quad (1)$$

$$\nabla_h v + \frac{\partial w}{\partial z} = 0 \quad (2)$$

$$\frac{\partial \zeta}{\partial t} = -\frac{\partial}{\partial x}\int_{-H}^{\zeta} u dz - \frac{\partial}{\partial y}\int_{-H}^{\zeta} v dz \quad (3)$$

$$\frac{\partial (T,S)}{\partial t} = -(v\nabla_h)(T,S) - w\frac{\partial (T,S)}{\partial z} + \nabla_h(K_h \nabla_h (T,S)) + \frac{\partial}{\partial z}\left(K_v \frac{\partial (T,S)}{\partial z}\right) \quad (4)$$

$$\rho = \rho(T,S) \quad (5)$$

where v is the horizontal velocity vector, w the vertical velocity, f the Coriolis parameter, g the gravity constant, ∇_h the horizontal divergence operator, ζ the sea surface elevation, H the depth, A_h and A_v are the horizontal and vertical eddy viscosities, K_h and K_v the horizontal and vertical diffusivities, and T and S the water temperature and salinity, respectively. We apply Knudsen's equation for calculation of density of sea water(eq.(5)).

We divide the water column into 8 levels vertically, and the horizontal grid size and other parameters used in the physical and biological model are shown in Table 1.

The Bekanbeushi River is considerd as the resource of fresh water to the Akkeshi Lake. The averaged river discharge is estimated from observed data(Hokkaido,1981), and the effect of the temporal precipitation is added immediately according to Takahashi(1978) by

$$Q = \frac{1}{360} C_2 R A \left(\frac{S}{A}\right)^{\frac{1}{P}} \quad (6)$$

where Q is the river discharge due to precipitation(ton/s), C_2 the outflow coefficient, R the precipitation (mm/hour), A the Bekanbeushi River basin, S the average slope of the basin, P the constant and these values are shown in Table 1, too. The vertical diffusion coefficient and viscosity coefficient are obtained from formulas by Pacanowski and Philander(1981).

2.2 Biological model

The governing equation of passive tracers is

$$\frac{\partial C}{\partial t} = -(v\nabla_h)C - w\frac{\partial C}{\partial z} + \nabla_h(K_{h_z}\nabla_h C) + \frac{\partial}{\partial z}\left(K_v \frac{\partial C}{\partial z}\right) + Q(C) \quad (7)$$

where C is the biological compartment and $Q(C)$ the biological processes. The horizontal diffusion coefficient (K_{h_z}) is shown in Table 1.

Ten biological compartments based on nitrogen and phosphorous flow are considered as phytoplankton (CHL), zooplankton (ZOO), nitrate (NO3), ammonium (NH4), phosphate (PO4), particulate organic nitrogen (PON), particulate organic phosphorous (POP), dissolved organic nitrogen (DON), dissolved organic phosphorous (DOP) and eelgrass (ZM).

The parenthesized characters are their mathematical symbols and are used in the text, too. Nitrite is included in NO3. Figure 2 shows a schematic view of the ecological model.

We assumed the eelgrass only as an external forcing, since the time evolution of eelgrass biomass is difficult

Table 1: Parameter values in the physical and ecological model.

Horizontal grid size	500	m
Time interval	20	sec.
Average Amplitude of Tide	0.5	m
Period of Tide	12	hours
A_h	7.5×10^6	cm^2/s
K_h	1.0×10^5	cm^2/s
K_{h_e}	7.5×10^5	cm^2/s
Averaged River Discharge	10	ton/s
C_2	0.5	-
A	869.1	km^2
S	0.001	-
P	4	-

Table 2: The average physical conditions in April.

Sea surface temperature	6.0	° C
Solar radiation maximum	1.29	ly/min.
River discharge	10.0	ton/s
Wind speed	0.0	m/s

to calculate based on the physical conditions and ambient nutrient concentration, and its biomass incleases twice linearly, through April to June, because eelgrass biomass in June was twice in April at Odawa Bay and Nabeta Cove (Aioi,1981). Based on the observation data of eelgrass biomass in June in Akkeshi Lake (Research and development of the coast Co. Ltd.,1991), eelgrass biomass in June is set as 1600 g/m^2(wet weight) and That in April is supposed as 800 g/m^2 (wet weight). We also assume that dry weight is quarter of wet weight and its height is 1 m. Nitrogen and phosphorous concentrations in eelgrass are converted using the C:dry weight ratio of 0.4(by weight; Mukai *et.al.*,1979), C:N ratio of 15(Aioi and Mukai,1980) and N:P ratio of 18(Atkinson and Smith,1983).

Biological processes related with eelgrass are as follows;

Photosysthesis: The uptake by leaves is taken into consideraion as a photosynthesis of eelgrass, because we don't include the benthic ecosystem in our model. Nitrogen uptake by eelgrass leaves is set as a linear function with the ambient nutrient concentration following to Short and McRoy(1984). We applied the Michaelis-Menten equation for *Thalassia hemprichii* by Stapel *et al.*(1996) on the phosphate uptake by eelgrass leaves, because we don't have the data.

Decrease: The decrease of eelgrass is separated into two parts, depending on depth and temperature(Bach,1993). The part depending on depth is supposed as mortality of eelgrass, and the other is respiration.

First physical-biological coupled model was run for ten days under the average physical conditions in April in order to get a steady state, secondary it was run using the actual boundary conditions (solar radiation, sea surface temperature, wind stress and precipitation) from 11th April to 27th April 1996. The case studies with and without eelgrass were carried out in order to discuss the role of eelgrass on the material budget in the lake.

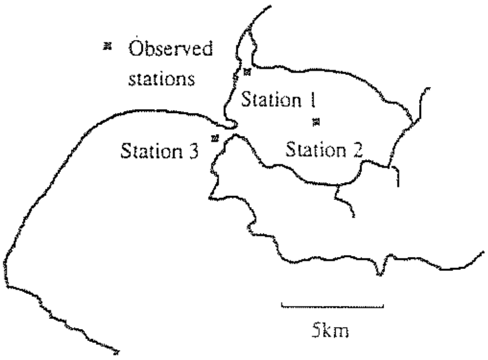

Figure 3: Observed stations in Akkeshi lake from 15 to 26 April 1996.

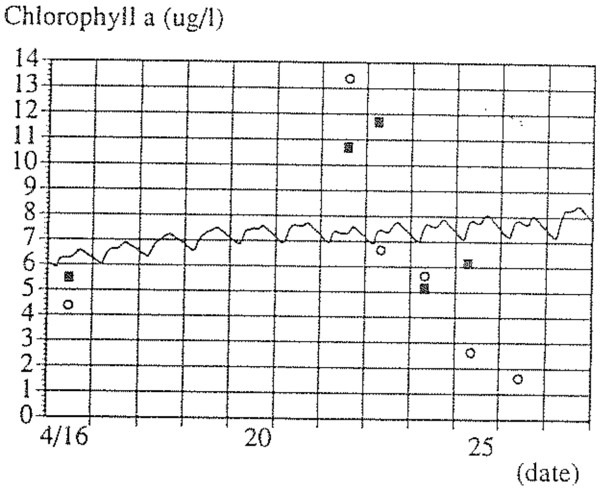

Figure 4: Time-dependent values of chlorophyll a obtained by the model (solid line) and observations (surface, circles and 1 m depth, boxes).

3. Observed Data

In Akkeshi Lake we collected samples eight times from 15th to 26th April 1996. Water temperature, salinity, chlorophyll a, nitrate, phosphate and PON concentration were analysed once a day at 3 stations shown in Figure 3. Water samples were collected at 0 m and 1 m depth at Stations 1 and 2, and five samples (0,1,2,3,5,7.5 m depth) at Station 3. At each layers, temperature and salinity were measured by T-S meter (Model 33 S-C-T meter, YSI). Chlorophyll a was determined fluorometrically with a Turner Designs 10R by using N,N-Dimethylformamide extraction method. Nutrient was measured by Technicon Auto Analyser II with DISMIC-25 (0.45 μm diameter) filtered sea water which was flozen immediately after sampling. PON was analyzed by Dr.H.Iizumi at Hokkaido National Fisheries Research Institute.

Furthermore, at the mouth of Bekanbeushi River, we observed water temperature, nitrate and phosphate concentration 4 times during that period.

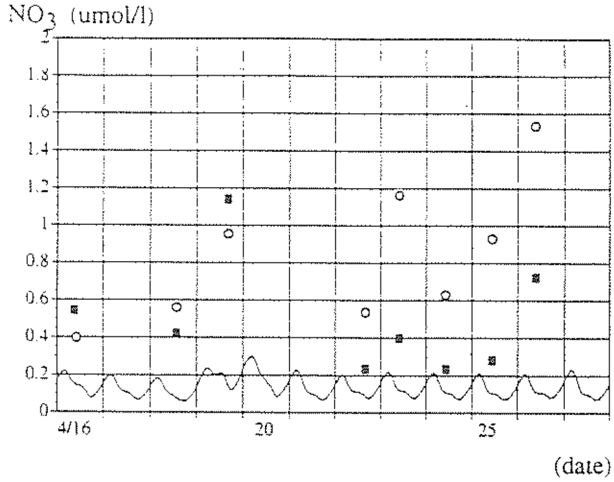

Figure 5: Time-dependent values of nitrate obtained by the model (solid line) and observations (surface, circles and 1 m depth, boxes).

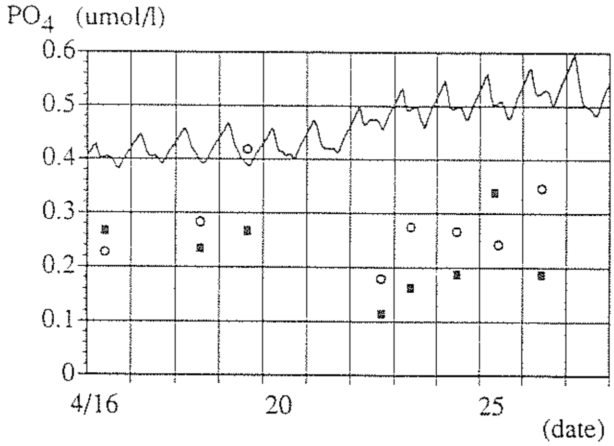

Figure 6: Time-dependent values of phosphate obtained by the model (solid line) and observations (surface, circles and 1 m depth, boxes).

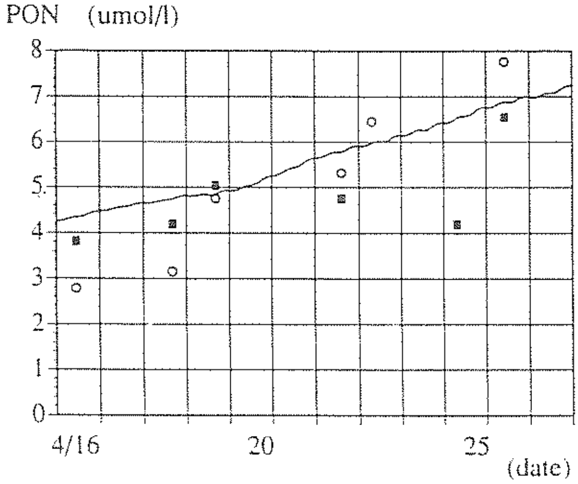

Figure 7: Time-dependent values of PON obtained by the model (solid line) and observations (surface, circles and 1 m depth, boxes).

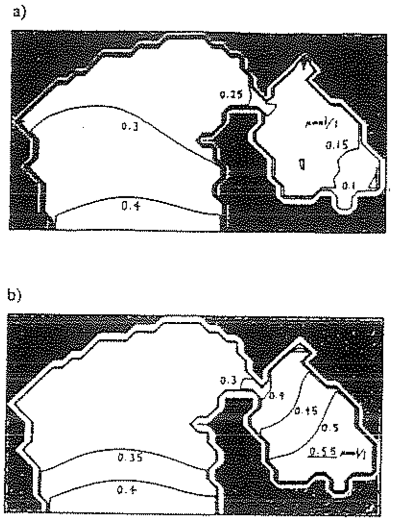

Figure 8: Simulated horizontal distribution of phosphate, (a)without eelgrass and (b)with eelgrass.

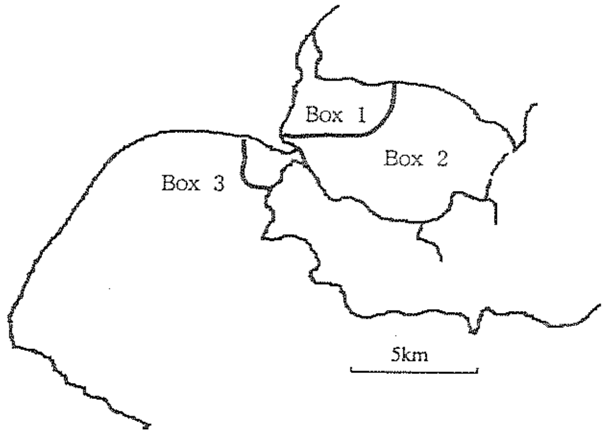

Figure 9: Devided three areas of Akkeshi lake; riverine, estuarine and marine area.

4. Results and Discussion

4.1 Time dependent features at station 2

Time series data using a coupled model at the point corresponding to upper layer of Station 2 were described in Figures 4-7 together with observed data. The magnitude of the concentrations show a good agreement with observed data although simulation cannot follow a detailed daily fluctuation. Especially the sudden inclease of chlorophyll a on 22nd April cannot be followed by simulation. Snow fall was observed from 18-19th April, however, the effect of melted snow is not considered in this model. This is one possibility for the explanation of descrepacy.

4.2 Horizontal distribution

We can see the difference between the case without eelgrass and the case with eelgrass of horizontal distribution especially in phosphate(Figure 8).

Table 3: Nutrient flux without eelgrass in Box 2.(mol/day)

	NO_3	NH_4	PO_4
Advection	172	498	353
P.plankton Photosynthesis	-10700	-67500	-7810
P.plankton Respiration	1450	9640	1110
Nitrification	1060	-1060	-
Nutrient Release	-	35300	3530
Decomposition of DOM	-	10500	1050
Decomposition of POM	-	11100	1110
Excretion by Zooplankton	-	2320	232
Sum of Other Processes	-8170	-2320	-845

Table 4: Nutrient flux with eelgrass in Box 2.(mol/day)

	NO_3	NH_4	PO_4
Advection	202	460	298
P.plankton Photosynthesis	-6040	-81200	-8730
P.plankton Respiration	764	10800	1150
Nitrification	1390	-1390	-
Nutrient Release	-	62700	5100
Decomposition of DOM	-	12300	1160
Decomposition of POM	-	19200	1580
Excretion by Zooplankton	-	2330	233
Eelgrass Photosynthesis	-9140	-28300	-125
Eelgrass Respiration	6230	6230	692
Sum of Other Processes	-6790	2560	1070

Based upon the observed salinity data in Akkeshi Lake by Iizumi *et al.*(1995), it is easy to clasify the lake into three region, i.e., riverine (Box 1 hereafter), estuarine (Box 2 hereafter) and marine area (Box 3 hereafter)(Figure 9).

4.3 Inflow and Outflow of nutrient in Akkeshi Lake

All biological and physical terms were integrated in the box. All processes in Box 2 were averaged during 16th April and 25th April and indicated in Tables 3 and 4. In these tables, the item of "Sum of Other Processes" indicates the sum of all terms of biological and chemical processes.

In the case without eelgrass, the sum of other processes are negative in all nutrient (NO3, NH4 and PO4) budgets, i.e., all nutrient are consumed in the Box 2 especially through photosynthesis by phytoplankton. On the other hand, in the case with eelgrass, the sign change to positive in NH4 and PO4. This is mainly caused by nutrient release from sediment.

If production by phytoplankton using ammonium is named 'reproduction' and that using nitrate is named 'new production', f-ratio is decided as division of reproduction by total production. The f-ratio in the case with eelgrass (0.07) is half of that in the case without eelgrass (0.14). This result shows that the nitrogen reproduction is accelerated by the eelgrass.

Figure 10 shows the simulated nutrient flow in Box 2 during one day of 23rd April with eelgrass. This figure supports the above discussion.

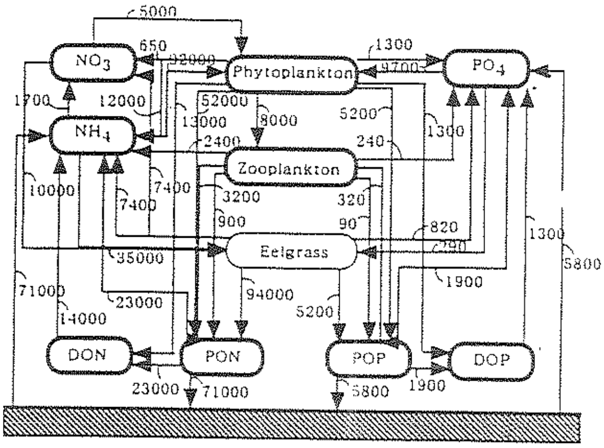

Figure 10: Nutrient flow with eelgrass.

The effect of the role of eelgrass in the estuarine ecosystem have been thought as large, but few people said so quantitatively.

The nutrient uptake of phytoplankton and eelgrass show little competition. In the case with eelgrass, though eelgrass uptake nutrient, reproduction of nutrient is accelerated by the effect of eelgrass.

5. Acknowledgements

We would like to thank Prof. H.Mukai of Akkeshi Marine Biological Station of Hokkaido University and Dr. H.Iizumi of Hokkaido National Fisheries Research Institute for their help of our research and observation. Thanks are also given to Dr. M.Kawamiya of Center for Climate System Research(CCSR) for his help to reconstruct a three dimensional physical-biological coupled model. Dr. T.Komatsu and Dr. K.Aioi of Ocean Research Institute helped us by providing the knowledge of eelgrass.

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