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The changes from phosphorus-limitation to nitrogen-limitation by eutrophication of Lake Soyang.

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INTRODUCTION

A lot of evidences for nutrient limitation in lakes is led from experimental studies in which algal growth is stimulated by nutrient additions. Most studies of nutrient limitation in lakes identified either nitrogen or phosphorus-limitation.

Increase in loading of phosphours to lakes often cause a change in nutrient balance. Forsberg(1979,[1]), and Pick and Lean(1987,[2]) showed that TN:TP ratios are low in eutrophic lakes and high in mesotrophic and oligotrophic ones. The phytoplankton community structure changes perennially by the change of limiting nutrient through eutrophication. Cyanobacteria are the typical indicators of eutrophy, which bloom with affluent phosphorus supply and low N/P ratio [3],[4]. Schindler(1977,[5]) suggested that when the loading ratio of TN:TP drops, nitrogen fixing phytoplankton may predominate. Nitrogen limitation may favour organisms capable of N_2 fixation. Nitrogen fixing ability of cyanobacteria and their preference to warm temperature enables them to flourish in nitrogen-depleted and phosphorus-rich warm waters[6].

Lake Soyang was well-known as a clear lake in the early years of impoundment. However, some symptoms have been observed which indicates eutrophication, such as the increase in chlorophyll a concentration[7], and the advent of anoxic layer[8]. Phytoplankton community of Lake Soyang has received attention because of the local bloom of a dinoflagellate, *Peridinium bipes*, occuring in warm seasons regularly every year[9],[10]. However, it was replaced with a blue-green alga, *Anabaena* sp. in late summer of 1986. After the first advent the period of cyanobacteria dominance showed increasing tendency year by year until 1990[11].

This investigation was made in order to determine limiting nutrients of phytoplankton in Lake Soyang. We examined the algal growth by nutrient addition experiment in the laboratory. The concentration of Chl.a, TP, NO_3-N, and NO_3-N/TP ratios were measured in Lake Soyang.

METHODS

Two species of unicellar algae were employed for the experiments; *Selenastrum capricornutum*, and *Senedesmus brasiliensis*. The growth medium was made according to Miller *et al*[12]. Lake water samples were quickly thawed and filtered with the membrane filter paper(0.2μm). Filtrate was autoclaved in flasks, and inoculated with pure culture of the test algae. Incubation time was about 3 weeks in the examination of 1985, and 1 week in 1992. Temperature was 24±2℃, and illumination was 200~300 $\mu E/m^2/sec$. Culture flasks was shaken three times each day manually. The growth of the algae were measured by measuring absorbance(680nm) by a spectrophotometer(model 20) in 1985. In 1992 in vivo fluorescence (680nm) was measured by a fluorescence spectrophotometer(Perkin Elmer LS3 model). Algal growth model parameters, k and r, were computed by fitting to the sigmoid growth model as followed equation[13]:

$$N = \frac{k}{(1+e^{(\ln((k-No)/No)-rt)})}$$

where N is the number of individuals, No is the number of initial individuals. k is the carrying capacity, r is the growth rate , and t is the time. Parameters were determined by the least square method of non-linear regression (Sigmaplot). Nutrients were analyzed according to Standard Methods[14]. Phosphate concentration were determined by the ascorbic acid method and nitrate was determined by the cadmium reduction method.

RESULTS AND DISCUSSION

From the results of algal assay, it can be concluded that the nutrient limitation changed from phosphorus-limitation in 1985(Fig. 1; Table 1) to nitrogen-limitation in 1992(Fig. 2, 3; Table 2), which is thought to be due to eutrophication of Lake Soyang. The most convincing evidence for eutrophication of Lake Soyang is revealed in the seasonal succession of phytoplankton and the increase of phosphorus concentration[11]. The phytoplankton community of Lake Soyang was dominated by diatoms of the species *Asterionella* and dinoflagellate of the species *Peridinium* throghout 1985-1986, but after the first development in 1986, cyanobacteria showed increasing dominancy year by year(Fig. 4).

The development and expansion of the blue-green algal blooms and the change of nutrient limitation in Lake Soyang implies that eutrophication is proceeding. When judged the TP level in 1990 and the US EPA standard(1976,[15]), the trophic status of Lake Soyang can be classified to be meso-eutrophy. Concentration of total phosphorus in Lake Soyang increased year by year from 5~6 μgP/l in 1985 to 20 μgP/l in 1992(Fig. 5), increasing algal biomass.

Lake Soyang has two major sources of phosphorus. The first is the natural loading from watershed. Because the watershed of Lake Soyang is sparcely populated, human release of phosphorus is negligible and most of watershed-origin phosphorus comes from the forest and livestocks[16]. The second source is the netcage-type fishfarms constructed within the lake. Phosphorus in the fish feed is released into water through excretion in the form of dissolved phosphate and feces[17]. Major cause of recent increasing in TP loading is considered to be provided by the enlargement of fishfarms within the lake[10]. The loading from the watershed and fishfarms in Lake Soyang were calculated to be 104 and 48 tP/yr, respectively[16]. Both combined, the phosphorus loading of Lake Soyang far exceeded the critical loading for eutrophication[18].

The seasonal variations of nitrate in Lake Soyang shows that nitrate nitrogen is affluent, above 0.5 mgN/l all the year(Fig. 6), though the NO_3-N:TP ratio decreased from 100 in 1985 to 25 in 1992(Fig. 7). The decrease of NO_3-N:TP ratio in Lake Soyang was associated with the increase in P supply rather than decrease of the NO_3-N concentration.

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Table. 1. The logistic growth model parameters of algal assay with *Selenastrum capricoruntum* in 1985. C: Control lake water, +N: Nitrogen(0.5mgN/l), +P: Phosphorus (0.05mgP/l), K: carrying capacity(in fluorescence unit), r: intrinsic rate of growth(day^{-1})

Date	Medium	Parameter	
		K	r
May	C	0.01	0.010
	+N	0.01	0.011
	+P	0.06	0.020
	+N+P	0.06	0.017
June	C	0.01	0.001
	+N	0.01	0.002
	+P	0.10	0.025
	+N+P	0.09	0.025
July	C	0.07	0.008
	+N	0.05	0.006
	+P	0.13	0.017
	+N+P	0.15	0.005

Table. 2. The logistic growth model parameters of algal assay with *Selenastrum capricoruntum* and *Scenedesmus brasiliensis* in 1992. C: Control lake water, +N: Nitrogen (0.5mgN/l), +P: Phosphorus(0.05mgP/l), K: carrying capacity (in fluorescence unit), r: intrinsic rate of growth(day^{-1})

Date	Species	Medium	Parameter K	Parameter r
Jun	*Selenastrum capricoruntum*	C	0.78	0.055
		+N	1.33	0.044
		+P	0.80	0.049
		+N+P	1.70	0.034
	Scenedesmus brasiliensis	C	1.32	0.043
		+N	1.90	0.049
		+P	1.32	0.051
		+N+P	1.85	0.044
July	*Selenastrum capricoruntum*	C	0.77	0.073
		+N	1.48	0.062
		+P	0.81	0.050
		+N+P	1.72	0.043
	Scenedesmus brasiliensis	C	1.11	0.063
		+N	1.36	0.090
		+P	0.96	0.048
		+N+P	1.43	0.065
August	*Selenastrum capricoruntum*	C	1.00	0.052
		+N	1.40	0.042
		+P	1.00	0.061
		+N+P	1.70	0.023
	Scenedesmus brasiliensis	C	1.10	0.065
		+N	1.50	0.062
		+P	1.20	0.051
		+N+P	1.50	0.062

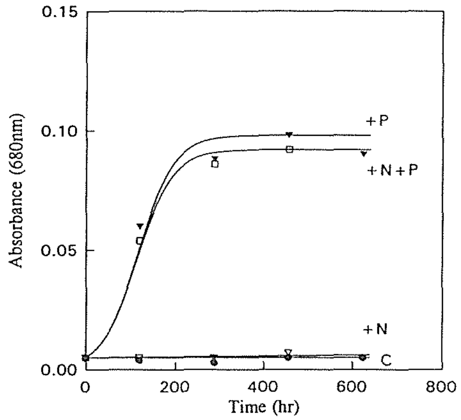

Fig. 1. The effects of nutrients addition on the growth of *Selenastrum capricornutum* in the algal assay with filtered surface water of Lake Soyang in July 1985. C: filtered lake water control, +N: +0.5mgN/l, +P: +0.05mgP/l.

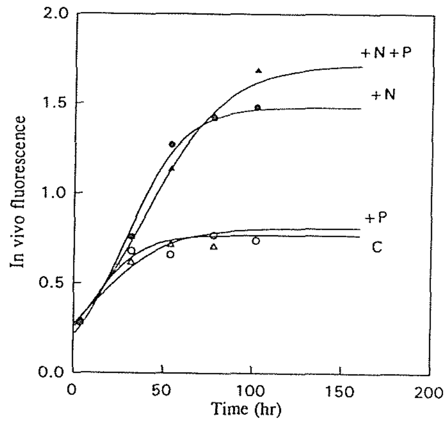

Fig. 2. The effects of nutrients addition on the growth of *Selenastrum capricornutum* in the algal assay with filtered surface water of Lake Soyang in July 1992. C: filtered lake water control, +N: +0.5mgN/l, +P: +0.05mgP/l.

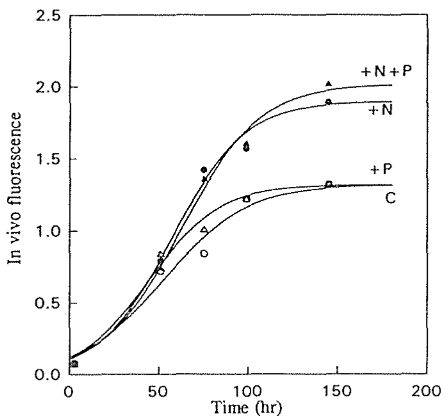

Fig. 3. The effects of nutrients addition on the growth of *Scenedesmus brasiliensis* in the algal assay with filtered surface water of Lake Soyang in Jun 1992. C: filtered lake water control, +N: +0.5mgN/l, +P: +0.05mgP/l.

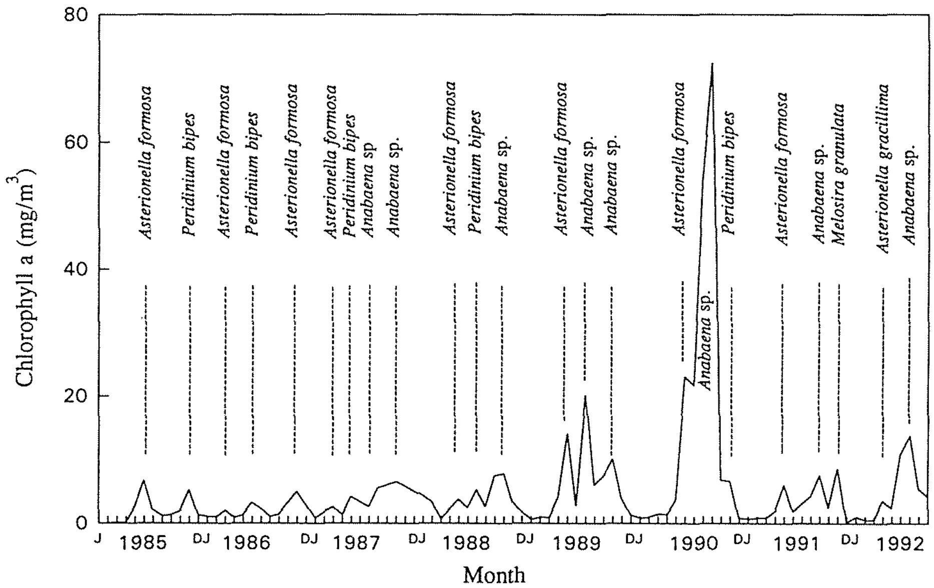

Fig. 4. The monthly variations of chlorophyll a concentration and the dominant phytoplankton in Lake Soyang.

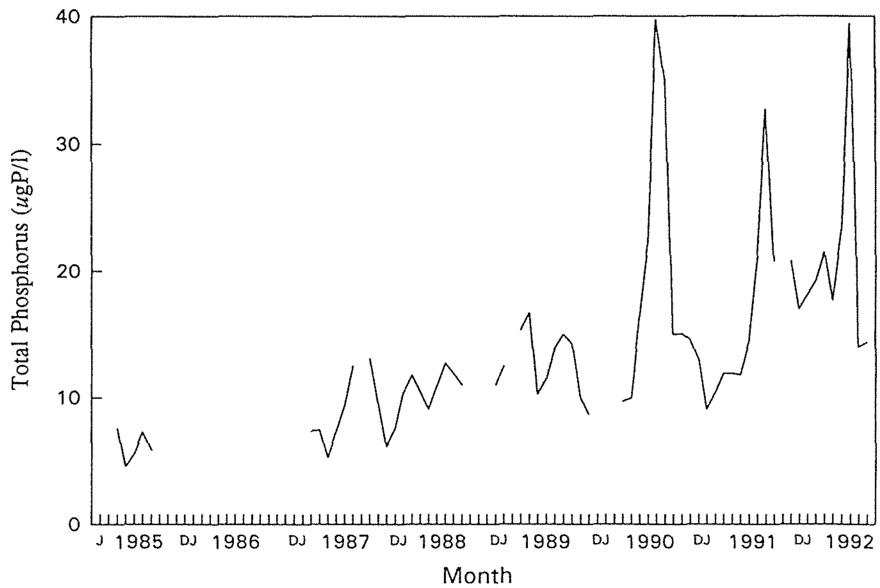

Fig. 5. The monthly variations of total phosphorus concentration in Lake Soyang (average of 0, 2, 5m).

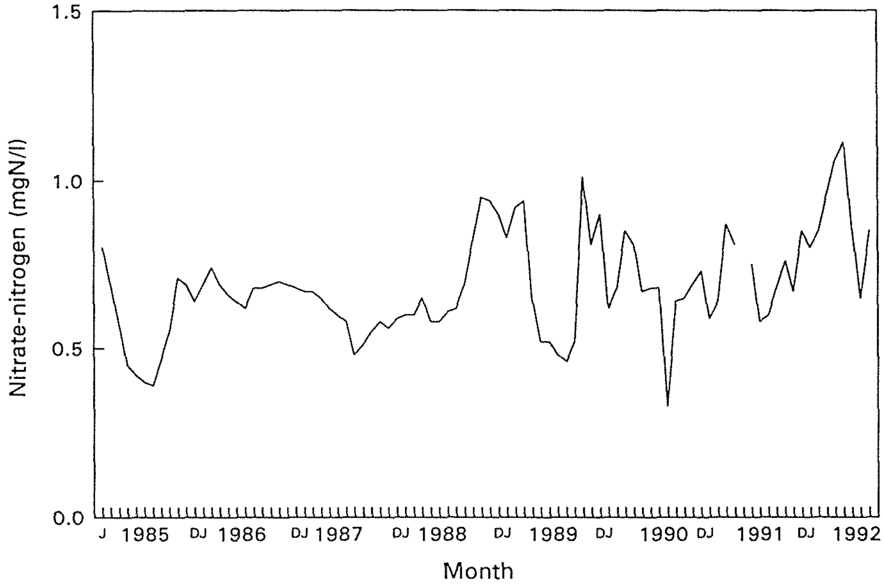

Fig. 6. The monthly variations of nitrate-nitrogen concentration in Lake Soyang (average of 0, 2, 5m).

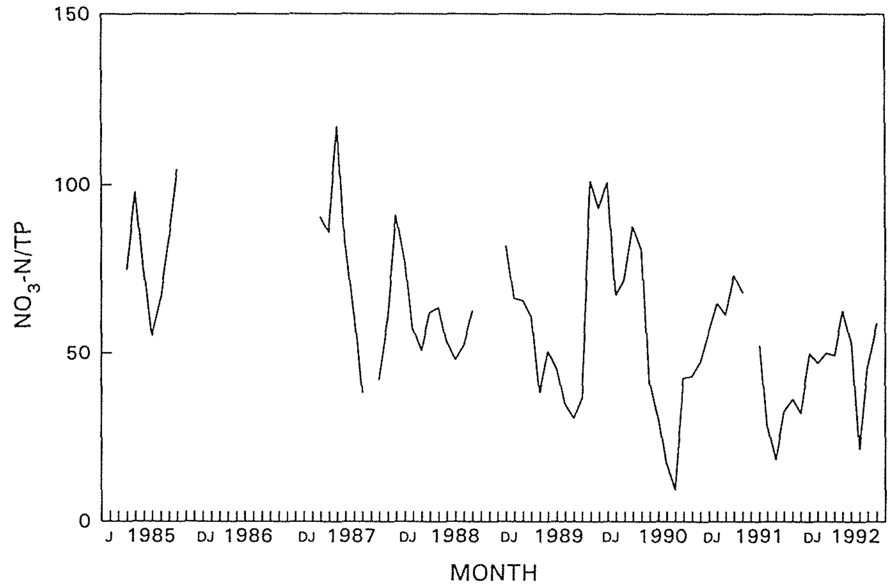

Fig. 7. The monthly variations of nitrate-nitrogen/total phosphorus weight ratio in Lake Soyang (average of 0, 2, 5m).