PERSPECTIVES OF WATER QUALITY IMPROVEMENT BY AQUATIC MACROPHYTES AS NUTRIENT SINK IN THE LAKE PALDANGHO, KOREA

Kim, Joon-Ho and Cho, Kang-Hyun

Dept. of Botany, Seoul Nat'l University, Seoul 151-742, Korea

ABSTRACT

Improvement of water quality by aquatic macrophytes was studied at the Lake Paldangho, a reservoir supplying the service water for 15 million inhabitants in the Capital of Korea.

Annual production of aboveground of emergent plants having 1800 g DW/m^2 for *Typha angustata* and 1700g DW/m^2 for *Zizania latifolia*, are 15- to 30-folds as large as those of submersed plants having 110 g DW/m^2 for *Ceratophyllum demersum* and 60 g DW/m^2 for *Hydrilla verticillata*.

Although concentrations of nitrogen and phosphorus in mg per g dry matter of emergent plants are small as a half of those of submersed ones, standing nutrients in g per m^2 of the former are 8- to 9-folds as large as that of the latter because of large production. Annual return of nutrients from the litters are also more in emergent plants than in submersed one.

In the whole Lake the uptake amounts by macrophyte (sink) are 30.3 ton of nitrogen and 4.9 ton of phosphorus, and the return amounts from the litter (source) are 18.5 ton of nitrogen and 4.3 ton of phosphorus. Difference between the sink and the source, 11.8 ton for nitrogen and 0.6 ton for phosphorus, will remain in sediment of littoral zone. If aboveground of macrohytes are weeded out on time occurring the maximum production nutrients remaining will be reduced. To increase the annual production, repetitive harvesting of *Zizania latifolia* is effective.

KEYWORD

Aquatic macrophyte, Water quality improvement, Resin bag, Litter bag, Nutrient cyclings

INTRODUCTION

The service water is supplied from an artificial lake, a dammed-up river, because there is not a natural lake in Korea. The Lake Paldangho, constructed at the junction of three rivers, i.e. north Han River, south Han River and Kyungan river, is a reservoir for a city water of 15 million inhabitants in the Capital area of Korea(Fig.1). The states of the Lake are as follows : 36.5 km^2 in average lake area; 11.3 x 10^9 ton in the annual running water; 244 x 10^6 ton in average pontage; 6.7 m in average water depth; $\pm$0.25 m in annual fluctuation range of the water level. Because both surface running water and sewage water from the basin flow into the Lake through the rivers, eutrophication has been proceeding.

Aquatic macrophytes grow vigorously along littoral zone occupying about 16% in area of the whole Lake. Out of aquatic macrophytes of which consisted 19 families and 37 species important species are *Zizania latifolia* and *Typha angustata* as emergent plant, *Nelumbo nucifera* as floating-leaved plant and *Ceratophyllum demersum* and *Hydrilla verticillata* as submersed plant(2).

NUTRIENT UPTAKES FROM SEDIMENT AND WATER

Ability of nutrient uptake by emergent plant was measured with resin bags(1). Resin bags were prepared by placing 15 g in wet mass of mixed-bed resin into 10 x 10 cm pouches made from nylon stockings, were inserted horizontally in the sediment with or without shoots of emergent plant to a depth of 5 cm for 14 days every months during growing season.

The plants with shoots absorb rapidly NH_4^+-N from sediments through roots for the whole growing season but slowly NO_3^--N for the late growing season only. Uptake of

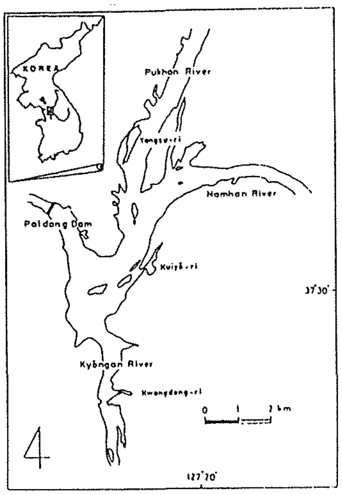

Fig. 1. Map showing Lake Paldangho.

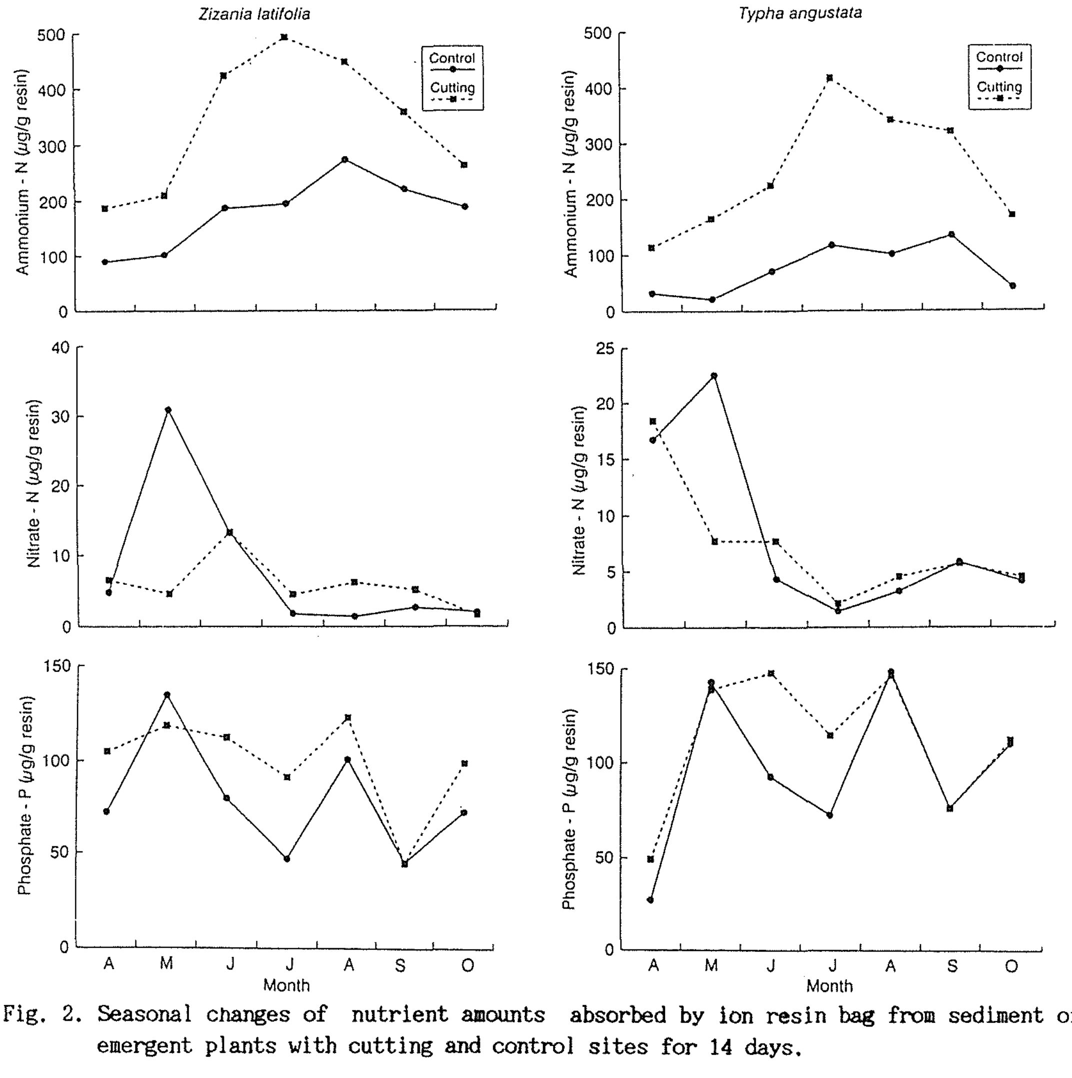

Fig. 2. Seasonal changes of nutrient amounts absorbed by ion resin bag from sediment of emergent plants with cutting and control sites for 14 days.

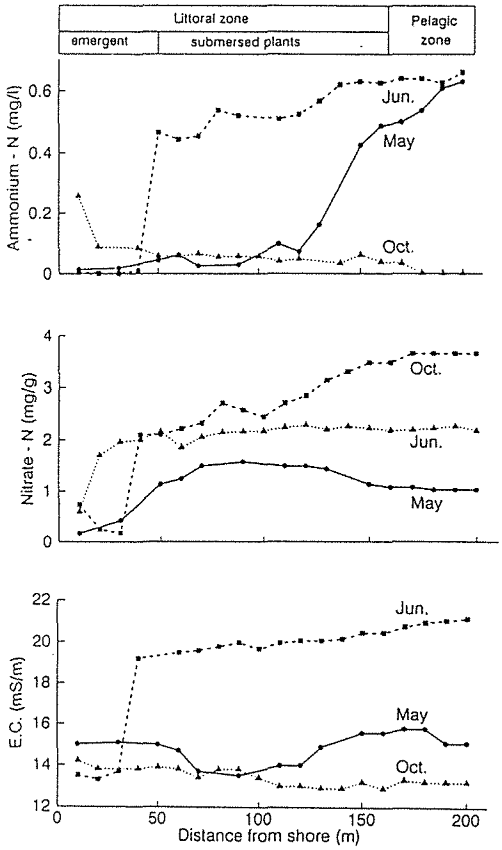

Fig. 3. Concentrations of ammonium and nitrate and electric conductivity in water along a transect from shore toward offshore.

phosphorus takes place for mid growing season(Fig.2). These results may be explained by a lower reduction potential, -100~-200 mV, of the sediment.

In order to clarify the dynamic of nutrient uptake from water by the different macrophytes, nutrient concentrations of water were determined along a transect placed from shore toward offshore in the Lake. The arrangement of the plants along the transect follows in the order, from shore to 50 m for emergent plant, from 50 m to 160 m for submersed plants and far off for pelagic zone. The growth of submersed plant is vigorous but that of emergent one is meager in May, but the reverse is true in June and all the plants decline in October. In May lower concentration of NH_4^+-N of water at emergent and submersed plant zones may be explained by considerable absorption of those plants. In June the low concentration at emergent plant zone and the opposite at submersed zone may be due to the rapid nutrient uptake by the luxuriant plants of the former and the nutrient release of the declined plants of the latter(Fig.3). In October high concentration of NH_4^+-N at emergent plant zone may be caused by the release from dead emergent plant.

In May high concentration of NO_3^--N at submersed plant zone may relate to oxidation of NH_4^+ to NO_3^- by dissolved oxygen derived from luxuriant submersed plant. In June lower concentration at emergent plant zone may be due to the uptake from sediment through roots of vigorous emergent plant. Electric conductivity of water along the transect coincides with the dynamic of cation such as NH_4^+. These

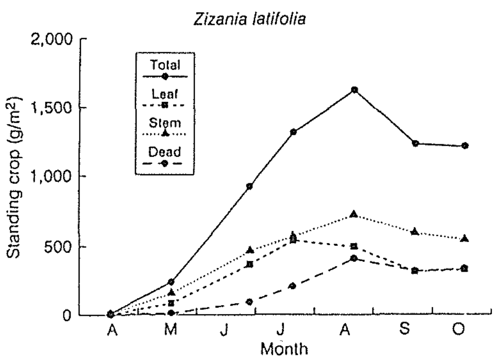

Fig. 4. Seasonal changes of standing crop of the different organs in *Zizania latifolia.*

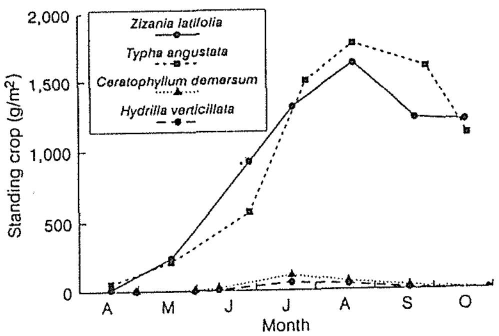

Fig. 5. Seasonal changes of standing crop of several macrophytes.

Table 1. Area occupied and annual net production of macrophytes in the Lake Paldangho

Plants	Area occupied (ha)	Annual net production (g m^{-2} yr^{-1})	Production in whole lake (ton/yr)
A. Emergent plants			
Typha angustata	60.0	1790	1074.0
Zizania latifolia	39.8	1720	684.5
Phragmites japonica	2.3	1480	34.0
Others	0.8	750	6.0
Subtotal	102.9 (38%)		1798.5 (84%)
B. Floating-leaved plants			
Nelumbo nucifera	9.4	590	55.5
Nymphoides indica	0.2	170	0.3
Subtotal	9.6 (4%)		55.8 (3%)
C. Submersed plants	154.6		
Ceratophyllum demersum		110	170.1
Hydrilla verticillata		60	92.8
Others		6	9.3
Subtotal	154.6 (58%)		272.2 (13%)
Total	267.1 (100%)		2126.5 (100%)

results show that uptake and release of nutrients by aquatic macrophytes reflect sensitively to nutrient concentrations of water in littoral zone.

ANNUAL PRODUCTION OF AQUATIC MACROPHYTES

Production of aboveground was determined by harvest method. The growth in dry weight of *Zizania latifolia* is larger in leaf blades than in stems with sheaths(Fig.4). The maximum production of aboveground of emergent plants, *Typha angustata*, *Zizania latifolia* and *Phragmites japonica*, are 1800 g DW/m^2, 1700 g DW/m^2 and 1500 g DW/m^2 in late August(Fig.5 and Table 1). Productions of these plants are larger in the Lake Paldangho than in the Lake Kasumigaura(3) in spite of the growth period reaching at the maximum production of them reduces as long as for 3 months in the former Lake(3), but similar to Biwako(5).

In submersed plants, *Ceratophyllum demersum* and *Hydrilla verticillata*, the maximum production is 110 g DW/m^2 and 60 g DW/m^2 at 0.5-1.0 m deep in the mid of July. The areas covered by the species are estimated from actual vegetation map drawn for macrophyte in the Lake, i.e. emergent plant covers on 103 ha in area(38% of the area for the whole

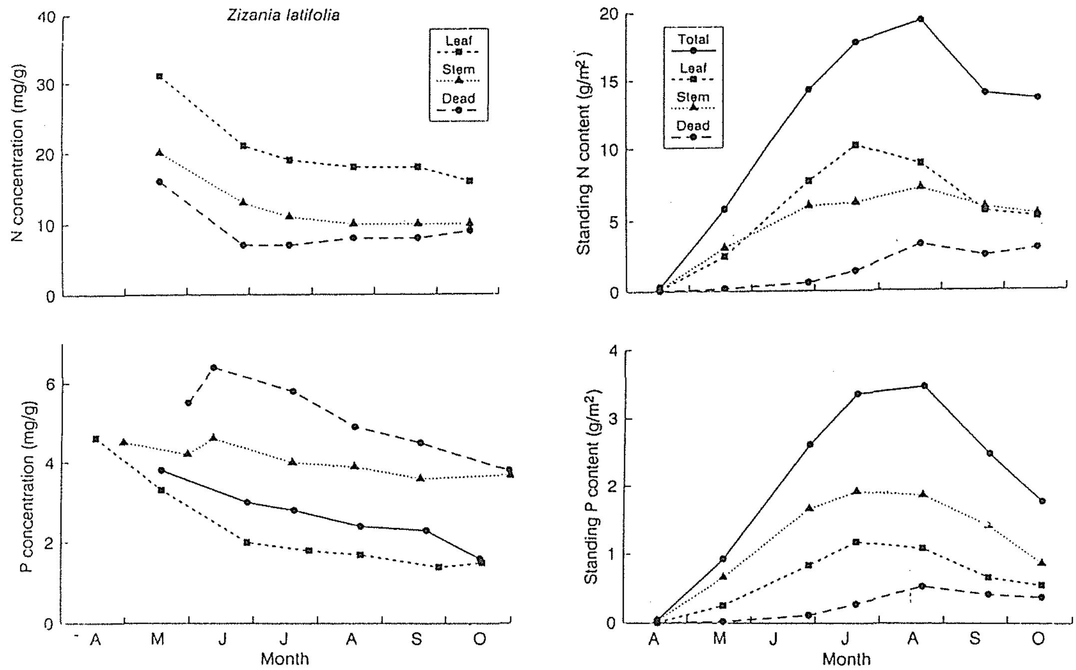

Fig. 6. Seasonal changes of concentrations and standing content for nitrogen and phosphorus in *Zizania latifolia*.

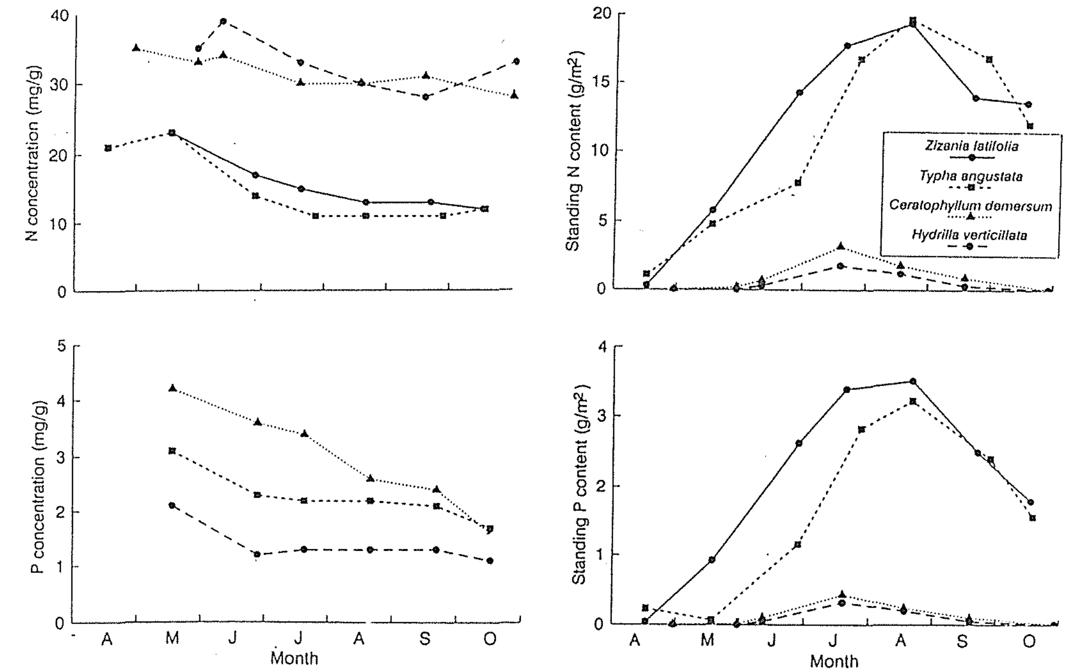

Fig. 7. Seasonal changes of concentrations and standing content for nitrogen and phosphorus in several macrophytes.

Table 2. Average concentration of nutrients in tissue and annual uptake of nutrients of macrophytes in the Lake Paldangho

Plants	Concentration in tissue (mg/g)		Annual uptake per unit area ($g\ m^{-2}\ yr^{-1}$)		Annual uptake in whole lake (ton/yr)	
	N	P	N	P	N	P
A. Emergent plants						
Typha angustata	11	1.7	19.7	3.04	11.81	1.82
Zizania latifolia	13	2.4	22.4	4.13	8.90	1.64
Phragmites japonica	12	0.9	17.8	1.33	0.41	0.03
Others	12	2.6	7.8	1.69	0.08	0.02
				Subtotal	21.20 (70%)	3.51 (72%)
B. Floating-leaved plants						
Nelumbo nucifera	17	3.1	10.3	1.83	0.94	0.17
Nymphoides indica	29	4.0	5.1	0.70	0.01	0.001
				Subtotal	0.95 (3%)	0.17 (4%)
C. Submersed plants						
Ceratophyllum demersum	30	4.0	3.3	0.44	5.10	0.68
Hydrilla verticillata	30	4.9	1.8	0.29	2.78	0.45
Others	28	3.6	1.6	0.21	0.26	0.03
				Subtotal	8.14 (27%)	1.16 (24%)
				Total	30.29 (100%)	4.84 (100%)

macrophytes), floating-leaved plant on 10 ha(4%) and submersed plants on 155 ha(58%) (Table 1). In the whole Lake annual production of macrophyte was calculated as multiplying the maximum production by the area occupied by each species on actual vegetation map. Production of the whole Lake is 2100 ton DW for the whole plants, in detail 1800 ton DW for emergent plant, 55 ton DW for floating-leaved plant and 272 ton DW for submersed plant(Table 1).

NUTRIENT SINK BY MACROPHYTES

In nutrient uptake of *Zizania latifolia*, concentrations of total-nitrogen(T-N) and phosphorus(P) in mg per g DW of live tissue decrease as season elapses(Fig.6). Concentration of T-N is higher in leaves than in stems with sheaths but the reverse is true for that of P. Standing nitrogen content in g N per m^2 increases from April to August but thereafter decreases. A similar trend is depicted in standing P except for the reverse relation between

Table 3. Comparison of decomposition rates(k) and turnover time($t_{1/2}$ and $t_{1/100}$) of ash-free dry weight(AFDW) and amounts of nitrogen and phosphorus in litters of macrophytes laid above sediments after 1 year in the Lake Paldangho

Plants	AFDW			N			P		
	k (yr^{-1})	$t_{1/2}$ (yrs)	$t_{1/100}$ (yrs)	k (yr^{-1})	$t_{1/2}$ (yrs)	$t_{1/100}$ (yrs)	k (yr^{-1})	$t_{1/2}$ (yrs)	$t_{1/100}$ (yrs)
Zizania latifolia	1.64	0.42	2.80	1.46	0.47	3.15	2.66	0.26	1.73
Typha angustata	1.10	0.63	4.21	0.44	1.58	10.51	1.57	0.44	2.93
Submersed plants	1.68	0.41	2.74	1.57	0.44	2.93	2.70	0.26	1.70

Table 4. Annual returns of nitrogen and phosphorus of aquatic macrophytes in Lake Paldangho

Plants	Annual return per unit area ($g\ m^{-2}\ yr^{-1}$)		Annual return in whole lake (ton/yr)	
	N	P	N	P
A. Emergent plants				
Typha angustata	6.98	2.41	4.19	1.45
Zizania latifolia	17.17	3.84	6.83	1.53
Phragmites japonica	10.88	1.17	0.25	0.03
Others			0.05	0.02
		Subtotal	11.32(61%)	3.03(71%)
B. Floating-leaved plants				
Nelumbo nucifera	7.70	1.70	0.72	0.16
Nymphoides indica	4.00	0.65	0.01	0.001
		Subtotal	0.73(4%)	0.16(4%)
C. Submerged plants				
Ceratophyllum demersum	2.61	0.41	4.04	0.63
Hydrilla verticillata	1.43	0.27	2.21	0.42
Others			0.20	0.03
		Subtotal	6.45(35%)	1.08(25%)
		Total	18.50(100%)	4.27(100%)

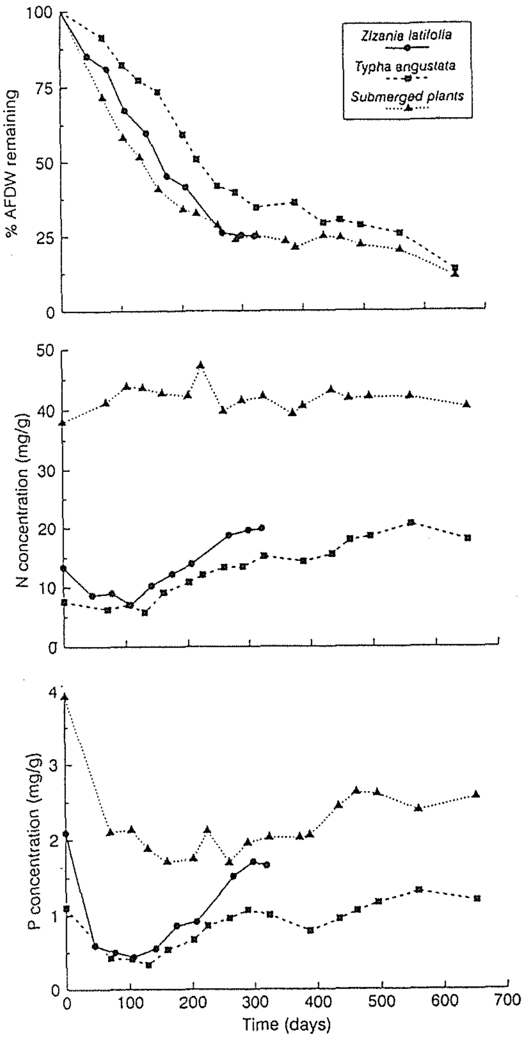

Fig. 8. Changes of ash-free dry matter and concentrations of nitrogen and phosphorus remaining in litterbags.

standing P of leaves and of stems(Fig.6).

In comparison of nutrient uptake among the different macrophytes concentrations of T-N and P of emergent plants are half of those of submersed plants(Table 2). Standing nutrients of emergent plants in August reaching the maximum content, are 8-9 folds as large as those of the maximum of submersed plant in July for T-N and P(Fig.7). Such reversal of order of the nutrient concentration and standing nutrient between emergent and submersed plant is due to a large production by the former, that is, the more the annual production is, the more the standing nutrients increase in macrophyte.

In the whole Lake the amounts of nutrients absorbed by macrophyte are 30.3 ton of T-N and 4.9 ton of P, which means that macrophytes in the Lake Paldangho play a role as a nutrient sink.

NUTRIENT SOURCE FROM MACROPHYTES

Litter bags with litters of *Zizania latifolia*, *Typha angustata* or submersed plant were laid on a bottom surface of littoral zone for 2 years. Ash-free dry matter, and concentrations of T-N and P in the litters remaining were determined on each month. Litter bag was placed on the early or late winter.

Decomposition rate(k) of the litters was calculated with exponential equation(4) on the 365th day after placing.

$$L_t = L_o e^{-kt}$$

Here L_o and L_t are the amounts of litters at initial and 365 days.

The amount of litters remaining decreases exponentially(Fig.8). *Zizania latifolia* and submersed plant showed high decomposition rate(k) and short half-life($t_{1/2}$) period of litters, but *Typha angustata* showed low decomposition rate and long half-life. The time($t_{1/100}$) taking 99% decomposition of the litter is 4.2 years for *Typha* and 2.7-2.8 years for *Zizania* and submersed plant(Table 3).

Although N concentration in litters of submersed plant continues to be high, that of emergent plant decreases to half of the initial concentration on the 100th-120th day, and then it increases. The N concentration of the former remains about 3 times larger than that of the latter. Phosphorus concentration in the litters of submersed plant decrease to 50% of the initial on the 70th day and then continues to be constant, and that of emergent plant decreases to 30-40% on the 70th day, thereafter recovers to 80-100%(Fig.8). These results suggest that the litters immersed into water release large amount of P but little T-N during the early, short period.

The amount of nutrients released from the litters was computed on basis of data of the litter bag for 1 year. Annual return amounts of N from the litters are the highest in *Zizania latifolia* with 17.2 g m^{-2} yr^{-1} and the lowest in *Hydrilla verticillata* with 1.4 g m^{-2} yr^{-1} (Table 4). In the whole Lake the annual return amounts of N and P are 18.5 ton and 4.3 ton, which means another role of macrophytes as a nutrient source. Nutrient derived from the discrapancy between the sink and the source, as much as 11.8 ton for nitrogen and 0.6 ton for phosphorus, may remain in the sediment of littoral zone for 1 year.

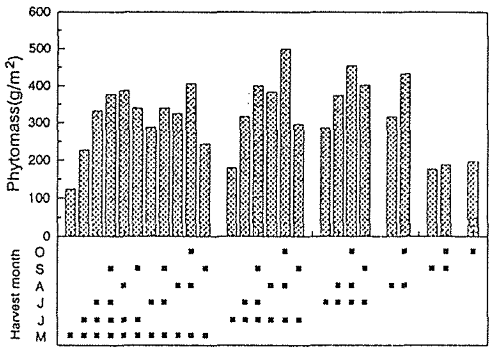

Fig. 9. Changes of phytomass produced under combinations of the numbers and time in repetitive harvests for *Zizania latifolia*.

If the source of nutrients through macrophytes was cut off, water quality will be improved. Weeding out abovegrounds of aquatic macrophytes, particularly of emergent plant with high production, from the Lake ecosystem, will be greatly effctive. The planning of weeding out has been advanced by Lake Environmental Research Laboratory, Korea. For effctive removal of nutrients, the increasing the annual production of macrophytes is studied. Repetitive harvesting of *Zizania latifolia* with controlled numbers and time increased about 40% of production(Fig.9).

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