Korean J Biol Sci 7: 289-294, 2003

Nutrient Leaching from Leaf Litter of Emergent Macrophyte (*Zizania latifolia*) and the Effects of Water Temperature on the Leaching Process

Sangkyu Park* and Kang-Hyun Cho[1]

West Sea Fisheries Research Institute, National Fisheries Research and Development Institute,
Incheon 400-420, Korea;
[1]*Department of Biological Sciences, College of Sciences, Inha University, Incheon 402-751, Korea*

Key Words:
Nutrient leaching
Litter
Macrophyte
Phosphorus
Water temperature
Zizania latifolia

To quantify nutrient loading from emergent macrophytes through leaching in the littoral zones of Paldang Reservoir, we conducted incubation experiments using leaf litter of the emergent macrophyte, *Zizania latifolia*. To separate the leaching process from microbial decay, we used $HgCl_2$ to suppress microbial activity during the experiment. We measured electric conductivity, absorbance at 280 nm, total nitrogen and dissolved inorganic nitrogen, total phosphorus and soluble reactive phosphorus, Na, K, Mg and Ca amounts in leaf litter and in water. In addition, we examined the effects of water temperature and ion concentrations of ambient water on the leaching process. A total of 6% of the initial ash- free dry mass of leaf litter was lost due to leaching during incubation (four days). Electric conductivity and A_{280} continued to increase and saturate during the incubation. To compare reaching rates of different nutrients, we fitted leaching dynamics with a hyperbolic saturation function [$Y=A\cdot X/(B+X)$]. From these fittings, we found that ratios of leaching amounts to nutrient concentration in the litter were in the order of K>Na>Mg>P>Ca>N. Leaching from leaf litter of *Z. latifolia* was dependent on water temperature while it was not related with ion concentrations in the ambient water. Our results suggest that the leaching process of nutrients, especially phosphorus, from aquatic macrophytes provides considerable contribution to the eutrophication of the Paldang Reservoir ecosystem.

Productivities of aquatic macrophytes in littoral zones of lakes and reservoirs are among the highest in the world (Westlake, 1963). Therefore, they are regarded as an important component in biogeochemistry of wetland ecosystems. Aquatic macrophytes serve as nutrient sources when their detritus are decomposed. Decomposition is defined as a process in which organic matter is converted into forms that primary producers can re-use. Decomposition includes three different processes: leaching, microbial decay and fragmentation (Webster and Benfield, 1986). The decay process usually involves microbial activities while fragmentation is a process involving mechanistic decomposition of organic matter by invertebrates (Webster and Benfield, 1986). Leaching is defined as a process in which dissolved material is produced from a particulate source when submerged in the water (Carpenter, 1980). The loss of soluble matter through leaching is particularly significant because the material is continually in contact with the water (Brinson et al., 1981). Therefore, initial rapid decomposition is generally regarded as a result of abiotic loss (leaching) of soluble components (Polunin, 1984).

Purposes of our study were 1) to quantify leaching of organic and inorganic elements from the leaf litter of an emergent macrophyte *Zizania latifolia* incubated in the water from the littoral zone of the Kyungan River which is one of the major tributaries feeding the Paldang Reservoir, 2) to investigate the effects of water temperature and ion concentration of ambient water on the leaching process and 3) to project nutrient loading of water from emergent aquatic macrophyte litter in the Paldang Reservoir ecosystem.

Materials and Methods

Preparation for leaching experiment

We used leaf litter of *Zizania latifolia*, a major emergent macrophyte in the littoral zone of the Kyungan River. Standing senescent leaves were collected in the middle

---

*To whom correspondence should be addressed.
Tel: 82-32-745-0603, Fax: 82-32-745-0549
E-mail: daphnia@hitel.net

of October and air-dried in the laboratory for two weeks. Dried leaves were cut into 3 cm pieces for easier processing. We used small nylon litterbags (11×8 cm with mesh openings of ca. 1 mm^2) containing 2 g of pre-cut leaves. The litterbag was submersed with plastic sieve in 500 ml lake water. Water was collected from the littoral zone of the Kyungan River and filtered through a 0.45 μm membrane filter (Milipore). To suppress microbial activity and separate leaching from microbial decay, $HgCl_2$ was added in the filtered lake water to a final concentration of 50 mg $HgCl_2 \cdot L^{-1}$ (McLachlan, 1971; Otsuki and Wetzel, 1974).

Leaching experiment: element changes in the litter and water

To study dynamics of macro- and micro-nutrients in addition to organic matter in the litter, we prepared a total of 32 bottles filled with the filtered reservoir water and litterbags of pre-cut leaf litter of *Z. latifolia.* We incubated these microcosms in a temperature controlled growth chamber at 20°C which is the annual mean water temperature of the Paldang Reservoir. We collected a litterbag from each of four bottles at 0, 0.5, 2, 4, 10, 24, 48 and 96 h after the immersion. The remaining water in the bottles was filtered through a 0.45 μm membrane filter (Milipore).

We analyzed electric conductivity (EC), absorbance at 280 nm, dissolved inorganic nitrogen (DIN: $NO_2^- + NO_3^- + NH_4^+$), soluble reactive phosphorus (SRP), Na, K, Ca, and Mg in the filtered water. We measured EC using a conductivity meter (YSI Model 33) and A_{280} using a spectrophotometer (Amersham Model Ultrospec 3100). Nitrate/nitrite and ammonium in the water were measured according to the hydrazine reduction method (Kamphake et al., 1967) and phenate method (APHA, 1989) while SRP in the water was measured using the ascorbic acid method (APHA, 1989). The amounts of Na, K, Mg and Ca in the water were measured using an atomic absorption spectrometer (Perkin Elmer Model 3110).

The plant samples collected from litterbags were dried at 105°C in a drying oven, weighed and ground with a laboratory mill for further chemical analysis. We measured ash-free dry mass (AFDM), total nitrogen (TN), total phosphorus (TP), Na, K, Mg, and Ca in the litter samples. AFDM was determined from ash contents of the samples measured after combustion for 4 hours at 550°C in a furnace. The ground samples were digested with the mixed acid solution (Se 0.42 g, Li_2SO_4 14 g, H_2O_2 350 ml and H_2SO_4 420 ml) for the analysis of nutrients (Allen et al., 1986). We measured TN using the Kjeldahl method, TP using the ascorbic acid method (APHA, 1989), and Na, K, Mg, and Ca using an atomic absorption spectrometer (Perkin Elmer Model 3110).

Table 1. Nutrient leaching from macrophyte litter

Nutrient	A (μmol g $AFDM^{-1}$)	B (h)	r^2	% Leaching
N	20.1	6.6	0.93^{***}	2.0
P	11.3	5.8	0.74^{***}	22.1
K	103.4	1.9	0.87^{***}	80.0
Na	16.8	2.3	0.60^{***}	72.1
Mg	20.2	4.3	0.60^{***}	35.0
Ca	–	–	–	3.1

A; Estimated saturation concentration, B; half-saturation time from linear transformation of Michaelis-Menten equation [$Y=A \cdot X/(B+X)$], and the percentages of A to the initial total amounts of elements in the leaf litter. For the calcium, the regression equation was not fitted and Ca concentration at the end of the experiment was used for A. The sample number was 24 for the determination of r^2. AFTM stands for ash-free dry mass. $^{***}p < 0.001$

From linear transformations of the Michaelis-Menton equation, we estimated saturation concentration and half saturation time for each element in the leaching experiment (Table 1). For linear transformation of the Michaelis-Menton equation

$$Y = A \cdot X / (B+X)$$

we replaced 1/Y by y′ and 1/X by x′

$$y' = B/A \cdot x' + 1/A$$

From the slopes and y′ intercepts of regressed lines from 1/Y and 1/X, we could estimate A (saturation amount) and B (half-saturation time).

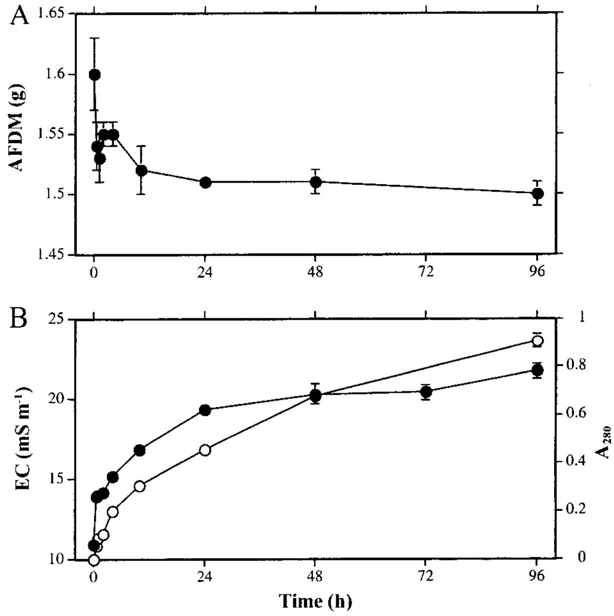

Fig. 1. Changes of ash free dry mass (AFDM) of *Zizania latifolia* leaf litter (A) and electric conductivity (EC, closed circles) and absorbance at 280 nm (open circles) in the water during the incubation experiment (B). Bars indicate standard deviations (n=4).

Factors affecting the leaching process

To examine our hypothesis that leaching would be influenced by water temperature and ambient ion concentrations, we conducted two leaching experiments in which we manipulated those factors. To keep the experiments simple, we used EC as an index for leaching because EC represents total ion activity (APHA, 1989). For temperature effects, we placed our experimental units in temperature controlled growth chambers set at several different temperatures (7, 20, 30, and 40°C). Undiluted filtered lake water was used for incubation and samples were collected 0, 3, 5, 9, 22, 49, 70, and 95 h after immersion in the water ($n=3$). For ambient ion concentration effects, we prepared undiluted, 1:1 diluted (filtered lake water : double deionized water (DDW)), 1:3 diluted and DDW only. All experimental units were incubated at 20°C in a growth chamber.

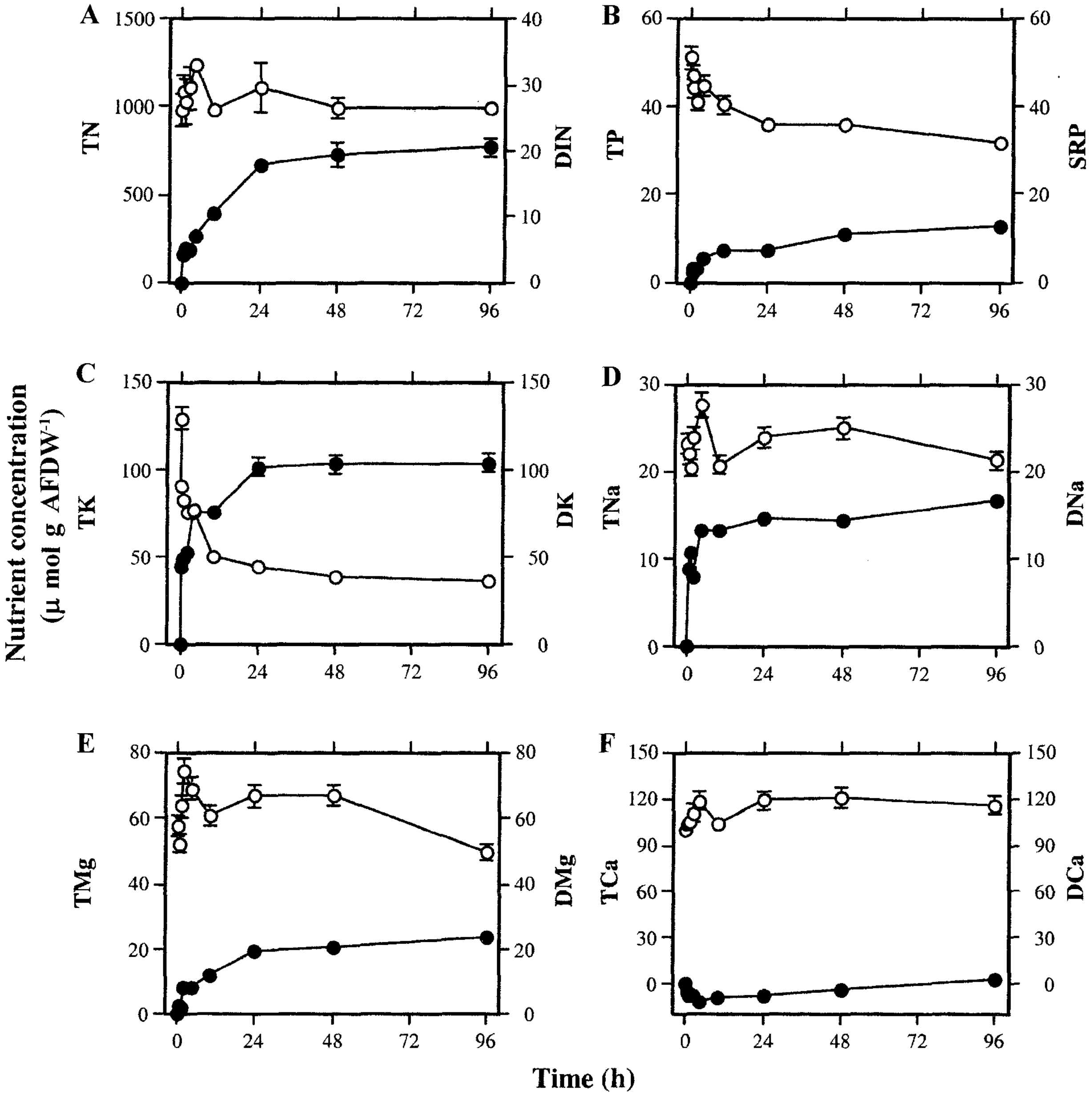

Fig. 2. Nutrient changes in leaf litter. A, Changes of total nitrogen (TN, ○) in leaf litter and dissolved inorganic nitrogen (DIN, ●) in the water. B, Total phosphorus (TP) and soluble reactive phosphorus (SRP). C, Total K (TK) and dissolved K (DK). D, Total Na (TNa) and dissolved Na (DNa). E. Total Mg (TMg) and dissolved Mg (DMg). F, Total Ca (TCa) and dissolved Ca (DCa). Bars indicate standard deviations (n=4).

Results

Changes of nutrients in the litter and in the ambient water

Decomposition with little biological activity showed significant changes in AFDM of the leaf litter, the EC and the A_{280} in the ambient water (Fig. 1). AFDM of the leaf litter decreased by 6.25% from average of 1.6 g to 1.5 g in 4 d. At the same time, EC, the index of total ions, approximately doubled from average of 10.9 to 21.8 mS m^{-1}. Absorbance at 280 nm, the index of dissolved organic matter (DOM) (Godshalk and Wetzel, 1978), dramatically increased from 0 to 0.91 during the leaching experiment.

With the changes of nutrient concentration in the leaf litter during the incubation (open circles in the Fig. 2), phosphorus and K exhibited dramatic decrease while decrease in nitrogen and other major elements such as Na, Mg and Ca were not detected (Fig. 2). Dissolved forms of nutrients in the medium water (closed circles in Fig. 2) such as phosphorus (SRP), nitrogen (DIN), K, Na, Mg increased markedly except for Ca.

Regarding the leaching rate, half saturation time for most elements was in the range of 2-7 h, suggesting that the leaching process occurs in a short time. Most of the K and the Na (80% and 72%, respectively) were leached out in 4 d while little of N and Ca were leached. Ca in particular did not show a typical saturation pattern of element concentration increase. Considerable amounts of Mg and phosphorous were leached out (35% and 22% respectively) in the 4 d.

Factors affecting the leaching process

The leaching process was influenced by ambient water temperature (Fig. 3), while ionic concentration of the ambient water did not affect the leaching process at all (data not shown). As incubation temperature increased, EC increased faster and saturation level of EC was higher although EC dynamics at 30°C and 40°C were similar.

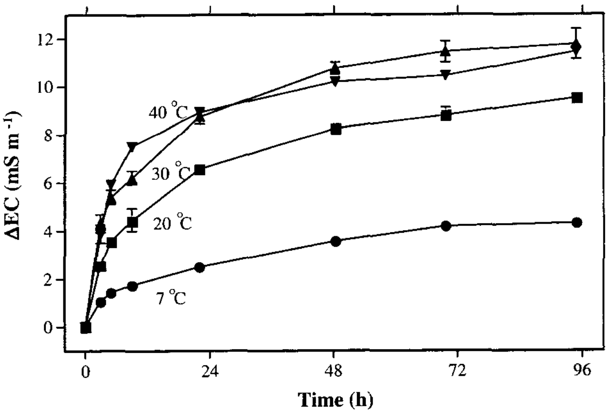

Fig. 3. Changes of electric conductivity increase (ΔEC) during the incubations of the leaf litter of *Zizania latifolia* under different water temperature. ΔEC was obtained by substrating the initial EC from EC values at each time. Bars indicate standard deviations (n=3).

We developed a correction factor for water temperature in developing a leaching model. From the temperature and EC data, we found that the saturation level (A) and half saturation time (B) were dependent on water temperature (T). Using the second- and first- power polynominal linear function, we developed general temperature correction factors for the saturation level (CFT_A) and half saturation time (CFT_B):

$$CFT_A = -0.00235 + 0.0675 \cdot T - 0.0009 \cdot T^2 \quad (r^2 = 0.999,\ n = 4)$$
$$CFT_B = 1.143 - 0.0123 \cdot T \quad (r^2 = 0.849,\ n = 4)$$

The leaching model with temperature factor would be:

$$ML = A \cdot t / (B + t) \quad \text{at } 20^{\circ}C$$
$$= A \cdot CFT_A \cdot t / (B \cdot CFT_B + t) \quad \text{at any temperature}$$

where, ML is the leaching amount of a nutrient and t is time after the litter of macrophytes is submerged in the water.

Since the leaching rate appears to be saturated within a day, we can ignore the saturating process and consider only the final leaching amounts (saturation level) (ML_f):

$$ML_f = A \cdot CFT_A \quad \text{at any temperature}$$

Discussion

Our results suggest that leached concentrations of major elements from aquatic emergent macrophytes are significant and that the leaching process occurs in a short time (on the order of a day). There appears to be some interspecific variations in the leachable fraction of aquatic macrophytes (Brock,1984). While up to 25% of the initial mass of litter was leached into various vascular plants (Polunin, 1982; Brock, 1984; Webster and Benfield, 1986), the leaching of dry mass from *Z. latifolia* was generally less (6%) than those from other macrophytes. The pattern of leaching from the immerged leaves of *Z. latifolia* was a rapid loss of nutrients over the first 24 h followed by a gradual decline for an extended period (Fig. 1), which is similar to other plants (Webster and Benfield, 1986).

Another important aspect of the leaching process which we learned in our study is that there is variable leaching dynamics of various nutrients. For example, the percentage of the leached amount to the initial total amount (% leaching) of nutrients varied from 80% to 2% with an order of K>Na>Mg>P>N (Table 1). The leaching rate of a nutrient is influenced by the way it is incorporated into the organic matter (Brock, 1984). K and Na are loosely bound in plant material, and these elements are the first ones to be lost during decomposition (Attiwill, 1968; Davis and Van der Valk, 1978).

Phosphorus is lost more rapidly than nitrogen in the initial stages of litter decomposition (Howard-Williams and Davies, 1979; Taylor and Parkinson, 1998). In the present study, about 20% of the total phosphorous leached out of the litter of *Z. latifolia* in 2 d while only 2% of the total nitrogen leached out during the same period. These results suggest that nitrogen will be mineralized mainly through microbial decay at a much slower rate than the fast non-microbial leaching. The differential mineralization rates between nitrogen and phosphorus during the decomposition processes would lead to changes in the nitrogen to phosphorus (N:P) ratio in nutrient loading in pelagic water. It is expected that the N:P ratio will change from low in early decomposition to high in late decomposition. Changes in the N:P supply rate may affect phytoplankton seasonal succession (Sommer, 1989).

The intensity of macrophyte leaching depends on plant species (size, morphological structure, initial chemistry) and on various external factors such as temperature, turbulence and oxygen content. Our results indicate that temperature of ambient water is an important factor affecting the leaching amount and rate. Carpenter and his colleague (1980) also examined temperature effects on leaching of phosphorus from submerged macrophytes. They concluded that leaching rates appeared to be independent of temperature, which is contradicting our results. The difference might be due to textual difference between submerged and emergent macrophytes. Since the microbial decay process is well known for its dependency on temperature, water temperature appears to be an important factor in nutrient loading from the decomposition of macrophytes. We also expect that water temperature increases due to long-term climatic change such as global warming would increase nutrient loadings from plant decomposition overall.

Our results can provide a basis for estimating nutrient loadings from submerged litter of emergent macrophytes in combination with information of water temperature, emergent macrophyte biomass and their falling pattern. In lake ecosystems in general, especially in the Paldang Reservoir system, the limiting nutrient for phytoplankton growth in the pelagic zone is phosphorus. Therefore, it is notable that falling of emergent macrophytes would provide considerable amounts of phosphorus loading for phytoplankton growth in the autumn. Since the annual average biomass of *Z. latifolia* is in the range of 556 tons in the entire Paldang Reservoir system (Cho, 1992), the estimated phosphorus loading through leaching would be 0.22 ton per year assuming water temperature is 18°C in October (Cho, 1992). This phosphorus loading is dependent on falling timing of emergent macrophyte litter. Weather would also affect the leaching process. To project the phosphorus loading through leaching in detail, it is necessary to study patterns in falling timing of emergent macrophytes.

The strong leaching of nutrients could be observed in the field. From the littoral zone of the reservoir occupied by *Z. latifolia* to the open water, the steep declines of P and K were found in autumn (Cho et al., 1994). The concentrations of dissolved organic carbon and inorganics leached from eelgrass were rapidly decreased out to the open water of a shallow saline lake (Pellikaan and Nienhuis, 1988).

The leaching phase of litter decomposition has an important influence on subsequent processes. There is a positive relation between the initial quantities of water-soluble substances in the litter and its rate of decomposition (Berg and Tamm, 1991). The derived nutrients from emergent macrophytes are supposed to contribute considerably to the organic and inorganic enrichment of the bottom of the littoral zone. These nutrients nourish the rapidly growing litter decomposers which are quick to colonize the litter when it falls into water (Polunin, 1982; Vahatalo and Sondergaard, 2002).

Our study focused only one emergent macrophyte *Z. latifolia*. Paldang Reservoir has other emergent macrophytes such as *Typha angustifolia, Phragmites australis* and *Scirpus* spp., submerged macrophyte such as *Ceratophyllum demersum*, *Hydrilla verticillata*, and floating-leaved plant such as *Nelumbo nucifera* (Cho and Kim, 1994). Leaching of nutrients from these different functional groups could be very different in amounts and rates of leaching (Godshalk and Wetzel, 1978; Ibrahima et al., 1995). Therefore, it is imperative to study leaching dynamics for other major macrophytes to assess the roles of the leaching process of the biogeochemistry in the Paldang Reservoir system.

Acknowledgements

Kang-Hyun Cho thanks Inha University for providing with a sabbatical year, 2002-2003.

References

AHPA (1989) Standard Methods for the Examination of Water and Wastewater, 17th Ed. American Public Health Association, Washington.

Allen SE, Grimshaw HM, and Rowland AP (1986) Chemical analysis. In: Moore PD and Chapman SB (eds), Methods in Plant Ecology, Blackwell Science Publisher, Oxford, pp 285-344.

Attiwill PM (1968) The loss of elements from decomposing litter. *Ecology* 49: 142-145.

Berg B and Tamm CO (1991) Decomposition and nutrient dynamics of litter in long-term optimum nutrition experiments. *Scand J Forest Res* 6: 305-321.

Brinson MM, Lugo AE, and Brown S (1981) Primary productivity, decomposition and consumer activity in freshwater wetlands.

Annu Rev Ecol Syst 12: 123-161.

Brock TCM (1984) Aspects of the decomposition of *Nymphoides peltata* (Gmel.) O. Kuntze (Menyanthaceae). *Aquat Bot* 19: 131-156.

Carpenter SR (1980) Enrichment of Lake Wingra, Wisconsin, by submerged macrophyte decay. *Ecology* 61: 1145-1155.

Cho KH (1992) Matter Production and Cycles of Nitrogen and Phosphorus by Aquatic Macrophytes in Lake Paltangho. Ph.D. Thesis, Seoul National University, Seoul, pp 1-233.

Cho KH and Kim JH (1994) Distribution of aquatic macrophytes in the littoral zone of Lake Paltangho, Korea. *Korean J Ecol* 17: 435-442.

Cho KH, Park SK, and Kim JH (1994) Reactions of macrophytes on sediment and water in the littoral zone of Lake Paltangho. *Korean J Limnol* 27: 59-67.

Davis CB and Van der Valk AG (1978) The decomposition of standing and fallen litter of *Typha glauca* and *Scirpus fluviatilis*. *Can J Bot* 56: 662-675.

Howard-Williams C and Davies B (1979) The rates of dry matter and nutrient loss from decomposing *Potamogeton pectinatus* in a brackish south-temperate coastal lake. *Freshwater Biol* 9: 13-21.

Godshalk GL and Wetzel RG (1978) Decomposition of aquatic angiosperms. I. Dissolved components. *Aquat Bot* 5: 281-300.

Ibrahima A, Joffre R, and Gillon D (1995) Changes in litter during the initial leaching phase: an experiment on the leaf litter of Mediterranean species. *Soil Biol Biochem* 27: 931-939.

Kamphake L, Hannah S, and Cohen J (1967) Automated analysis for nitrate by hydrazine reduction. *Water Res* 1: 205.

McLachlan SM (1971) The rate of nutrient release from grass and dung following immersion in lake water. *Hydrobiologia* 37: 521-530.

Otsuki A and Wetzel RG (1974) Release of dissolved organic matter by autolysis of a submersed macrophyte, *Scirpus subterminalis*. *Limnol Oceanogr* 19: 842-845.

Pellikaan GC and Nienhuis PH (1988) Nutrient uptake and release during growth and decomposition of eelgrass, *Zostera marina* L., and its effects on the nutrient dynamics of Lake Grevelingen. *Aquat Bot* 30: 189-214.

Polunin NVC (1982) Processes contributing to the decay of reed (*Phragmites australis*) litter in fresh water. *Arch Hydrobiol* 94: 182-209.

Polunin NVC (1984) The decomposition of emergent macrophytes in fresh water. *Adv Ecol Res* 14: 115-166.

Sommer U (1989) Phytoplankton Ecology: Succession in Plankton Communities. Springer-Verlag, New York.

Taylor BR and Parkinson D (1998) Annual differences in quality of leaf litter of aspen (*Populus tremuloides* Michx.) affecting rates of decomposition. *Can J Bot* 66: 1940-1947.

Vahatalo AV and Sondergaard M (2002) Carbon transfer from detrital leaves of eelgrass (*Zostera marina*) to bacteria. *Aquat Bot* 73: 265-273.

Webster JR and Benfield EF (1986) Vascular plant breakdown in freshwater ecosystems. *Annu Rev Ecol Syst* 17: 567-594.

Westlake DF (1963) Comparison of plant productivity. *Biol Rev* 38: 385-425.

[Received September 17, 2003; accepted October 13, 2003]