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Limnological Characteristics and Influences of Free-floating Plants on the Woopo Wetland during the Summer

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During January 1998-October 1999, the impact of free-floating plants (FFP) on limnology of the wetland ecosystem was evaluated through the investigation of physico-chemical characteristics of the Woopo Wetland along with *in situ* manipulation experiments of aquatic plants. Flooding events occurred in the wetland during the summer period (Jun.-Aug.) and water levels rose to 2-3 m due to precipitation from the catchment and inflow from the main channel of the Nakdong River. Physico-chemical parameters and plankton dynamics in the wetland during the summer were greatly influenced by floods and growth of free-floating plants. Dissolved oxygen (Jun.-Sept., 4.5±2.5 mg/l; Oct.-May, 8.1±4.0 mg/l) and pH (Jun.-Sept., 6.9±0.4; Oct.-May, 7.4±0.8) levels were significantly lower during the summer than any other seasons. Three types of enclosure experiments (100 L, treatments with floating plants, screened and opened) were conducted under the presence and absence of sediment for 15 days in the 1999 summer. The treatments with sediment had higher levels of nutrient concentrations than those of the others. Among the treatments with sediment, nutrient concentrations in the treatments with free-floating plants were higher than the others. Zooplankton communities in each treatment showed a similar variation, although the scale of zooplankton densities differed. Rotifer community dominated the zooplankton at the initial phase of the experiment, but decreased drastically along with an increase of cladoceran and copepod communities. In conclusion, low levels of dissolved oxygen and pH in the Woopo Wetland during the summer seemed to be caused by a proliferation of free-floating plants and active decomposition process at the bottom of the sediment.

Key words : Woopo Wetland, free-floating plants, plankton dynamics, sediment

INTRODUCTION

Wetland is one of the most productive ecosystems on the earth and is valuable as sources, sinks and transformers of a multitude of chemical, biological and genetic materials (Mitsch and Gosselink, 1986). The system plays major roles in the landscape by providing unique habitats for a wide variety of biota as well as in flood control by detaining and retaining water (Sather *et al.*, 1990).

Hydrological regime is considered as an important factor controlling primary production in wetland ecosystems. Studies on seasonality of physico-chemical parameters of floodplain water bodies in South American and Australian showed distinctive annual cycles of certain physico-chemical parameters (Welcomme, 1988). There are continuous interactions between the river and the floodplain lakes, but the magnitude of the variation and characteristics are not well understood (Joo, 1990).

Aquatic plant is one of the important primary

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producers in wetland ecosystems, and serves as habitats or refugees for aquatic biota such as fishes, aquatic invertebrates and zooplankton. However, the plants may also serve as a light inhibitor for phytoplankton growth in certain systems when they proliferate on the surface of the water. Seasonal floods and proliferations of aquatic plants in a wetland system may modify the ecosystem behavior. In Far Eastern Asia, intense rainfall in summer period due to the monsoon climate and typhoons is known as major cause of limnological variabilities in freshwater systems (Park *et al*., 2002). Choi *et al*. (1998) reported influences of summer floods on a natural wetland system in S. Korea. Floods induced changes in the distribution of floating aquatic plants, which may cause changes in biotic properties. The combination of the timing of flood occurrences with aquatic plant growth might be an important issue in ecosystem dynamics in wetlands.

The Woopo Wetland, which is the largest riverine wetland in Korea, is well known for its high biodiversity and habitat of migratory birds. Intense floods occur 2-3 times a year especially in summer, with water levels rising to 2-3 m, which usually lasts 7 to 15 days. On occasion, this lasts more than two weeks due to the clogging of the wetland outlet with free-floating plants and the prolonged flooding (Choi *et al*., 1998). From June to October, free-floating plants such as *Spirodela polyrhiza*, *Lemma paucicostata* and *Salvinia natans* covered most of the open surface water in the wetland, which caused a sharp decline of DO and pH concentrations (Chang *et al*., 1998).

In this study, we tried to define the role of free-floating plants in the Woopo Wetland by means of two manipulation experiments and routine monitoring of limnological variables for two years. Time-series monitoring in the wetland could suggest information about the influence of floods on limnological characteristics. In addition, the direct influences of free-floating plants on the plankton community and limnological variables were experimentally evaluated.

MATERIALS AND METHODS

1. Site description

The Woopo Wetland is located in Changnyeong-gun of Gyeongsangnam-do, South Korea (Fig. 1). The total surface area of the wetland is about 2.4 km^2 and the mean depth is about 1 m (Baek, 1988). The Mokpo Wetland (Northern part of Woopo) and the Sajipo Wetland (2 km North East of Woopo) are interconnected with the Woopo Wetland. The main channel of Nakdong River (Jukpo) is about 5 km from the wetland and connected through Topyeong Stream. The Woopo Wetland was designated as a Natural Ecosystem Conservation Area by the Ministry of Environment in 1997 and registered as the second Ramsar site of South Korea in March 1988.

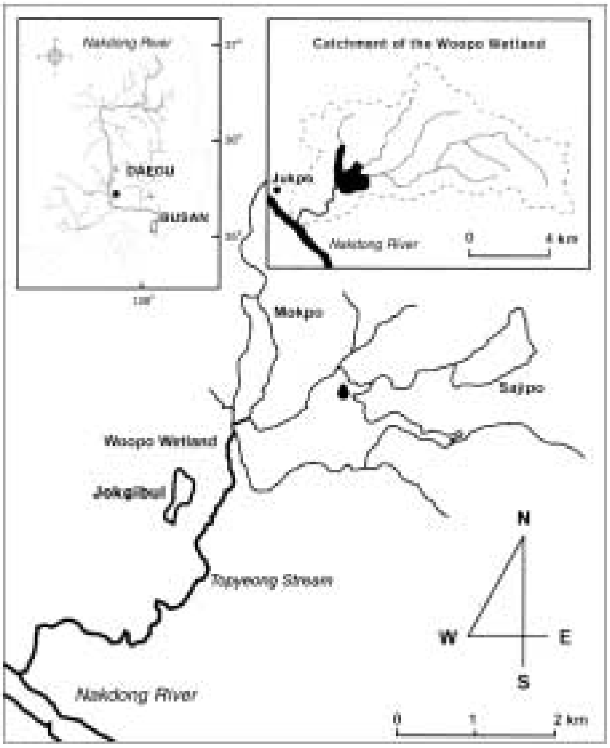

Fig. 1. The Map of Woopo Wetland (● indicates sampling site).

The sampling site for physico-chemical parameters and plankton samples was located on the Ibang-myeon side of the Woopo Wetland, close to the floodgate. The site is shallow (< 1 m) and is seasonally covered with free-floating plants such as *Spirodela polyrhiza*, *Lemma paucicostata* and *Salvinia natans*.

2. Analysis of limnological parameters

The sampling was conducted on biweekly and/or monthly basis from January 1998 to October 1999. The physical parameters such as water temperature, turbidity and water level and chemical parameters such as conductivity, alkalinity, dissolved oxygen, pH, NO_3-N, NH_4-N and PO_4-P were determined to characterize the limnology of the study site. Precipitation data of Miryang region (approximately 20 km from the wetland) was obtained from the Busan Meteorological Office. Water level of the wetland was recorded manually at the floodgate, which is located 150 m from the sampling site. The iron ladder on the floodgate (Ibang) was used as a fixed point and from this point water level was measured.

Water temperature, turbidity and conductivity were measured using YSI DO meter (Model 58), Shaban turbidimeter (Model 20052), Fisher conductivity meter (Model 152), respectively. Alkalinity was measured using titration method (Wetzel and Liken, 1991). Winkler method and YSI DO meter (Model 58) were used for the measurement of dissolved oxygen (DO). pH was measured using an Orion pH Meter (Model 407A). Nutrient concentrations such as NO_3-N, NH_4-N, and PO_4-P were determined using a QuickChem Automated Ion Analyzer (Lachat, NO_3-N, No. 10-107-04-1-O; NH_4-N, No. 10-107-06-1-B; PO_4-P, No. 10-115-01-1-B).

Phytoplankton samples were collected using a Van-Dorn water sampler. The subsamples of 100 ml were immediately preserved with acid Lugol's solution. Utermöhl (1955) sedimentation method was used to prepare the samples for identification and enumeration. Identification of species was conducted with a Nikon microscope (×100). Water samples of 10 ml were settled in chambers (diameter, 2.5 cm; volume, 10 ml) for 4-5 hours before counting.

Water samples for phytoplankton biomass were collected from the 0.5 m strata for the determination of chlorophyll *a* concentration and filtered through 0.45 μm glass fiber filters (Whatman GF/C) and stored frozen until analyzed. Chlorophyll *a* was determined spectrophotometrically using a monochromatic method (Wetzel and Liken, 1991). For the analysis of zooplankton, water of 2 L were filtered through a 32 μm mesh (Wildco 48C60), resuspended in 50-60 ml water and fixed with formaldehyde (final concentration 4%). To determine zooplankton abundance, either the whole sample or at least 200 individuals were counted in subsamples of each replicate.

3. Experimental design

To evaluate influences of free-floating plants and sediment on limnological characteristics in the wetland, several experiments were conducted near the Ibang-myeon side of Woopo Wetland. The experiments were lasted from June 1 to June 15, 1999. The design of experimental setting is

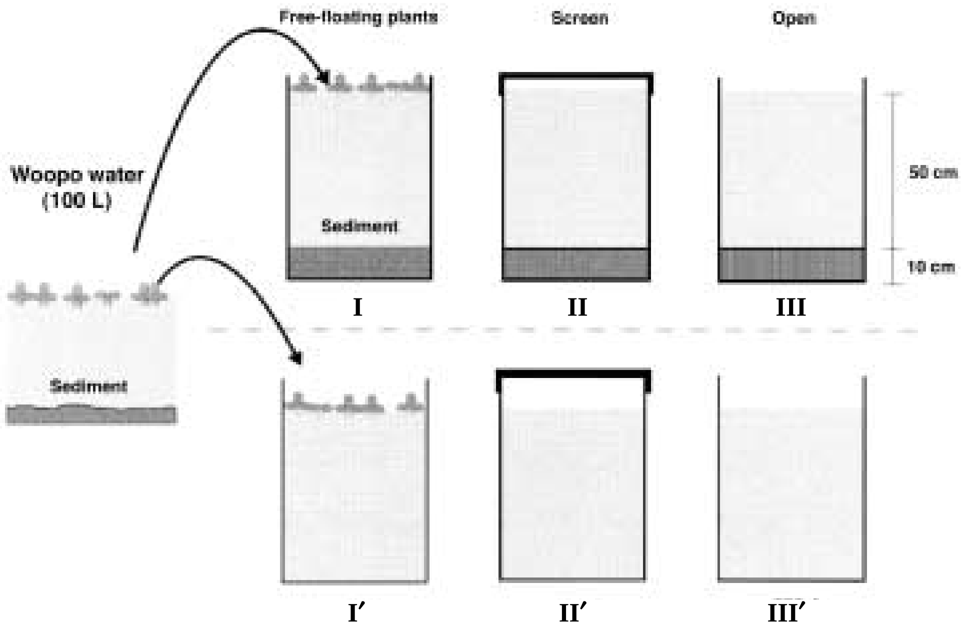

Fig. 2. Experimental design.

shown in Fig. 2.

Six treatments had 2 replicates, and each plastic tank (diameter, 55 cm; height, 62 cm) was filled with 100 L water of the Woopo Wetland. Water samples in the enclosures were taken on 2 or 3 days interval at a depth of 30 cm using a siphon. Same amounts of sediment were placed to three treatments of I, II and III before the beginning of the experiment (10 cm off the plastic tank bottom). In the treatment I and I′, free-floating plants (*Spirodela polyrhiza*, *Lemma paucicostata* and *Salvinia natans*) fully covered the surface water, while the surface water was free from floating plants and completely uncovered in treatment III and III′. To prevent full sunlight from penetrating the water and simulate a semi-natural environment, the surface of the water in treatment II and II′ was covered by textile screens (50% reduction).

The second experiment, which was identical to the first experiment, was conducted in the beginning of the Sept. 1999 but most enclosures were lost due to unexpected flooding events.

RESULTS AND DISCUSSION

1. Seasonal changes of limnological characteristics

1) Physico-chemical parameters

The Woopo Wetland is influenced by monsoon climates. Over 60% of total annual rainfall occurs in the summer (Jun.-Sept.). Annual precipitation of the Woopo area for the last twenty years was 1,231 mm, which is slightly above the Korean average. The annual precipitation in 1998 and 1999 (Jan.-Oct.) was 1,553 mm and 1,860 mm, respectively (Fig. 3). In 1999, the annual precipitation was much higher than that of 1998 with about 1,200 mm of rainfall from Jul. to Sept.

During the study period, large floods occurred twice a year. The water level during the floods rose to 2-3 m due to precipitation at the catchment and inflows from the main channel of the Nakdong River (Jukpo). When the water level peaked, it usually took 7 to 15 days for the return of a normal water level. Sometimes, it took more than two weeks, since the outlet of the wetland clogged up with free-floating plants (Choi *et al*., 1998).

Mean water temperature during the study period averaged 19.9 ± 8.1°C ($n = 35$), rising from late March or early April and reaching up to 30°C in July and August. It dropped sharply in October. Seasonal change of dissolved oxygen in the Woopo Wetland was strongly influenced by water temperature and seasonal growth of the free-floating plants (Fig. 3). Mean DO (7.3 ± 4.2 mg/l ($n = 35$)) was lower during late spring and summer than during winter. When free-floating plants covered the surface of the wetland from June to September (Jun.-Sept., 4.5 ± 2.5 mg/l; Oct.-May, 8.1 ± 4.0 mg/l), the DO dropped as low as 1.4 mg/l. The reduced DO was attributed to decreased photosynthetic activities of phytoplankton by low light penetration, and active decomposition of organic matter derived from floating plants and sediment.

Seasonal changes of pH were similar to the changes of DO (Fig. 3). Mean pH averaged 7.2 ± 0.7 ($n = 35$) during the study period. and the mean during the covering of free-floating plants on the surface of the wetland from June to September (6.9 ± 0.4) was lower than that of the remaining periods (7.3 ± 0.8).

Conductivity showed a significant difference between summer and the other seasons (Jun.-Sept., 211 ± 109 μS/cm; Oct.-May, 294 ± 112 μS/cm). The lower conductivity was due to the intense precipitation along with influences from the main channel (Fig. 3). When river water flows into the wetland, conductivity can be a good indicator of the penetration by water (Mitsch, 1978; Joo and Francko, 1995). The mean alkalinity was relatively high (59.9 ± 20.8 mg/l) and the patterns in the seasonal changes were similar to that of conductivity. During the flooding events, alkalinity of the river (Jun.-Sept., 56.8 ± 23.0 mg/l; Oct.-May, 62.0 ± 20.9 mg/l) decreased while that of the wetland increased. It seemed that the increased alkalinity was attributed to an inflow of ionic matters from the river as the river water mixed with the water column within the wetland. Seasonal changes of turbidity were relatively minor except during the floods and the active growth period of free-floating plants such as *Spirodela polyrhiza*, *Lemma paucicostata* and *Salvinia natans* (Fig. 3). After the series of floods, sediment loading resulted in higher turbidity (Jun.-Sept., 3.9-157 NTU; Oct.-May, 3.7-80 NTU).

Seasonal changes of nutrients in the Woopo Wetland were largely influenced by summer floods. Mean concentrations of NH_4-N, NO_3-N,

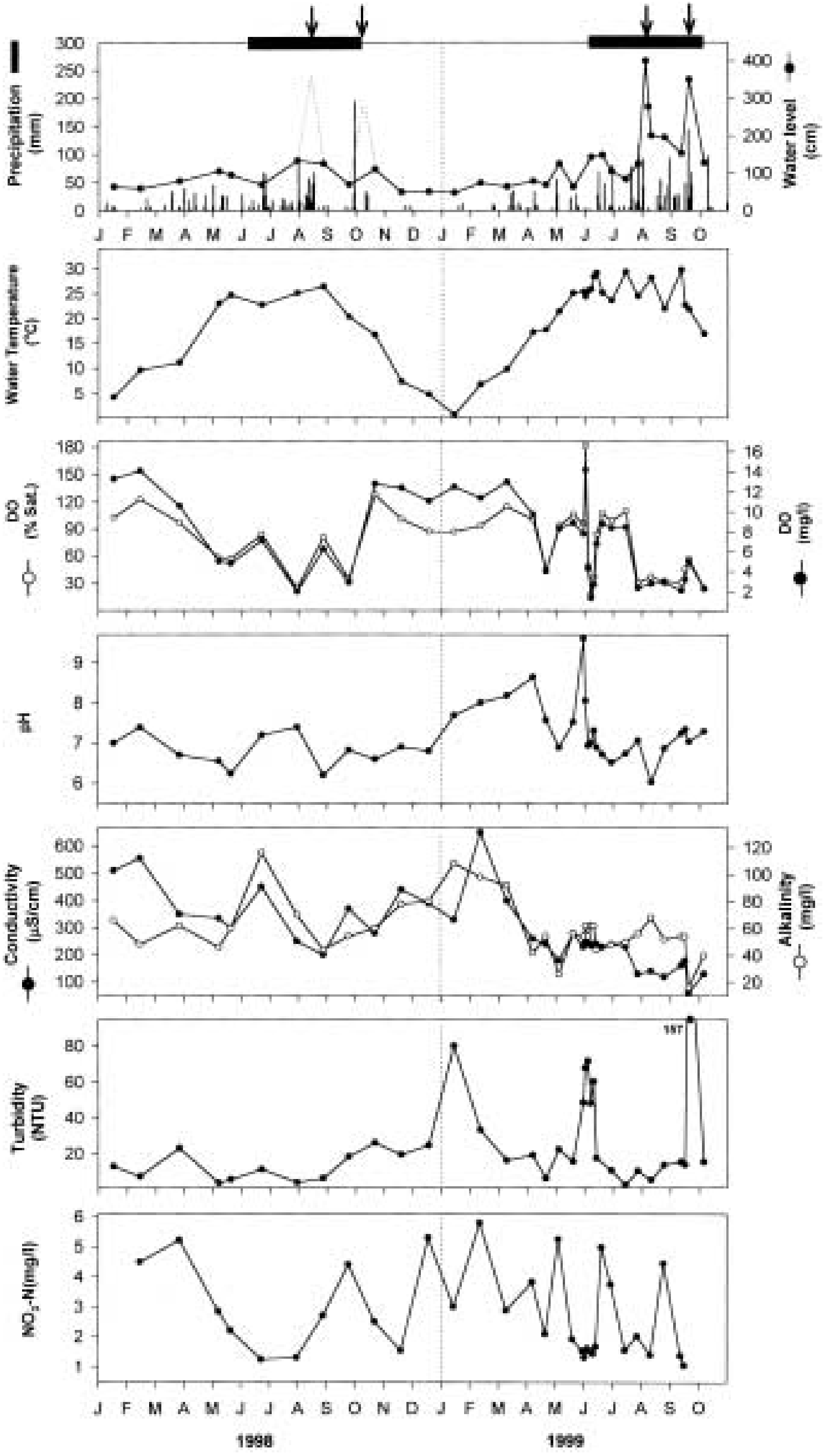

Fig. 3. Seasonal changes of physico-chemical parameters in the Woopo Wetland. Arrows indicate flooding events. Dashed lines in water level are estimated values.

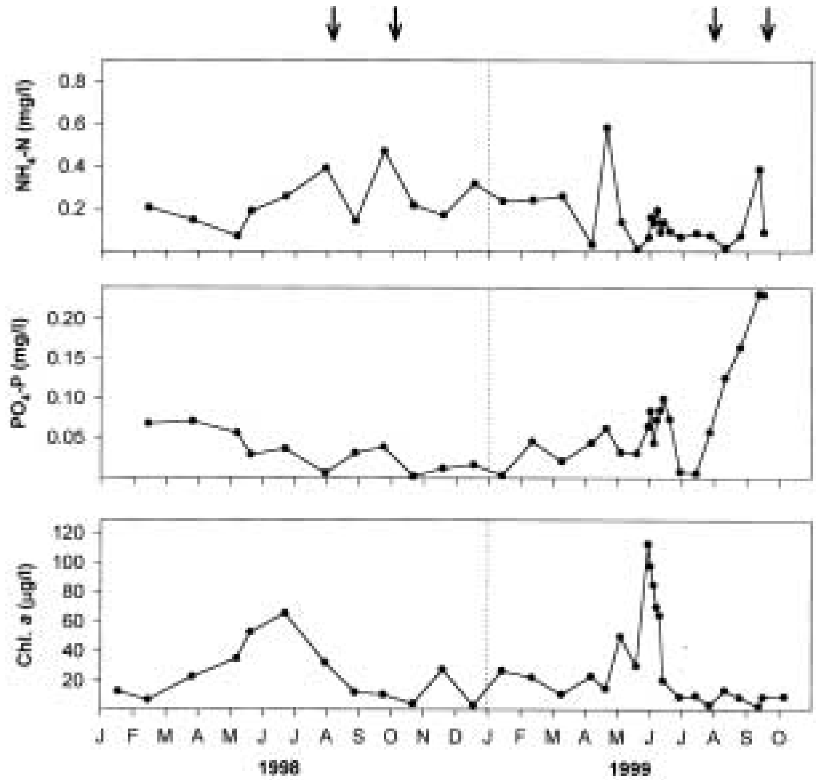

Fig. 3. Continued.

and PO_4-P were 0.18±0.14 mg/l, 2.67±1.46 mg/l and 65.0±64.0 μg/l, respectively and these values varied depending on the magnitudes and frequencies of rainfall events. Due to the intensive farming and irrigation in the catchment area, it is possible that a massive amount of nutrients were introduced into the wetland during the flooding. During the summer, the concentration of Chl. *a* was higher than other seasons (Fig. 3).

Consequently, flooding events and the proliferation of free-floating plants seemed to be major environmental factors influencing the limnology of the Woopo Wetland in summer. The active growth of free-floating plants resulted in the sharp declines of DO and pH.

2. Influences of free-floating plants (FFP) on the ambient water of enclosures

1) Physico-chemical conditions

Among the three treatments, the influences of FFP in the treatments of I and I′ on the water chemistry was evident. In particular, the values of DO and pH in treatments with open surfaces (III and III′) were higher than those of the others (Fig. 4, Table 1). Nutrient concentrations varied depending on the treatments. Distinctive differences in physico-chemical parameters were observed between the presence and absence of sediment. In the treatments with sediment (I, II and III′), higher conductivity and nutrient concentrations and lower DO and pH levels than the other treatments (I′, II′ and III′) were observed.

Changes of DO and pH in all treatments were similar during the experiments. Dissolved oxygen and pH levels were lowest in the treatment I (DO, 2.1±1.9 mg/l; pH, 6.9±0.2), whereas they were higher in the treatment II′ than any other treatments (DO, 7.0±3.0 mg/l; pH, 7.9±0.4). Mean DO and pH (DO, 5.9±5.1 mg/l; pH, 7.2±0.5) of the Woopo Wetland were relatively higher than the experimental data, since the experiment was conducted just at the beginning of the active growth of FFP. According to the statistical analysis, DO and pH levels of treatment I and II were similar, but those of the treatment with an open surface were different from the other treatments with sediment. Among treatments without sediment (I′, II′ and III′), treatment III′ with

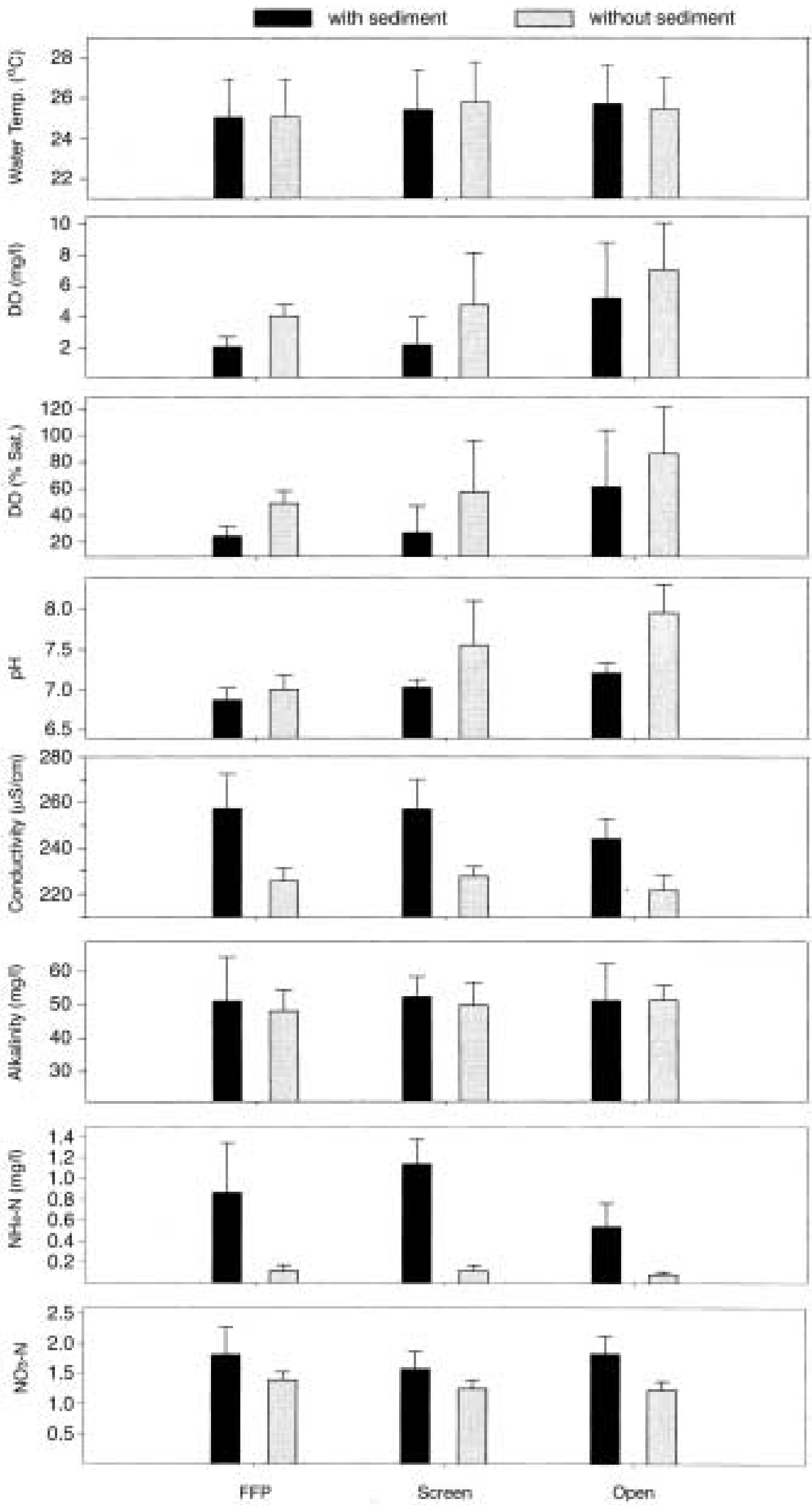

Fig. 4. Physico−chemical conditions during the enclosure experiments.

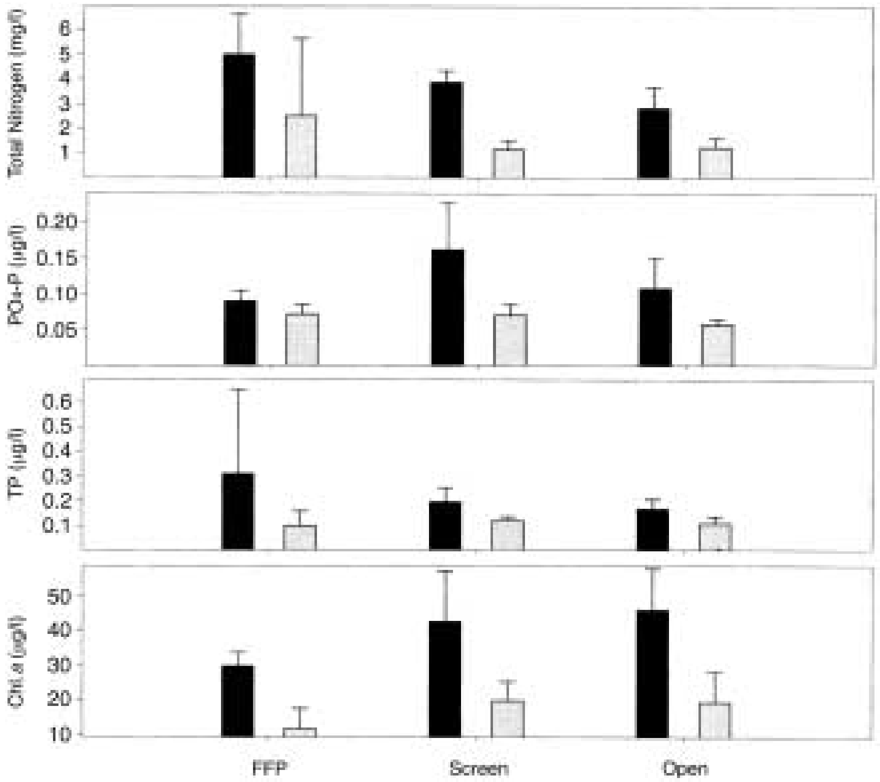

Fig. 4. Continued.

Table 1. Summary of the physico-chemical parameters on the Woopo Wetland during the experimental period of June 1-15, 1999 (mean ± SD, n = 5).

Parameters	Treatment						
	I	II	III	I′	II′	III′	Woopo Wetland
Water Temp. (°C)	25.0 ± 1.9	25.4 ± 2.0	25.7 ± 1.9	25.1 ± 1.9	25.4 ± 1.6	25.8 ± 2.0	27.3 ± 2.9
DO (mg/l)	2.1 ± 1.9	2.2 ± 1.8	5.2 ± 3.6	4.0 ± 0.8	7.0 ± 3.0	4.8 ± 3.4	5.9 ± 5.1
DO (% saturation)	24.2 ± 7.2	26.6 ± 20.3	61.2 ± 42.3	48.6 ± 9.3	85.8 ± 35.1	57.2 ± 38.5	73.7 ± 64.7
pH	6.9 ± 0.2	7.0 ± 0.1	7.2 ± 0.1	7.0 ± 0.2	7.9 ± 0.4	7.6 ± 0.5	7.2 ± 0.5
Conductivity (μS/cm)	257 ± 15	257 ± 13	244 ± 9	226 ± 5.7	222 ± 7	228 ± 4	241 ± 4
Alkalinity (mg/l)	51.0 ± 13.2	52.2 ± 6.1	51.2 ± 11.2	48.0 ± 6.3	51.4 ± 4.3	49.8 ± 6.7	56.8 ± 7.9
Turbidity (NTU)	14.9 ± 8.5	11.0 ± 4.4	12.2 ± 4.8	6.0 ± 4.9	6.8 ± 2.3	7.9 ± 3.2	53.1 ± 21.8
NH_4-N (mg/l)	0.87 ± 0.48	1.14 ± 0.24	0.54 ± 0.23	0.11 ± 0.06	0.08 ± 0.02	0.12 ± 0.05	0.12 ± 0.03
NO_3-N (mg/l)	1.81 ± 0.47	1.57 ± 0.30	1.83 ± 0.29	1.39 ± 0.13	1.23 ± 0.14	1.25 ± 0.14	1.53 ± 0.14
Total-N (mg/l)	4.99 ± 1.59	3.86 ± 0.47	2.81 ± 0.85	2.50 ± 3.13	1.23 ± 0.35	1.14 ± 0.37	4.02 ± 2.82
PO_4-P (μg/l)	90 ± 15	161 ± 66	108 ± 43	72 ± 13	58 ± 8	71 ± 14	77 ± 21
Total-P (μg/l)	310 ± 341	196 ± 57	169 ± 38	100 ± 58	108 ± 29	120 ± 15	395 ± 223
Chlorophyll *a* (μg/l)	36.9 ± 43.9	39.1 ± 12.6	47.8 ± 15.8	17.0 ± 17.6	27.5 ± 14.5	19.0 ± 7.4	67.7 ± 29.4

an open surface was also different from the others. All of treatments with sediment maintained lower values of DO and pH comparing with the other treatments.

Low DO and pH levels in the treatments of I, II, I′ and II′ were probably due to the inhibition of light penetration into the water by the FFP and textile screens. Compared to treatments I vs. I′ and II vs. II′, DO and pH of treatments I and III was lower than that of treatments without sediment. We believe that since the Woopo Wetland is shallow (< 1 m), decomposition of organic matter and respiration of biota on the bottom of the sediment could be important factors in low DO and pH concentrations (Chang *et al*., 1998). As a result, low DO and pH levels resulted from the combined effects of the presence of FFP and the decomposition and respiration at the bottom

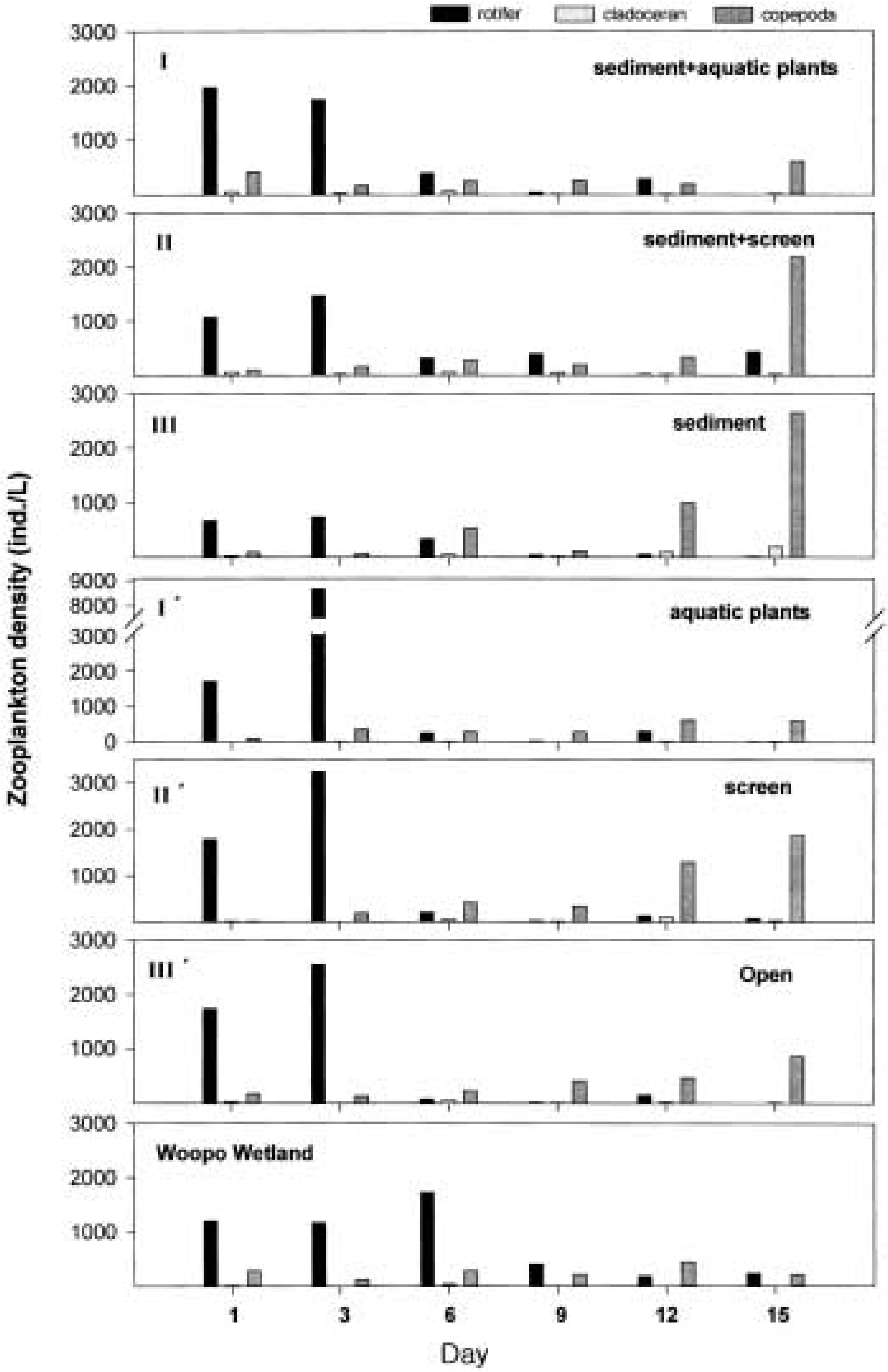

Fig. 5. Changes of zooplankton community during the enclosure experiments.

of the sediment.

Conductivity and turbidity were slightly higher in the treatments with sediment (I, II and III) than the other treatments (I′, II′ and III′) (Fig. 6, Table 1). It seemed that releasing of ionic matter from the sediment caused the higher conductivity and turbidity. The presence (I, II, I′ and II′) and absence (III and III′) of light inhibition did not affect conductivity and turbidity statistically. Similar values for alkalinity were observed during the experiment.

All nutrients (NH_4-N, NO_3-N, PO_4-P, TN, and TP) were higher in treatments with sediment than the others. The concentration of total nitrogen and total phosphorous were highest in the treatment I, probably due to the influences of sediment and sedimentation of the FFP.

The concentration of NH_4-N and PO_4-P in the treatments with FFP (I and I′) and an open surface (III and III′) were slightly higher than the treatment with a closed surface (II and II′). The concentration of NH_4-N and PO_4-P in treatments I, III, I′ and III′ increased at the beginning of the experiment, but then decreased sharply. The reduced NH_4-N and PO_4-P in the treatments of I and I′ might have caused an uptake of nutrients by the FFP. Relatively high phytoplankton biomass (Chl. *a*) was shown in the treatments of III and III′ compared with treatments II and II′. It seemed that phytoplankton in treatments of III and III′ utilized NH_4-N and PO_4-P more actively with a better underwater light condition.

2) Changes of plankton communities

Chlorophyll *a* in the treatments with sediment (I, II and III) was much higher than the others (I′, II′ and III′). In the treatments with sediment, the Chl. *a* concentration was highest in III (47.8 ± 15.8 μg/l, $n = 24$). Chlorophyll *a* in II′ (27.5 ± 14.5 μg/l, $n = 24$) was highest among the treatments without sediment. Treatments without

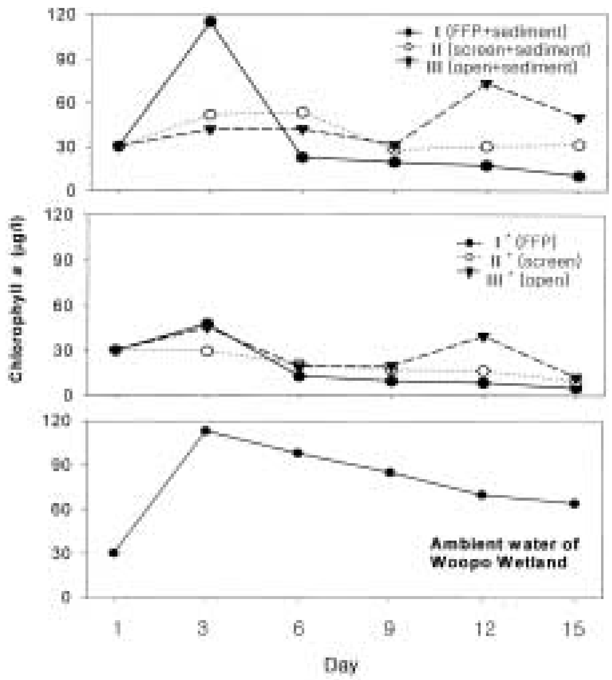

Fig. 6. Changes of Chl. *a* during the enclosure experiments.

Table 2. Statistical tests on the limnological variables during the experiments (two-way ANOVA with replication and Tukey test for *post-hoc* test, $\alpha = 0.05$, n = 72). (FFP: free-floating plants, S: screen, O: open, PS: presence of sediment, AS: absence of sediment).

Parameters	Aquatic plants			Sediments			Interaction	
	F	*p*	groups	*F*	*p*	groups	*F*	*p*
Water Temp. (°C)	0.86	0.427		0.17	0.682			
DO (mg/l)	4.86	0.010	FFP, S : O	16.33	0.0001	PS : AS		
DO (% saturation)	6.03	0.003	FFP, S : O	10.70	0.0001	PS : AS		
pH	7.05	0.001	FFP : O	41.49	0.0001	PS : AS	2.67	0.076
Conductivity (μS/cm)	3.00	0.056		68.63	0.0001	PS : AS		
Alkalinity (mg/l)	0.37	0.689		1.50	0.224		0.02	0.980
Conductivity (NTU)	0.06	0.940		5.28	0.024	PS : AS		
NH_4-N (mg/l)	3.79	0.027	S : O	78.79	0.0001	PS : AS	4.74	0.011
NO_3-N (mg/l)	1.72	0.187		35.57	0.0001	PS : AS		
Total-N (mg/l)	2.52	0.088		144.62	0.0001	PS : AS		
PO_4-P (μg/l)	6.15	0.003	FFP, O : S	20.88	0.0001	PS : AS	4.22	0.018
Total-P (μg/l)	0.93	0.400		19.17	0.0001	PS : AS		
Chlorophyll *a* (μg/l)	0.29	0.752		7.49	0.007	PS : AS		

sediment and free-floating plants had the lowest Chl. *a* (17.0±17.6 μg/l, n = 24). Treatments with sediment and open surface (III) had a high Chl. *a* due to probably active growth. In the treatments with sediment, a continuous supply of nutrients from the bottom of the sediment resulted in higher concentrations of Chl. *a* compared with the others. The Ambient Chl. *a* in the surface water of the wetland was high (67.7±29.4 μg/l (n = 12)) throughout the enclosure experiments. Since the experiments were conducted just beginning of the FFP bloom, relatively high phytoplankton biomass was observed. According to statistical analysis, there was no difference in Chl. *a*, among the treatments with sediment (I, II and III), although that of the III (open surface) was highest. Probably light inhibition by the FFP on the wetland was minor to phytoplankton biomass. During the experimental period, *Keratella cochelearis*, *Polyarthra* sp. and *Filinia* sp. were dominant rotifer species. Dominant cladoceran and copepoda taxa were, *Ceriodaphnia* sp., *Moina micrura* and Nauplius. The changes of zooplankton communities in all treatments were similar, although density differences were evident among the treatments during the experiments. Planktonic rotifer dominated the zooplankton in the all treatments at the beginning (by day 6), and then decreased drastically along with increases of cladoceran and copepoda communities. Higher densities of rotifer were observed in the treatments without sediments than those of the others. We believe that relatively low concentrations of nutrients and predators (cladoceran and copepoda) were maintained. The density of copepoda in the treatments with FFP (I and I′) were lower than those of the others (II, III, II′ and III′). Low Chl. *a* in the treatments of I and I′ might be caused by relatively high densities of copepoda (Fig. 6). Two-way ANOVA showed that the presence or absence of free-floating plants had differences in parameters such as DO, pH and NH_4-N. Except for water temperature and alkalinity, sediments influenced values of pH, conductivity, NH_4-N and TN (Table 2).

Accordingly, free-floating plants proliferated in late spring due to the rising water temperature and the decomposition process at the bottom of the sediment but declined during summer floods. After the floods, the plants covered most of the Woopo Wetland surface again. Further study should be done on the fate of organic matter produced within the wetland and flux of nutrients between the catchment of the Woopo Wetland and the main channel of the Nakdong River.

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＜**국문적요**＞

하계 우포습지의 육수학적 특성 및 부유수생식물의 영향

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본 연구는 하계동안 습지 수면을 덮고 있는 부유성 수생식물이 습지생태계에 미치는 영향을 알기 위하여 1998년 1월부터 1999년 10월까지 우포습지의 이 · 화학적 변화를 파악하고 하계에 부유수생식물 및 저토가 수질에 미치는 영향을 현장실험을 통하여 평가하였다. 우포습지의 수위는 홍수발생 시 낙동강의 범람으로 2-3 m 정도의 변화를 보였다. 대부분의 이 · 화학적 요인들 및 동 · 식물플랑크톤의 밀도는 여름동안의 홍수와 6월에서 10월까지 습지 수표면을 거의 덮고 있는 수생식물에 의해 많은 영향을 받는 것으로 나타났다. 용존산소(Jun.-Sept., 4.5±2.5 mg/l; Oct.-May, 8.1±4.0 mg/l)와 pH (Jun.-Sept., 6.9±0.4; Oct.-May, 7.4±0.8)는 다른 계절에 비해 여름철에 현저히 낮았다. 여름철에 번성하는 부유성 수생식물(개구리밥, 생이가래, 좀개구리밥)과 수중의 저토가 하계의 육수학적 특성이 미치는 영향을 파악하기 위하여 수표면에 enclosure (100 L, 6개)를 설치하고 부유식물, 천 그리고 노출 상태의 처리군을 부유식물의 유 · 무, 수중 저토의 유 · 무에 대해 실험한 결과, 부유식물이 있는 처리군이 다른 경우에 비하여 DO, pH가 낮게 나타났고, 노출된 대조구에서 상대적으로 식물플랑크톤(chl. *a*)의 생체량이 높았다. 또한 각 처리군에서 수중 저토가 있는 경우 영양염류농도가 높았고, 특히 부유식물이 있는 처리구에서 높은 영양염류의 농도를 보였다. 동물플랑크톤 군집의 변화는 부유식물에 의한 뚜렷한 영향은 보이지 않았지만, 초기에 rotifer가 우점하였고, 이후 cladoceran과 copepoda의 증가로 rotifer의 밀도가 급격히 감소하였다. 결과적으로, 조사기간 중 하계에 지속적으로 관찰된 DO와 pH가 감소하는 것은 수생부유식물의 번성과 수중 퇴적물의 분해에 따른 영향인 것으로 나타났다.