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Ecological Studies on Togyo Reservoir in Chulwon, Korea. VIII. The Epilithic Algal Community after the Experimental Acidification on the Artificial Substrata (Tiles) at Mesocosm

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The epilithic algal communities on the artificial substrata (unglazed ceramic tiles) were investigated from 5th July to 24th July 1999 with two or three days intervals for elucidating the effects of the experimental acidification. They were harvested inside the mesocosm with and without the acid treatment on Togyo reservoir within the Civilian Passage Restriction Line near Demilitarized Zone (DMZ) in Korea. After the colonization of epilithic algal community, their standing crops revealed differnet patterns outside and inside the mesocosm. However the time lapse of 5 days was observed on the inside with acid treatment. The dominant species were different: *Achnanthes minutissima* was outside but *Coenochloris polycocca* was inside and inside with acid treatment. The differences in floral composition were also found. *Achnanthes minutissima* which has been the most important species in the colonization by the epilithic algal community of the mesocosm was less important at the lower pH. *Coenochloris polycocca* is a species well adapted to low pH.

Key Words: artificial substrata (tiles), epilithic algae, experimental acidification, mesocosm, Togyo reservoir

INTRODUCTION

Acid input to aquatic ecosystems can occur either through natural processes, such as volcanic emissions, thermal effluents, peat bog drainage inflow and oxidation in geological areas with sulfur containing rocks, or through anthropogenic activity (Planas 1996). Rapporteur *et al.* (1994) argued that acidification was due to natural factors in aquatic ecosystems. Actually, acidification affects all components of biological components in lakes and streams: microbes, algae, macrophytes, invertebrates, fish, amphibians, and other vertebrates that rely on aquatic ecosystems for habitat and food. However other acidification studies have focused on anthropogenic activities such as mining, and waste leachates, alteration in land use, the increase in atmospheric sulfur and nitrogen oxide originating from smelters and fossil fuel (Planas 1996).

Since Grahn *et al.* (1974) stated that the acidification of aquatic ecosystems could lead to the oligotrophication of lakes, the phytoplankton growth due to acidification focused on lentic and lotic water ecosystems (Havens and DeCosta 1986; Schindler 1988; Battarbee 1994). However lake acidification became an environmental issue of international significance in the late 1960s and 1970s when Scandinavian scientists claimed that 'acid rain' was the principal reason why fish populations had declined dramatically in Swedish and Norwegian lakes (Battarbee *et al.* 1999). Also the effect of acidification on periphyton communities has been studied (Mulholland *et al.* 1986; Turner *et al.* 1991) together with some studies on experimental acidification (Planas and Moreau 1986; Planas *et al.* 1989; Turner *et al.* 1991). Hendrey (1976) suggested that periphyton biomass and productivity in streams increased under highly acidic conditions because densities of grazing macroinvertebrates and microheterotrophs was reduced at low pH. Since then two hypothesis to explain increase in the biomass and production of lotic periphytic communities in acidified habitats were tested by Planas and Moreau (1986). One hypothesis involves a greater bioavailability of P due to

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Table 1. The physicochemical factors for Togyo reservoir from 5th July to 24th July 1999

Date and Time	pH			Temperature (°C)			
				Air	Water		
	outside	inside	inside with acid treatment		outside	inside	inside with acid treatment
5th July 13:15	8.7	9.2	9.5	31.5	27.6	28.6	28.5
7th July 11:10	8.6	9.1	8.6	30.0	28.6	28.6	28.2
9th July 12:10	8.8	9.4	6.5	25.5	25.8	25.8	25.6
12th July 11:30	8.8	9.7	4.0	26.2	25.0	25.5	24.8
14th July 12:50	8.3	9.1	3.6	28.8	27.0	27.0	26.8
17th July 11:10	8.4	8.7	3.8	27.5	25.2	25.2	25.2
19th July 12:45	8.4	8.6	3.7	29.5	28.4	28.2	27.8
24th July 12:30	7.5	6.8	3.8	24.2	26.0	25.6	26.0

its greater release from sediments at low pH and the other is utilization of S from the H_2SO_4 addition. Later Planas *et al.* (1989) suggested three hypothesis: the first one is an increase in available nutrients either by resolution from the sediments, or by nitrogen and sulfur additions from the acidifying agents (NOx and SOx), the second one is a reduction in grazing by micro and macrobenthic organisms because of the disappearance of certain species sensitive to acidification, the third one is a change in algal species composition with a dominance of species better adapted to habitats with high concentrations of hydrogen ions and metals.

. An acidification study was focused in Korea because especially in the Far East, atomospheric sulfur and nitrogen oxide originating from smelters and fossil fuel in northeast China caused acidification of aquatic ecosystems in Korea, especially in the middle area of Korea (Kim 1990; Carmichael *et al.* 1994). This study is a continuation of the previous works by Lee *et al.* (submitted) and the aim of the present study is to elucidate the effect of experimental acidification on epilithic algal communities on unglazed ceramic tiles after 9 weeks of algal colonization in the enclosed mesocosm on Togyo reservoir within the Civilian Passage Restriction Line near Demilitarized Zone (DMZ), which has not been influenced by the human activities or agricultural and industrial wastes from the surrounding areas.

MATERIALS AND METHODS

The measurement of general environmental factors (i.e., air temperature, water temperature and pH) were made *in situ* according to Han *et al.* (1995) and Lee *et al.* (1996). The epilithic algal community structure were investigated from 5th July to 24th July 1999 with two or three days intervals as recommended by Wetzel (1983). Sulfuric acid was added sufficient to reduce the pH of the experimental chamber around the range of pH 4.0.

Samples were scraped from the surface of the tiles, washed with distilled water, transferred into glass vials, fixed with neutral formalin, and counted in a Sedgwick-Rafter counting chamber under a light microscope at ×100 magnification. Cleaning was by nitric acid or hydrogen peroxide, and mounting was with Naphrax. Identification was made at ×1,000 magnification. The identification of diatoms followed Krammer and Lange-Bertalot (1986, 1988, 1991a, 1991b) and that of bluegreens and greens followed Prescott (1962) mainly. The algal populations were also estimated indirectly by chlorophyll-*a* content (Lorenzen, 1967).

RESULTS AND DISCUSSION

General environmental factors

Water temperature varied from 25.0°C on the 12th July to 28.6°C on the 7th July outside the mesocosm and from 25.2°C on 17th July to 28.6°C on the 5th and 7th July inside the mesocosm. pH varied from 7.5 on the 24th July to 8.8 on the 9th and 12th July outside the mesocosm and did from 6.8 on the 24th July to 9.7 on the 12th July inside the the mesocosm and also through the acid treatment, we could reach the proper value of pH 4.0 on 12th July after three times acid treatment (Table 1).

pH did not change from the 5th July to 12th July but a gradual decrease of pH occurred until the end of experiment outside the mesocosm. Inside the mesocosm, the highest value of pH 9.7 on the 12th May appeared, while the lowest value of pH 6.8 appeared on 24th July. From 5th July, pH increased gradually and reached the

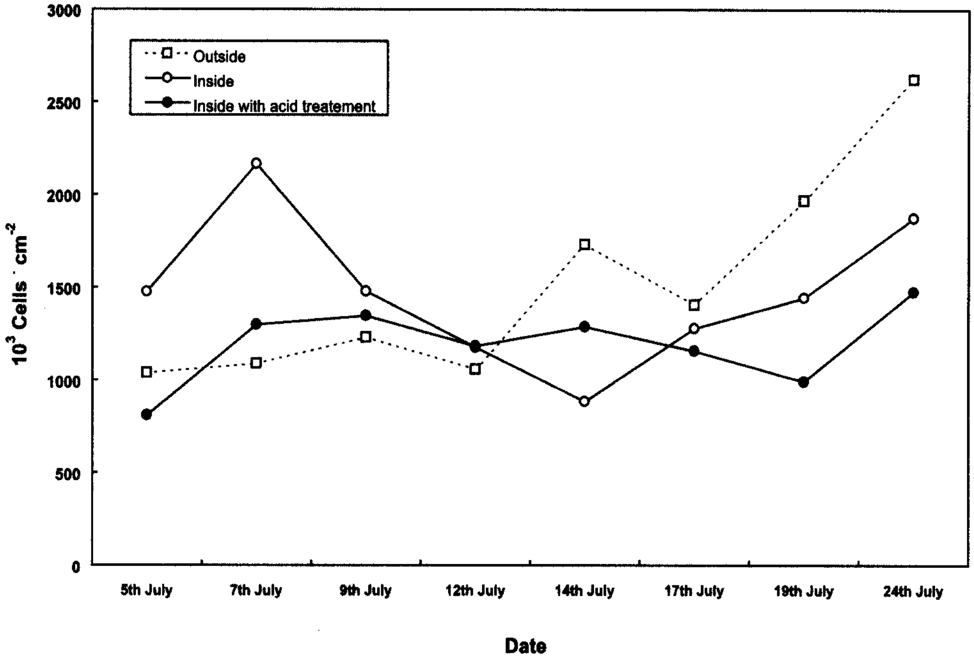

Fig. 1. The variations of standing crops of epilithic algae in Togyo reservoir from 5th July to 24th July 1999 (□: outside the mesocosm, ○: inside the mesocosm, ●: inside the mesocosm with acid treatment).

highest on the 12th July. Since then, pH decreased gradually until 19th July but on the 24th July it showed the decrease drastically. Due to the heavy rain, we could see the lowest pH value at both side of mesocosm on 24th July and also we could see the similar variation pattern of pH at the both side of mesocosm.

Standing crops of epilithic algae and chlorophyll-a content

After the colonization of epilithon at the artificial substrata (unglazed ceramic tiles) (Lee *et al.*: submitted), epilithic algal community outside the mesocosm grew slowly and after 7 days they grew rapidly and reached to $1{,}731.1 \cdot 10^3$ cells · cm^{-2} on 14th July and decreased to some extent due to the heavy rain and increased again rapidly and reached to the highest value of $2{,}622.8 \cdot 10^3$ cells · cm^{-2} on 24th July, 19 days after the experiment began. On the other hands, inside the mesocosm, the standing crops of epilithon (artificial substrata: unglazed ceramic tiles) showed the highest value of $2{,}163.7 \cdot 10^3$ cells · cm^{-2} on 7th July, 2 days after the experiment began. It showed the rapid increase and decreased to the lowest, $884.2 \cdot 10^3$ cells · cm^{-2} on 14th July and then it increased again. Otherwise the standing crops of epilithon (artificial substrata: unglazed ceramic tiles) with acid treatment inside the mesocosm showed the rapid increase at the beginning and reached to the first highest value on 9th July, 4 days after the acid treatment but it slowly decreased until 12th July, which showed pH 4.0 but it increased again slowly for a while and decreased to some extent slowly until 19th July and increased to the highest value of $1{,}475.5 \cdot 10^3$ cells · cm^{-2} on 24h July, 19 days after the experiment began (Fig. 1).

The variation pattern of total standing crops differed between the outside and inside of the mesocosm and we suggest that it was due to the mesocosm itself (Lee *et al.*: submitted). However it was also similar inside with acid treatment although the time lapse of 5 days was observed on the inside with acid treatment.

Outside the mesocosm chlorophyll-a content reached the highest value of 14.4 mg · m^{-2} on 24th July at the end of the experiment. The pattern of the chlorophyll-a contents outside the mesocosm was very similar to the standing crops of epilithic algal community outside the mesocosm. From the beginning of 5th July to 14th July, chlorophyll-a content maintained the same level. On 17th July it increased slowly and after that it maintained the same level and then increased rapidly. On the other hand, inside the mesocosm chlorophyll-a content maintained same level from 5th July to 9th July but it decreased slowly and reached it's lowest value of 7.2 mg · m^{-2} on 17th July and it maintained this for a short time and decreased again. Inside the mesocosm the variation pattern of chlorophyll-a content was similar

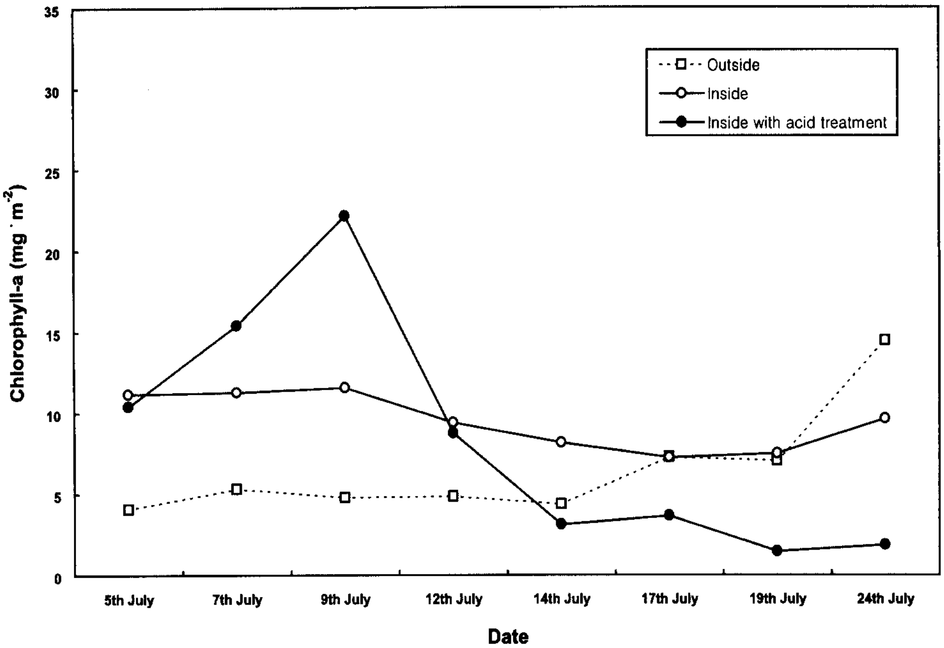

Fig. 2. The variations of chlorophyll-a contents in Togyo reservoir from 5th July to 24th July 1999 (□: outside the mesocosm, ○: inside the mesocosm, ●: inside the mesocosm with acid treatment).

Table 2. The dominants in epilithic algal community outside the mesocosm in Togyo reservoir from 5th July to 24th July 1999

Date / Dominant species	July							
	5th	7th	9th	12th	14th	17th	19th	24th
Achnanthes minutissima	463.2 (44.7%)	662.0 (60.8%)	897.2 (73.0%)	374.5 (35.4%)	1061.7 (61.3%)	831.0 (59.2%)	753.7 (38.3%)	1227.7 (46.8%)
Cylindrospermum stagnale				384.8 (36.4%)			767.3 (39.0%)	572.0 (21.8%)
Navicula bicephala	131.6 (12.7%)				188.3 (10.9%)			
Oscillatoria angusta				115.4 (10.9%)				
Spondylosium ellipticum								
Total standing crops (10^3 cells · cm^{-2})	1036.9	1088.4	1229.1	1056.8	1731.1	1404.4	1967.9	2622.8

with the standing crops of epilithic algal community but the variation range between the standing crops and chlorophyll-a content was different. On the other hand, the chlorophyll-a content inside with acid treatment increased rapidly from the beginning of the experiment on 5th July to 9th July and reached it's highest value of 22.1 mg · m^{-2} on 9th July. After that it decreased rapidly until the 14th July and then remained low until the end of experiment on 24th July. The variation pattern of chlorophyll-a content was almost similar with the standing crops of epilithic algal community but the range was wider on chlorophyll-a content than that of the standing crops and the value of chlorophyll-a content on 9th July was exceptional (Fig. 2).

Outside the mesocosm pennate diatoms were co-dominants with filamentous forms of bluegreen algae. 4 species were dominants (Table 2): the diatoms, *Achnanthes minutissima* and *Navicula bicephala* and the bluegreens, *Cylindrospermum stagnale* and *Oscillatoria angusta*. Throughtout the investigated periods, *Achnanthes minutissima* was the major dominant species accounting for over 30% of the total standing crops and the second dominant was a *Cylindrospermum stagnale*. Other dominants, *Navicula bicephala* and *Oscillatoria angusta* occupied about 10% of the total standing crops (Fig. 3).

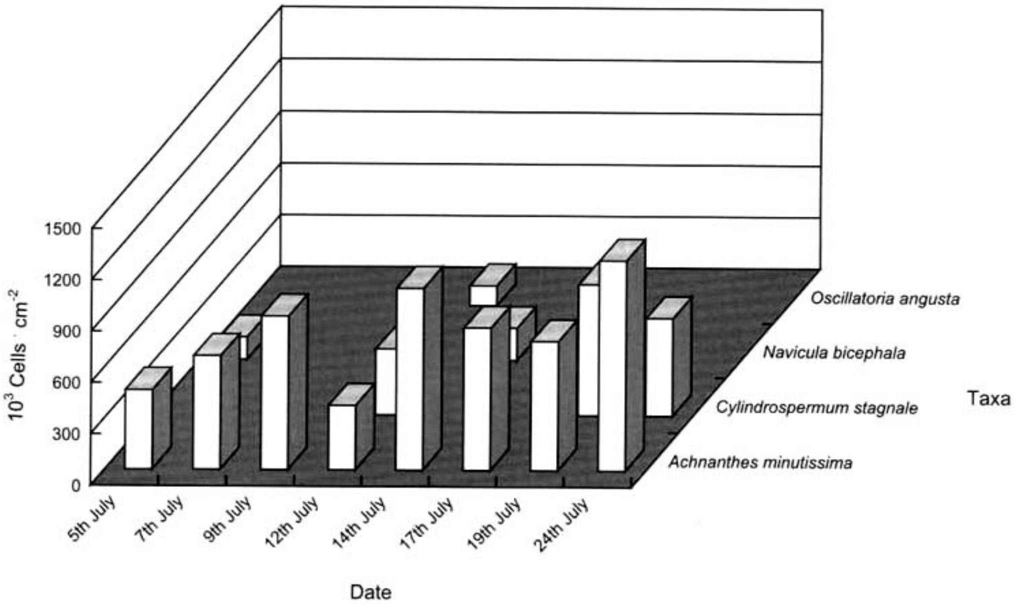

Fig. 3. The variations of standing crops of dominants outside the mesocosm in Togyo reservoir from 5th July to 24th July 1999.

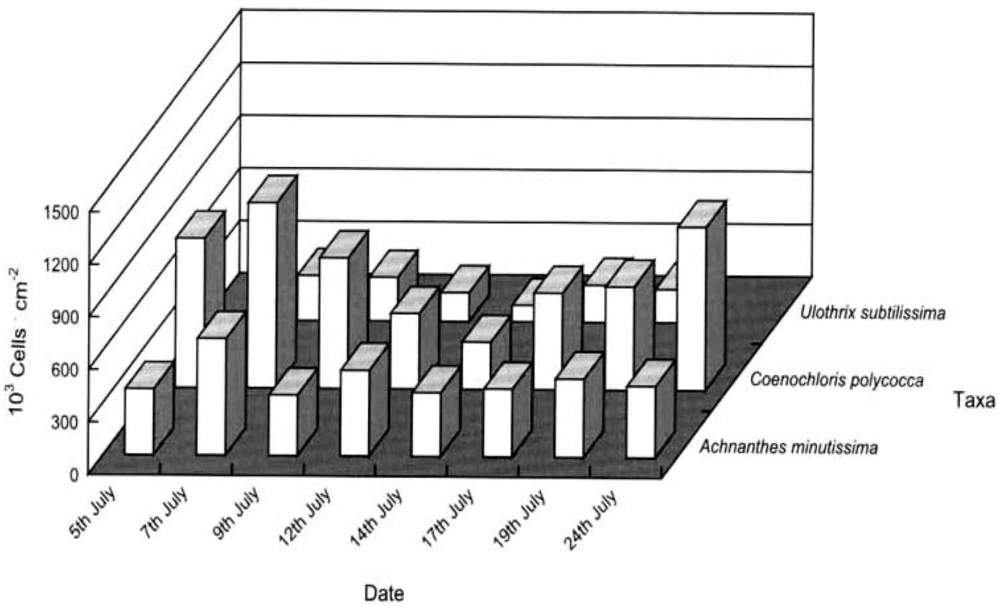

Fig. 4. The variations of standing crops of dominants inside the mesocosm in Togyo reservoir from 5th July to 24th July 1999.

Inside the mesocosm, 3 species were co-dominants: *Achnanthes minutissima*, *Coenochloris polycocca* and *Ulothrix subtilissima* (Table 3). Among those, *Achnanthes minutissima* was a major components of the species composition but the coverage of the total standing crops was lower than outside. *Coenochloris polycocca* was green alga which is planktonic and has a spherical colony formation. The third one was *Ulothrix subtilissima*, which is free floating or liable to attach to the substrata. *Achnanthes minutissima* composed a relatively similar proportion of the total standing crops throughout the investigated periods but *Coenochloris polycocca* dominated at the beginning of the experiment (Fig. 4).

Inside the mesocosm with acid treatment, the dominants (Table 4) were *Achnanthes minutissima*, *Coenochloris polycocca*, *Cylindrospermum stagnale* and *Ulothrix subtilissima*. The major dominant was *Coenochloris polycocca* throughtout the investigated periods (Fig. 5). On acidification, derived acid value was reached on the 12th July. Before and after the this date, *Coenochloris polycocca* was dominant. However species composition differed between the inside and and

Table 3. The dominants in epilithic algal community inside the mesocosm in Togyo reservoir from 5th July to 24th July 1999

Date / Dominant species	July							
	5th	7th	9th	12th	14th	17th	19th	24th
Achnanthes minutissima	377.1 (25.6%)	665.9 (30.8%)	346.9 (23.5%)	489.2 (41.7%)	364.0 (41.2%)	387.3 (30.3%)	447.7 (31.0%)	407.5 (21.8%)
Coenochloris polycocca	853.8 (57.9%)	1058.1 (49.0%)	745.4 (50.4%)	429.9 (36.6%)	268.4 (30.4%)	552.2 (40.9%)	589.1 (40.8%)	932.9 (49.8%)
Ulothrix subtilissima		258.6 (12.0%)	250.8 (17.0%)	166.0 (14.1%)	95.6 (10.8%)	212.7 (16.6%)	190.9 (13.2%)	
Total standing crops (10^3 cells · cm^{-2})	1474.8	2163.7	1477.8	1175.6	884.2	1277.8	1442.1	1872.9

Table 4. The dominants in epilithic algal community inside the mesocosm with acid treatment in Togyo reservoir from 5th July to 24th July 1999

Date / Dominant species	July								
	July	5th	7th	9th	12th	14th	17th	19th	24th
Achnanthes minutissima		163.7 (12.6%)		176.1 (14.9%)			193.5 (19.5%)	288.7 (19.6%)	
Coenochloris polycocca	567.5 (70.1%)	646.3 (49.8%)	663.1 (49.3%)	866.7 (73.3%)	577.8 (44.9%)	751.1 (64.9%)	483.7 (48.8%)	755.4 (51.2%)	
Cylindrospermum stagnale		330.1 (25.4%)	152.2 (11.3%)		395.8 (30.8%)	167.8 (14.5%)	147.2 (14.8%)		
Ulothrix subtilissima	98.7 (12.2%)		312.0 (23.2%)		136.5 (10.6%)		102.0 (10.3%)	226.6 (15.4%)	
Total standing crops (10^3 cells · cm^{-2})	809.2	1298.2	1345.8	1183.1	1286.2	1157.0	991.6	1475.5	

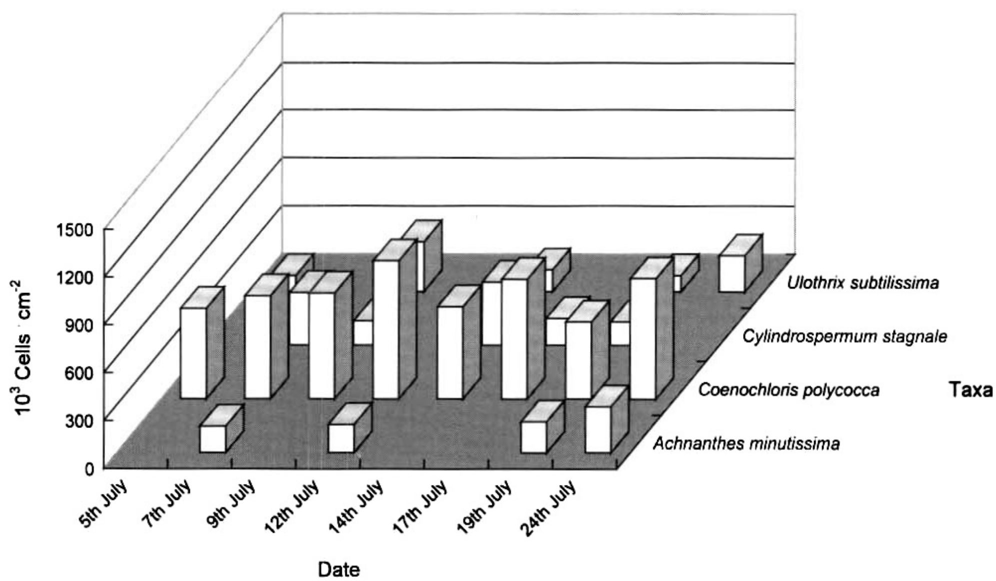

Fig. 5. The variations of standing crops of dominants inside the mesocosm with acid treatment in Togyo reservoir from 5th July to 24th July 1999.

outside. *Achnanthes minutissima* did not account for as much standing crop as inside the mesocosm without acid treatment. During the periods with reduced pH after 12th July, *Coenochloris polycocca* dominated the total standing crops. Then we propose that this species was well adapted to the low pH.

Among the dominants in the course of experimental acidification, *Coenochloris polycocca* is clearly the most important species. On the other hand, *Achnanthes minutissima* which has been the most important species in the colonization by the epilithic algal community of the mesocosm (Lee *et al.*: submitted) was less important at the lower pH. *Coenochloris polycocca* is a species well adapted to low pH confirming the results of Planas *et al.* (1989).

Epilithic algal assemblage

The algal assemblages were dominated by diatoms, green and bluegreen algae. From a view of life forms, filamentous, colonial and adnate forms were most abundant, and often surrounded by mucilage. The total number of species observed was 98 species: 75 species occurred inside the mesocosm and 61 species inside the mesocosm with acid treatment. Throughout the investigation periods, *Achnanthes minutissima, Coenochloris polycocca. Pedogonim* sp. and *Ulothrix subtilissima* appeared very frequently inside of mesocosm: colonial and filamentous forms of green algae were most abundant rather than araphid diatoms. Inside of mesocosm with acid treatment, *Achnanthes minutissima, Bullbochaete* sp., *Coenochloris polycocca, Cylindrospermum stagnale, Oedogonium* sp. and *Ulothrix subtilissima* appeared very frequently: colonial and filamentous forms of green algae were most abundant. We recorded little change in algal species composition after the acid treatment as suggested by Planas *et al.* (1989).

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