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ECOLOGY

Effects of agriculture on the abundance and community structure of epilithic algae in mountain streams of subtropical Taiwan

Shu-Fen YU and Hsing-Juh LIN*

Department of Life Sciences, National Chung Hsing University, Taichung 402, Taiwan

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ABSTRACT. This study aimed to characterize the abundance and community structure of epilithic algae and to examine the effects of intensive agriculture in mountain streams of the Wuling area. There were significant seasonal variations in epilithic algal biomass, with higher values in spring and winter and lower values in summer and fall. Effects of agriculture on the subtropical streams of the Wuling area were significant and varied with the extent of agriculture in the catchment. The biomass was significantly higher in Yousheng Stream with a larger area of agriculture than in other streams. Diatoms were the most abundant species, contributing over 85% to the total cell number. Most of these were pennatae diatoms, of which the genus *Achnanthidium* was the most abundant in the area. However, the communities showed clear seasonal and spatial changes. BIOENV analysis suggested that the combination of water temperature, conductivity , NO_2+NO_3 and SiO_2 concentrations and current velocity comprised the major factors explaining seasonal changes in the community, while the combination of NO_2+NO_3 and SiO_2 concentration and grazer density comprised the major factors affecting spatial changes. Changes in abundance and community structure of epilithic algae can be used to monitor the effects of agriculture in tropical/subtropical mountain streams.

Keywords: *Achnanthidium*; Current velocity; Diatoms; Grazer density; NO_2+NO_3; Wuling.

INTRODUCTION

Agriculture in a particular catchment area is considered among the most-serious threats to the streams within that area (Squires and Saoud 1986; Johnson et al., 1997; Wilby et al., 1998). There are positive relationships between stream nutrient concentrations and the area under agriculture (Leland and Porter, 2000; Rhodes et al., 2001; Kao and Chiu, 2004; Inwood et al., 2005). Nutrient loading from agricultural land is 10-20 times the load from forested land (Rekolainen, 1989; Pekárová and Pekár, 1996). Agricultural runoff can lead to higher nutrient concentrations in nearby streams (Chételat et al., 1999; Pan et al., 1999; Dodds et al., 2002) and to an acceleration of eutrophication (Rekolainen, 1989; Soranno et al., 1996). Although eutrophic impacts are thought to be greater in the tropics than at higher latitudes (Downing et al., 1999), studies of how agriculture effects tropical/subtropical streams are still very scarce.

Attached algae are often regulated by a variety of factors, such as nutrients, discharge, current velocity, light, grazers, and water temperature (Rosemend et al., 1993; Pan et al., 1999; Soininen and Könönen, 2004). The nutrient contents of attached algae often show a positive correlation with the percent of the catchment area altered by human activities (Ekholm et al., 2000; Rhodes et al., 2001). Higher water temperatures resulting from the removal of riparian vegetation will increase attached algae abundance (Dodds et al., 2002), which may be 2-4-times higher in clear-cut streams than at other sites (Hill and Knight, 1988; Kiffney and Bull, 2000). However, little is known about the response of attached algae to agricultural land use in tropical/subtropical streams.

In Taiwan, many catchments of mountain streams at >1,500 m elevation have been developed for farming fruits and vegetables. The Wuling area is located in the upstream reaches of the Dajia River of central Taiwan at about 1,800 m in elevation, comprising three third-order streams: Cijiawan Stream, Yousheng Stream and Gaoshan Stream (Figure 1). They are characterized by having short, straight, steep channels and are often influenced by fluctuations in precipitation and typhoons. The catchment of Gaoshan Stream is vegetated by natural forests. The catchments of the Cijiawan and Yousheng Streams have each been developed for agriculture, but it is more intensive in the catchment of Yousheng Stream. The Cijiawan and Gaoshan Streams are the only habitats of the endangered Taiwanese masu salmon (*Oncorhynchus masou formosanus*). An early warning system to indicate

*Corresponding author: E-mail: hjlin@dragon.nchu.edu.tw; Tel: +886-4-22840416; Fax: +886-4-22874740.

if the streams in the Wuling area are changing due to agriculture is required. Comparative studies of the three streams with their different degrees of local agriculture would be helpful in determining the effects of agriculture on tropical/subtropical streams. The aims of the present study were: (1) to characterize the biomass and community structure of epilithic algae in the streams of the Wuling area; (2) to examine the effects of agriculture on this biomass and community structure.

MATERIALS AND METHODS

Study sites

In total, twelve sites were sampled in the streams of the Wuling area (Figure 1). The stream beds contain abundant rocks, primarily deposited by the weathering of sandstone and slate. The mean water temperature was 12°C, ranging from 18°C in summer to 10°C in winter. Climatic data derived from a local weather station (Wuling) during 2003-2004 (Climatological Data Annual Report, Central Weather Bureau of Taiwan) showed that in the dry season of October-April, the mean monthly rainfall normally does not exceed 40 mm, and that in the wet season of May-September, the average monthly rainfall frequently exceeds 150 mm. The mean discharge in the dry season was 1.84-2.30 $m^3 s^{-1}$ and in the wet season was 2.58-2.96 $m^3 s^{-1}$ (Chung et al., 2008).

Gaoshan Stream is 10.6 km long with a mean gradient of 140 m/km and a catchment area of 40 km^2. The stream bed is dominated by pebble (39%) and rubble (27%) in winter, but consists of a high proportion of boulders (44%) in summer (Yeh, 2006). This catchment is vegetated by natural forests, and no agriculture is present (Wang, 1989), so the stream is assumed to be in a pristine state. Cijiawan Stream is 15.3 km long with a mean gradient of 130 m/km and a catchment area of 76 km^2. The stream bed consists of a high proportion of pebble (42%) in winter, but is dominated by rubble (26%) and boulders (21%) in summer (Yeh, 2006). The upper reach of Cijiawan Stream is bordered by riparian forest, but the lower reach has been developed for agriculture, including an area of 104 ha of vegetables, apples, peaches, and pears. It is considered to be moderately influenced by agriculture. Yousheng Stream is 11.4 km long with a mean gradient of 68 m/km and a catchment area of 31 km^2. The substrate is dominated by gravel (39%) and pebble (39%) (Yeh, 2006). The entire reach with an area of 295 ha has been intensively developed for farming vegetables since the 1970s. The stream has been channelized, and the natural riparian vegetation has been almost completely removed. It is regarded as highly influenced by agriculture. Canopy cover was higher in the Gaoshan Stream (90%) and the upper reach of the Cijiawan Stream (86%), and it was lower in the lower reach of the Cijiawan (57%) and Yousheng Streams (50%).

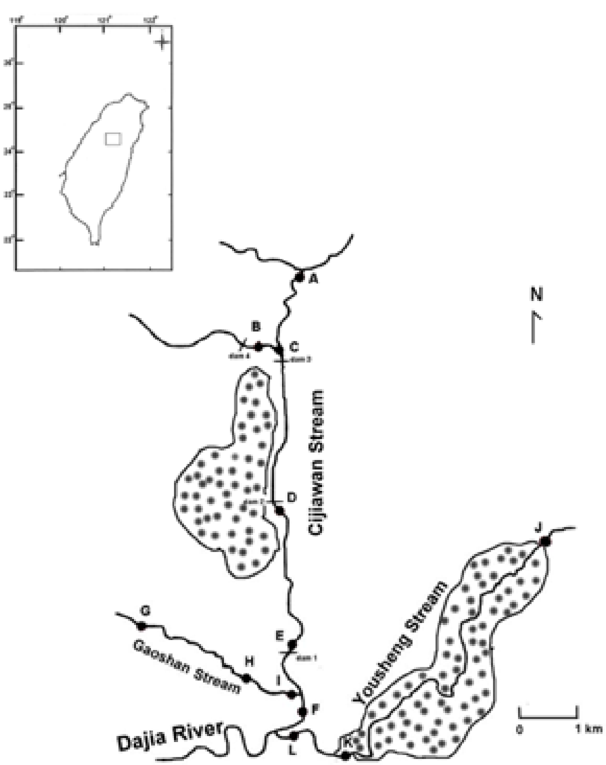

Figure 1. Sampling sites and agricultural areas (black circles) in the streams of the Wuling area.

Sample collection

Riffles are the major habitat in the streams of the Wuling area. Attached algae samples were collected monthly from randomly selected rocks (*n* = 5) in the riffle zone of streams at 7:00-10:00 am from March 2003 to March 2004. On each rock, a frame made of steel was used to define a sampling area of an algal patch of 12.5 cm^2, and four algal patches were scraped off a surface area of 50 cm^2 with a toothbrush. The scraped algae were then washed off the toothbrush and rocks with 50-100 mL of filtered stream water. In the laboratory, the algal samples were centrifuged for 10 min to concentrate them to 5 mL. A 3-mL subsample was extracted for chlorophyll *a* in 90% acetone (Lobban et al., 1988). The other 2-mL subsample was fixed in Lugol's solution for taxon identification.

The taxon was identified and counted using a light microscope of Differential Interference Contrast (Zeiss Axioplan 2). Filamentous algae such as *Oscillatoria* and *Cladophora* were counted in every cell with a hemocytometer. Diatom samples were further treated with H_2SO_4 and KNO_3 (Sabater et al., 1990) and mounted with Naphrax. At least 500 diatom valves were counted per sample. Identification was carried out according to Patrick and Reimer (1966), Patrick and Reimer (1975), Round et al. (1990), Vyverman (1991), Yamagishi (1992), Round and Bukhtiyarova (1996), and Krammer and Lange-Bertalot (1997).

On each sampling occasion, water temperature, pH, conductivity, turbidity, dissolved oxygen (DO), and current velocity of the stream were measured *in situ* with portable meters (YSI 6560 multiparameter monitoring sensors and Son Tek Flow Tracker Handheld ADV) at 7:00-10:00 am. Water samples for other chemical factors were immediately placed on ice in a cooler and brought back to the laboratory for analyses of nitrite (NO_2^-) and nitrate (NO_3^-), total phosphorus (TP), biological oxygen demand (BOD), and SiO_2 following the standard methods of APHA (Clesceri et al., 1998). Density of grazers including Ephemeroptera and Trichoptera was determined by collecting with Suber net sampler (30.5 × 30.5 cm) by Kuo and Chiu (2004; 2005).

Data analysis

Shannon-Weiner diversity indices (*H'*) were calculated using natural logs as indices of epilithic algal communities. A two-way fixed ANOVA model was used to determine whether environmental factors, epilithic algal biomass in terms of chlorophyll *a* or Shannon-Weiner diversity indices significantly differed among study sites or among seasons. Before the analyses, values of chlorophyll *a* were log-transformed (Clarke and Warwick, 1994) to conform to normality and homogeneity of variance assumptions. If the results of the ANOVA indicated significant treatment effects at the 0.05 probability level (p), then Fisher's protected least significant difference (LSD) test was used to determine which means significantly differed. The relationships of abundance of the epilithic algal taxon with environmental variables were determined using Spearman rank correlations.

In order to reveal spatial and seasonal patterns of the epilithic algal community, species compositions were studied using multivariate analyses in the PRIMER (vers. 5.2) computer package (Clarke and Gorley, 2001). The Bray-Curtis coefficient was used to produce a similarity matrix of species composition between any two samples according to the cell number of each taxon. Cell numbers were log-transformed to reduce the weighting of the dominant taxon in the communities (Krebs, 1999). The similarity matrix was first classified by hierarchical agglomerative clustering using the unweighted pair group mean arithmetic (UPGMA) linking method, and it was then ordinated using non-metric multidimensional scaling (MDS) techniques. A two-way crossed ANOSIM (analysis of similarities) was used to determine whether the effects of site and season on the community structure were significant by comparing the observed statistic to its permutation distribution in the absence of differences (Clarke and Warwick, 1994). If the results indicated significance at the 0.05 probability level, pairwise comparisons and the Bonferroni correction for the significance level were used to determine which levels differed. Similarity of percentages (SIMPER) was employed to reveal the most-common taxon in replicate samples for each group. BIOENV was employed to reveal the most influential environmental variables affecting the structure of the epilithic algal community. BIOENV selects the most influential environmental variable subset by maximizing the weighted Spearman rank correlation (ρ_w) between the similarity matrix of species composition and similarity matrices of a combination of environmental variables considered at steadily increasing levels of complexity.

RESULTS

Environmental variables

For each site, monthly samples were pooled into one sample. Classification and MDS ordination separated the epilithic algal communities into four regions (Figure 1), including region I of the upper reach of the Cijiawan Stream (site A), region II of the lower reach of the Cijiawan Stream (sites B-F), region III of the Gaoshan Stream (sites G-I), and region IV of the Yousheng Stream (sites J-L).

In the Wuling area, water temperature ranged between 5.1-18.5°C (Table 1). DO remained high (> 6.8 mg L^{-1}), but turbidity (< 0.68 NTU) and BOD (< 2 mg L^{-1}) remained low in all regions. pH values and conductivity, respectively, averaged 8.3~8.5 and 152-239 µS cm^{-1}. Current velocity was high with an average of 33 -65 cm s^{-1}. Concentrations of SiO_2 and TP in the water column were low and remained 4.18-6.14 and 0.02-0.03 mg L^{-1}, respectively, in all regions. However, NO_2+NO_3 concentrations corresponded well with the area of agriculture in the catchment of the streams. NO_2+NO_3 concentrations were high in the lower reaches of the Cijiawan Stream and even higher in the Yousheng Stream. The mean NO_2+NO_3 concentration reached 5.65 mg L^{-1} in the Yousheng Stream. Mean canopy cover was 50%-90%. Grazer density averaged 261-839 individual m^{-2}.

Water temperature, turbidity, conductivity, current velocity, and grazer density underwent significant seasonal and regional changes (Table 2). Water temperature was higher in summer (18.5°C) and lower in winter (5.1°C). It was higher in the Yousheng Stream which lacked a canopy due to the agricultural activity, and lower in the Gaoshan Stream which had a high canopy. Turbidity was higher in the Yousheng Stream and lower in the upper reach of the Cijiawan Stream. It was higher in spring and lower in fall. Yousheng Stream and the upper reach of the Cijiawan Stream possessed greater conductivity values than other regions. The greatest conductivity value was observed in winter when the discharge was small. Current velocity was fastest in Gaoshan Stream, followed by the lower reach of Cijiawan Stream and Yousheng Stream, and was slowest in the upper reach of Cijiawan Stream. It was faster in summer and fall and slower in winter and spring. Grazer density was greater in Cijiawan Stream and lower in Gaoshan Stream and Yousheng Stream. It was greater in fall and winter and lower in spring and summer.

Nutrient concentrations also showed significant seasonal and regional changes (Table 2). TP concentrations did not differ among the regions. Concentrations of NO_2+NO_3 were higher in Yousheng Stream, and the

Table 1. Environmental variables and grazer density of the four regions collected from March 2003 to March 2004 in the Wuling area. Values are presented as the mean±SD with the range in parentheses.

Site group	I	II	III	IV
Water temperature (°C)	11.8±2.4 (7.4-15.5)	11.8±2.4 (5.1-16.5)	11.2±2.8 (5.1-15.2)	12.8±3.3 (8.0-18.5)
DO (mg/L)	9.8±1.2 (7.5-11.4)	9.9±1.4 (6.9-13.2)	10.3±1.2 (7.0-13.0)	10.1±1.2 (6.8-12.2)
Turbidity (NTU)	0.14±0.11 (0.01-0.35)	0.19±0.17 (0.01-0.67)	0.24±0.18 (0.01-0.62)	0.34±0.23 (0.02-0.68)
BOD (mg/L)	0.60±0.39 (0.03-1.40)	0.61±0.33 (0.00-1.32)	0.62±0.40 (0.05-1.70)	0.69±0.42 (0.01-1.59)
pH	8.5±0.3 (8.1-9.1)	8.3 ±0.3 (7.7-9.2)	8.3 ±0.2 (7.9 -8.9)	8.3±0.6 (7.1-9.1)
Conductivity (μS/cm)	233±45 (200-350)	152±36 (90-230)	152±27 (125-210)	239±72 (130-390)
Current velocity (cm/s)	33±15 (15-60)	55 ±29 (14 -123)	65±26 (55-122)	53 ±27 (16-94)
SiO_2 (mg/L)	6.14±0.74 (5.00-7.01)	4.18±0.81 (2.70 - 6.43)	4.99±0.72 (3.66-6.61)	4.53±0.87 (2.80-6.04)
NO_2+NO_3 (mg/L)	0.24±0.14 (0.11-0.62)	0.70±0.60 (0.10-2.91)	0.26±0.39 (0.04-2.22)	5.65±3.84 (0.26-18.66)
Total P (mg/L)	0.02±0.02 (0.00-0.06)	0.02±0.03 (0.00-0.17)	0.03±0.05 (0.00-0.19)	0.02±0.02 (0.00-0.11)
Grazer density (individual/m^2)	839±354 (191-1444)	743±417 (69-1794)	310±179 (152-739)	261±203 (54-680)

Region I: the upper reach of Cijiawan Stream, region II: the lower reach of Cijiawan Stream, region III: Gaoshan Stream and region IV: Yousheng Stream.

mean value was 6-8-times that of other regions. SiO_2 concentrations were higher in the upper reach of Cijiawan and Gaoshan Streams. In general, these nutrient concentrations were higher in summer and fall and lower in winter and spring.

Epilithic algal community and biomass

Diatoms were the most dominant taxa of the epilithic algal communities in the streams of the Wuling area. Of 114 taxa identified, 107 taxa were diatoms, followed by cyanobacteria and Chlorophyta. Diatoms contributed 85% of the total cell numbers of the algal communities. Most diatoms belonged to pennatae genera, and > 40% of the genera were of *Achnanthidium*. *A. atomus, A. minutissimus*, and *Platessa hustedtii* were the most abundant species.

Samples from all study sites were also pooled into monthly samples of combined sites. Classification and MDS ordination of the cell number of each taxon of the communities separated the monthly samples into four seasonal categories (Figure 2). The winter category contained samples collected during the period of December 2003 to February 2004; the spring category comprised samples from March 2004 and March 2003; the summer category was from April 2003 to October 2003; and the fall category was from November 2003.

Table 2. Two-way ANOVA (site × season) of environmental variables and grazer density collected from the four regions in different seasons in the Wuling area. If the results of the ANOVA indicated significant treatment effects at the 0.05 probability level (p), then Fisher's protected LSD test was used to determine which means significantly differed. Means with the same letter do not significantly differ.

Source	df	F value	Pr > F	
Water temperature				
Site	3	5.01	0.003	IV^{a} I^{ab} II^{ab} III^{b}
Season	3	69.95	< 0.001	$Summer^{a}$ $Fall^{b}$ $Spring^{c}$ $Winter^{d}$
Site × Season	9	0.85	0.575	
DO				
Site	3	1.01	0.389	
Season	3	0.35	0.790	
Site × Season	9	1.90	0.057	
Turbidity				
Site	3	7.88	< 0.001	IV^{a} III^{b} II^{bc} I^{c}
Season	3	13.22	< 0.001	$Spring^{a}$ $Winter^{b}$ $Summer^{b}$ $Fall^{c}$
Site × Season	9	0.22	0.992	
BOD				
Site	3	0.38	0.764	
Season	3	0.77	0.514	
Site × Season	9	0.66	0.742	
pH				
Site	3	0.69	0.560	
Season	3	2.63	0.053	
Site × Season	9	0.37	0.946	
Conductivity				
Site	3	43.86	< 0.001	IV^{a} I^{a} II^{b} III^{b}
Season	3	7.70	< 0.001	$Winter^{a}$ $Spring^{b}$ $Summer^{b}$ $Fall^{b}$
Site × Season	9	1.13	0.348	
Current velocity				
Site	3	17.06	< 0.001	III^{a} II^{b} IV^{c} I^{c}
Season	3	9.22	< 0.001	$Summer^{a}$ $Fall^{ab}$ $Winter^{bc}$ $Spring^{c}$
Site × Season	9	1.27	0.260	
SiO_2				
Site	3	45.00	< 0.001	I^{a} III^{b} IV^{c} II^{d}
Season	3	42.66	< 0.001	$Fall^{a}$ $Summer^{a}$ $Spring^{b}$ $Winter^{c}$
Site × Season	9	0.85	0.568	
NO_2+NO_3				
Site	3	59.88	< 0.001	IV^{a} II^{b} III^{b} I^{b}
Season	3	4.48	0.005	$Summer^{a}$ $Winter^{ab}$ $Spring^{b}$ $Fall^{b}$
Site × Season	9	8.35	< 0.001	
TP				
Site	3	0.79	0.501	
Season	3	5.98	0.001	$Fall^{a}$ $Summer^{a}$ $Winter^{b}$ $Spring^{b}$
Site × Season	9	0.28	0.979	
Grazer density				
Site	3	22.33	< 0.001	I^{a} II^{b} III^{c} IV^{c}
Season	3	3.18	0.026	$Fall^{a}$ $Winter^{ab}$ $Summer^{b}$ $Spring^{b}$
Site × Season	9	0.73	0.682	

df = degree of freedom. Region I: the upper reach of Cijiawan Stream, region II: the lower reach of Cijiawan Stream, region III: Gaoshan Stream and region IV: Yousheng Stream.

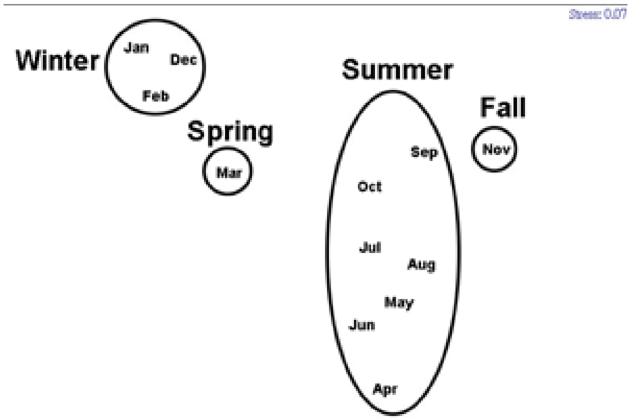

Figure 2. MDS ordination of Bray-Curtis similarities between epilithic algal communities collected monthly from March 2003 to March 2004 in the streams of the Wuling area.

The MDS ordination (stress = 0.07) revealed a clear and gradual seasonal shift in species composition from April 2003 to April 2004 in a counter-clockwise direction. There appeared to be a rapid shift in the epilithic algae communities from November (fall) to December (winter).

ANOSIM analysis demonstrated significant differences in epilithic algae communities among seasons ($R = 0.36$, $p = 0.001$). The pairwise comparisons further showed that the epilithic algae communities sampled in winter could be separated from those sampled in summer ($R = 0.55$, $p = 0.001$), fall ($R = 0.36$, $p = 0.001$), and spring ($R = 0.28$, $p = 0.001$).

The species richness of the epilithic algal communities was higher in Yousheng Stream, with its intense exposure to agricultural influences, than in other regions. Shannon-Wiener diversity indices of the epilithic algal communities revealed significant seasonal and regional differences. The Shannon-Weiner diversity indices were significantly higher in Yousheng Stream (1.85 ± 0.50) than in Gaoshan Stream (1.79 ± 0.36). The lower reach of Cijiawan Stream had the lowest diversity indices (1.62 ± 0.47). Diversity indices were significantly higher in fall (1.85 ± 0.41) and summer (1.79 ± 0.47) than in winter (1.70 ± 0.42) or spring (1.62 ± 0.47).

SIMPER analysis showed that mean similarity between any two regions was relatively lower in region IV (Yousheng Stream) with region I, II and III (Table 3). Region I (upper reach of Cijiawan Steam) and region II (lower reach of Cijiawan Steam) had a higher similarity. The mean similarity between winter and other seasons was lower than that between other seasons and each other (Table 4). There was a relatively higher similarity between summer and fall. The mean similarity of the algal communities within each season was relatively lower in spring and higher in fall, indicating that the variability among replicated samples was greater in spring (Table 5). The seasonal shift in the epilithic algal communities in the Wuling area could be illustrated by changes in the relative abundances of the six most distinct taxa in each season, including the diatoms *A. atomus*, *A. minutissimum, P. hustedtii*, *Cocconeis placentula* and *Planothidium lanceolatum*, and the cyanobacteria *Oscillatoria* spp. *A. atomus* was the most frequently observed taxon year round, but it occurred more frequently in spring and less in fall. *P. hustedtii* also occurred year round, but was more frequently observed in fall and winter. *A. minutissimum* and *P. lanceolatum* also occurred year round, but showed unclear seasonal changes. *C. placentula* occurred more frequently in summer and fall, but disappeared in winter. The cyanobacteria including *Oscillatoria* spp., *Chroococcus* spp. and *Lyngbya* sp. and the chlorophyte *Cladophora* sp. also occurred more frequently in winter.

Achnanthidium, *Cocconeis*, and *Planothidium* were the most frequently observed genera of the epilithic algal communities in all of the regions examined in the Wuling area (Table 6). In the region I (upper reach of Cijiawan Steam), the two diatom genera *Cocconeis* and *Navicula* occurred more frequently than in other regions. The cyanobacteria *Chroococcus* spp., *Lyngbya* sp. and *Oscillatoria* spp. occurred more frequently in the region II (lower reach of Cijiawan Steam) than in other regions. In the region III (Gaoshan Stream), no cyanobacteria were observed, but *Gomphonema* was the most representative diatom genus. The diatoms *Cymbella cymbiformis* var. *nonpunctata*, *Cymbella* sp1., *Diatoma vulgaris*, *Encyonema minutum*, *Nitzschia sinuata* var. *tabellaria*, and *Nitzschia* sp1. occurred more frequently in Yousheng Stream than in other regions.

Epilithic algal biomass in terms of chlorophyll *a* also showed significant seasonal and regional differences (Figure 3). However, season and region showed a significant interaction. Chlorophyll *a* concentrations of epilithic algae collected from Yousheng Stream increased more rapidly and became greater in winter and spring, but no significant difference was detected from other regions in summer. Mean chlorophyll *a* concentrations of epilithic algae in Yousheng Stream reached 320 mg

Table 3. Mean similarity (%) of epilithic algal communities between any two regions of the streams in the Wuling area.

	I	II	III	IV
I	100	35.7	34.0	29.7
II		100	33.6	29.1
III			100	32.4
IV				100

Table 4. Mean similarity (%) of epilithic algal communities between any two seasons of the streams in the Wuling area.

	Spring	Summer	Fall	Winter
Spring	100	32.9	33.8	29.5
Summer		100	40.1	26.8
Fall			100	29.6
Winter				100

Table 5. Contribution (%) of species occurrence in seasonal epilithic algal communities in the streams of the Wuling area.

Season	Spring	Summer	Fall	Winter
Average similarity within each season	34.8	39.7	46.3	36.4
Species				
Bacillariophyta				
Achnanthidium atomus (Hust.) O. Monnier, Lange-Bert. Et Ector	22.1	15.5	14.2	16.9
Achnanthidium minutissimum (Kütz.) Czarn.	8.00	6.54	7.85	7.22
Achnanthidium sp.1	3.17	6.15	4.78	3.16
Achnanthidium sp.2		1.68		2.00
Achnanthidium sp.3		1.27	5.81	1.57
Caloneis sp.				10.7
Cocconeis pediculus Ehrenb. var. *pediculus*	5.17	1.62	2.55	1.45
Cocconeis placentula var. *euglypta* (Ehrenb.) Grunow	6.10	15.6	13.8	
Cymbella affinis Kütz.				4.25
Cymbella sp.1	1.68			1.80
Diatoma hyemalis var. *mesodon* (Ehrenb.) Grunow	2.03	1.38		
Gomphonema dichotomum Kütz. var. *dichotomum*	1.11			
Gomphonema minutum (C. Agardh) C. Agardh	1.23	3.59		
Gomphonema occultum E. Reichardt & Lange-Bert.		1.24	1.66	
Gomphonema olivaceum (Hornem.) Bréb. var. *olivaceum*	1.70			
Gomphonema tergestinum Fricke var. *tergestinum*		2.68		
Gomphonema sp.2				1.63
Navicula cryptocephala Kütz.	1.08			
Navicula sp.1	2.58			
Navicula sp.2		1.97	1.37	
Navicula sp.4			2.11	
Nitzschia sinuata var. *tabellaria* (Grunow) Grunow			1.16	
Nitzschia sp.1			1.23	
Planothidium lanceolatum (Bréb. ex Kütz.) Round & Burkhtiy.	6.98	7.21	8.79	7.16
Platessa hustedtii (Krasske) Lange-Bert.	10.8	9.58	13.8	14.8
Reimeria sinuata (W. Greg.) J.P. Kociolek & Stoermer	1.49	3.6	3.46	
Rossithidium pusillum (Grunow) Round & Bukht.	3.74			1.40
Synedra ungeriana var. *pseudogaillonii* (H. Kobayasi et ldei)		1.25	3.86	
Chlorophyta				
Cladophora sp.				0.90
Cyanobacteria				
Chroococcus spp.	1.74	1.75		0.91
Lyngbya spp.	1.38	2.18		3.84
Oscillatoria spp.	7.11	5.27	3.93	8.41
Total	89.3	90.0	90.3	88.1

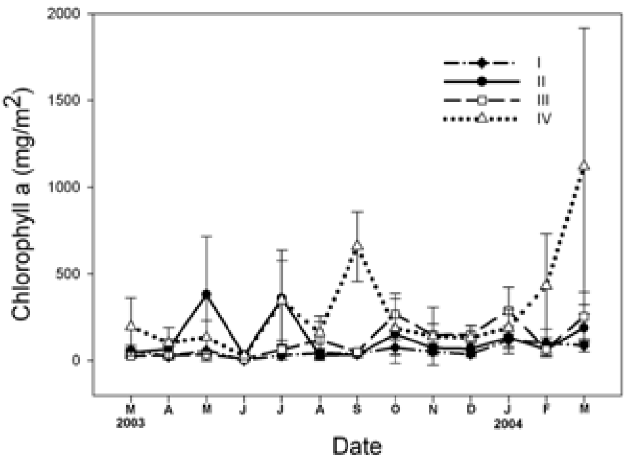

Figure 3. Monthly changes in epilithic algal chlorophyll *a* concentrations (mean±SD) from March 2003 to March 2004 collected in four regions of the streams in the Wuling area. Region I: the upper reach of Cijiawan Stream, region II: the lower reach of Cijiawan Stream, region III: Gaoshan Stream and region IV: Yousheng Stream.

m^{-2}. The chlorophyll *a* concentrations collected from the lower reach of Cijiawan Steam averaged 96 mg m^{-2}. The chlorophyll *a* concentrations in the upper reach of Cijiawan Steam and Gaoshan Stream were lower and averaged 52 mg m^{-2} and 82 mg m^{-2}, respectively.

Correlation of epilithic algae with environmental variables

BIOENV analysis showed that the combination of water temperature, conductivity, NO_2+NO_3 and SiO_2 concentrations, and current velocity were the main factors (ρ_w = 0.688) explaining the seasonal shifts in the epilithic algal communities in the Wuling area. It also showed that the combination of NO_2+NO_3 and SiO_2 concentrations and grazer density were the main factors (ρ_w = 0.589) responsible for the regional variations.

The diatoms *A. atomus*, *Achnanthes* sp. 1, *Caloneis* sp., *Cymbella*, *Planothidium*, *P. hustedtii* and *Rossithidium pusillum*, the chlorophyte *Cladophora* sp. and the cyanobacteria *Oscillatoria* spp. were negatively correlated with water temperature (Table 7). Conversely, the diatoms *Cocconeis, Diatoma, Encyonema, Gomphonema*, *Navicula*, and *Reimeria* were positively correlated with water temperature. Almost all the species were negatively correlated with current velocity. *A. atomus*, *Achnanthes* sp. 1, *G. dichotomum*, *Achnanthidium*, *Diatoma, Encyonema, Gomphonema*, *Planothidium*, and *Rossithidium* were negatively correlated with grazer density, while the cyanobacteria *Chroococcus* and *Oscillatoria* were positively correlated with grazer density. *A. atomus*, *A. minutissimum, Achnanthes* sp. 1., *D. vulgaris, E. minutum, N. sinuata* var. *tabellaria, Nitzschia* sp. 2, *Reimeria sinuate*, *Synedra ungeriana* var. *pseudogaillonii*, and the cyanobacteria *Nostoc* spp. were positively correlated with NO_2+NO_3 concentrations. However, *C. placentula* var. *euglypta*, *C. cymbiformis* var. *nonpunctata*, *Gomphonema tergestinum* var. *tergestinum*, and *Gomphonema* sp. 1 were positively correlated with TP concentrations. Almost all diatoms were positively correlated with SiO_2 concentrations, but *Oscillatoria* spp. was negatively correlated with SiO_2 concentrations.

DISCUSSION

Classification of trophic state in stream systems is most appropriately based on algal biomass and secondarily on nutrients (Dodds et al., 1998). Dodds et al. (1998) suggested the boundary of mean benthic chlorophyll *a* concentration for eutrophic stream systems is > 70 mg m^{-2} and the boundary between mesotrophic and oligotrophic systems is 20 mg m^{-2}. Mean chlorophyll *a* concentrations of epilithic algae in Yousheng Stream (320 mg m^{-2}) and the lower reach of Cijiawan Stream (96 mg m^{-2}) were far beyond the boundary for eutrophic systems. However, the mean chlorophyll *a* concentration in Gaoshan Stream (82 mg m^{-2}) was slightly greater than the boundary for eutrophic systems. The mean chlorophyll *a* concentration in the upper reach of Cijiawan Steam (52 mg m^{-2}) was lower than the boundary for eutrophic systems. In addition, Dodds et al. (1998) suggested the boundary of mean total nitrogen (TN) concentration for eutrophic stream systems is > 1500 µg L^{-1} and the boundary between mesotrophic and oligotrophic systems is < 700 µg L^{-1}. In this study, although organic N was not measured due to low nutrient loading through sewer drains, mean NO_2+NO_3 concentration in Yousheng Stream (5650 µg L^{-1}) was still far beyond the boundary for eutrophic stream systems. Accordingly, the severely agriculturally-influenced Yousheng Stream (region IV) could be classified as a eutrophic system. In the lower reach of Cijiawan Steam (region II), which was moderately influenced by agriculture, mean NO_2+NO_3 concentration (700 µg L^{-1}) was just beyond the boundary for mesotrophic systems. Mean NO_2+NO_3 concentrations in the upper reach of Cijiawan Steam (region I, 240 µg L^{-1}) and Gaoshan Stream (region III, 260 µg L^{-1}) were far below the boundary between oligotrophic and mesotrophic systems. These streams could therefore be classified as oligotrophic or as reference systems.

The influence of agricultural land use on NO_2+NO_3 concentrations and epilithic algal biomass is clearly demonstrated by a comparison of forested and agricultural regions. The impact of agriculture on the mountain streams of the Wuling area were significant and varied with the area of agriculture in the catchment. In the highly agriculturally-influenced Yousheng Stream, NO_2+NO_3 concentrations were extremely high, but not the concentrations of TP. Epilithic algal biomass was significantly higher in Yousheng Stream, where NO_2+NO_3 concentrations were the highest of any stream. NO_2+NO_3 concentrations were low in the upper reach of Cijiawan Stream, but increased remarkably in the lower reach after the stream had passed through the agricultural area (Figure 1). In Japanese agricultural land, the N load of chemical

Table 6. Contribution (%) of species occurrence in regional epilithic algal community in the streams of the Wuling area.

Region	I	II	III	IV
Average similarity within each region	39.9	38.4	41.6	34.6
Species				
Bacillariophyta				
Achnanthidium atomus (Hust.) O. Monnier, Lange-Bert. Et Ector	16.1	18.2	17.6	15.5
Achnanthidium minutissimum (Kütz.) Czarn.	6.88	5.04	7.57	12.5
Achnanthidium sp.1	7.13	4.52	7.11	3.11
Achnanthidium sp.2			3.87	1.66
Achnanthidium sp.3	3.51	2.04		0.87
Achnanthes sp.1				2.38
Caloneis sp.		0.91		0.67
Cocconeis pediculus Ehrenb. var. *pediculus*	5.23	1.48	1.33	3.25
Cocconeis placentula var. *euglypta* (Ehrenb.) Grunow	15.12	9.22	7.53	6.07
Cymbella sp.1				1.10
Cymbella cymbiformis var. *nonpunctata* Font.				0.91
Diatoma hyemalis var. *mesodon* (Ehrenb.) Grunow	2.64	1.01		0.60
Diatoma vulgaris Bory var. *vulgare*				3.99
Encyonema minutum (Hilse ex Rab.) D.G. Mann				1.99
Gomphonema dichotomum Kütz var. *dichotomum*			1.80	
Gomphonema minutum (C. Agardh) C. Agardh		0.83	4.76	1.56
Gomphonema occultum E. Reichardt & Lange-Bert.			1.63	
Gomphonema parvulum (Kütz.) Kütz.			1.25	0.61
Gomphonema tergestinum Fricke var. *tergestinum*			3.40	1.73
Gomphonema sp.1			1.38	
Navicula angusta Grunow	1.44			0.98
Navicula menisculus Schum.	1.07			
Navicula sp.1	1.04			
Navicula sp.2	2.29	1.30	1.33	0.72
Navicula sp.3	0.97			
Nitzschia sinuata var. *tabellaria* (Grunow) Grunow				0.89
Nitzschia sp.2				1.75
Planothidium lanceolatum (Bréb. ex Kütz.) Round & Burkhtiy.	9.76	5.55	11.4	6.65
Platessa hustedtii (Krasske) Lange-Bert.	7.61	11.9	15.3	8.88
Reimeria sinuata (W. Greg.) J.P. Kociolek & Stoermer		2.48	1.25	2.08
Rossithidium pusillum (Grunow) Round & Bukht.			2.05	0.92
Synedra ungeriana var. *pseudogaillonii* (H. Kobayasi et ldei)	0.90	0.93		2.54
Cyanobacteria				
Chroococcus spp.		4.71		
Lyngbya spp.		5.70		
Nostoc spp.				0.93
Oscillatoria spp.	8.62	14.9		2.22
Total	90.3	90.7	90.5	87.1

Table 7. Spearman rank correlation coefficients between abundance of epilithic algal species and environmental variables in the streams of the Wuling area.

	Temperature	pH	Turbidity	Conductivity	NO_2+NO_3	TP	SiO_2	DO	Current velocity	BOD	Grazer density
Bacillariophyta											
Achnanthidium atomus (Hust.) O. Monnier, Lange-Bert. Et Ector	-0.201*			0.264***	0.174*						-0.348***
Achnanthidium minutissimum (Kütz.) Czarn.		0.197*	0.171*	0.373***	0.305***			0.177*	-0.158*		-0.346***
Achnanthidium sp.1							0.237**				
Achnanthidium sp.2											
Achnanthidium sp.3			-0.262***				0.157*		-0.289***		
Achnanthes sp.1		0.253**		0.324***	0.307***						-0.313***
Caloneis sp.	-0.658***			0.293***		-0.243**	-0.534***		-0.242**		
Cocconeis pediculus Ehrenb. var. *pediculus*				0.160*					-0.314***		
Cocconeis placentula var. *euglypta* (Ehrenb.) Grunow	0.529***		-0.264***	-0.261***		0.281***	0.527***			0.159*	
Cymbella affinis Kütz.	-0.526***			0.190*			-0.450***				
Cymbella cymbiformis var. *nonpunctata* Font.	0.302***					0.158*	0.169*				
Cymbella sp.1	-0.463***		0.198*	0.326***		-0.295***	-0.374***		-0.199*	-0.218**	
Diatoma hyemalis var. *mesodon* (Ehrenb.) Grunow	0.171*			-0.264***			0.200*	-0.165*			
Diatoma vulgaris Bory var. *vulgare*		0.202*	0.180*	0.455***	0.442***						-0.161*
Encyonema minutum (Hilse ex Rab.) D.G. Mann	0.344***		0.183*		0.320***						-0.229**
Gomphonema dichotomum Kütz var. *dichotomum*	0.164*			-0.165*			0.185*				-0.268***
Gomphonema minutum (C. Agardh) C. Agardh	0.341***			-0.168*			0.198*		0.231**		-0.320***
Gomphonema occultum E. Reichardt & Lange-Bert.			0.352***	0.314***							-0.175*
Gomphonema olivaceum (Hornem.) Bréb. var. *olivaceum*			0.352***	0.314***							-0.290***
Gomphonema parvulum (Kütz.) Kütz.											-0.171*
Gomphonema tergestinum Fricke var. *tergestinum*	0.542***					0.179*	0.394***				-0.269***
Gomphonema sp.1	0.361***		-0.191*	-0.195*		0.181*	0.332***			0.213**	-0.182*
Gomphonema sp.2	-0.462***			0.201*			-0.373***				
Navicula angusta Grunow	0.206**						0.297***				
Navicula cryptocephala Kütz.						-0.166*				-0.186*	
Navicula menisculus Schum.	0.319***		-0.199*	-0.224**			0.406***				
Navicula sp.1			0.171*			-0.231**					
Navicula sp.2			-0.181*	-0.178*			0.215**				
Navicula sp.4									-0.275***		
Nitzschia sinuata var. *tabellaria* (Grunow) Grunow	-0.164*	0.275***	0.170*	0.419***	0.227**		-0.191*		-0.216**		
Nitzschia sp.1	0.175*		-0.211**								

Table 7. (Continued)

	Temperature	pH	Turbidity	Conductivity	NO_2+NO_3	TP	SiO_2	DO	Current velocity	BOD	Grazer density
Nitzschia sp.2		0.163*		0.374***	0.387***						
Planothidium lanceolatum (Bréb. ex Kütz.) Round & Burkhtiy.	-0.212**										-0.254**
Platessa hustedtii (Krasske) Lange-Bert.	-0.211**			0.221**				0.221**			
Reimeria sinuata (W. Greg.) J.P. Kociolek & Stoermer	0.314***		-0.165*		0.222**		0.176*				
Rossithidium pusillum (Grunow) Round & Bukht.	-0.169*										-0.174*
Synedra ungeriana var. *pseudogaillonii* (H. Kobayasi et Idei)	0.188*		-0.236**	0.206**	0.352**		0.178*			0.215**	
Chlorophyta											
Cladophora sp.	-0.227**			0.212**					-0.173*	-0.160*	
Cyanobacteria											
Chroococcus spp.						-0.157*					0.204*
Lyngbya spp.											
Nostoc spp.					0.193*						
Oscillatoria spp.	-0.213**						-0.288***				0.351***

*P<0.05; **P<0.01 and ***P<0.001.

agricultural fertilizers reached 59% of the total N load (Kunikane and Magara, 1984). The increases in NO_2+NO_3 concentrations are indicative of runoff from agriculture in the catchment. The NO_2+NO_3 concentration in Yousheng Stream is significantly higher than that of the Cijiawan and Gaoshan Streams, reflecting the high levels of fertilizers applied to agricultural land in comparison with other regions.

N, but not P, was found to stimulate attached algal production in subtropical streams with sufficient light (Mosisch et al., 2001). Filamentous green algae was also observed more frequently in open streams subject to high irradiance. Yousheng Stream basin had been clear cut, and the NO_2+NO_3 concentrations and chlorophyll *a* values significantly exceeded other regions. It thus had more filamentous green algae than other regions. Moreover, turbidity was also higher in Yousheng Stream and the lower reach of Cijiawan Stream. However, in Gaoshan Stream, bordered by riparian forests, NO_2+NO_3 concentrations and water temperatures remained low. Hill and Knight (1988) indicated that removal of riparian vegetation may change the amount of sunlight reaching the stream surface and thus the water temperature. In the upper Michigan River, forests were associated with lower stream NO_3 concentrations (Inwood et al., 2005). Our results suggest that clearing forests for agriculture in the catchment of subtropical streams not only increases NO_2+NO_3 concentrations, but also substantially increases erosion and sediment load from slope lands (Hornung and Newson, 1986) and water temperature.

Dissolved silicate in streams usually comes from mineral soils and bedrock, and the concentrations are higher in headwaters of the catchment. Detenbeck et al. (2003) indicated that SiO_2 concentrations in streams would decrease by reducing contact with mineral soils and bedrock in a stream system with high catchment storage, which is defined as the fraction of the catchment area covered by lakes and wetlands. In this study, we found that SiO_2 concentrations were lower in the agriculture-influenced Yousheng Stream and the lower reach of Cijiawan Stream. It appears that agriculture in the catchment reduced the inflow of dissolved silicate from mineral soils and bedrock into the streams. Dissolved silicate is known to be a main limiting factor for diatoms. In this study, we also found that almost all diatoms were positively correlated with SiO_2. Therefore, diatoms were relatively less abundant in the agriculturally-influenced regions and in winter and fall when the discharge and SiO_2 concentrations were lower in the Wuling area.

The tropical/subtropical monsoon climate in Taiwan is characterized by abundant rainfall in summer and dryness in winter. Streams of the Wuling area are thus dominated by flow regimes. Running waters in monsoon Asia often show distinct seasonality (Cusing et al., 1995). A lower stream discharge was found to result in greater attached algae biomass (Kishi et al., 2004). In mountain streams of the Wuling area, the discharge in the dry season of October-April was < 5 $m^3 s^{-1}$, and the current velocity was relatively slow (15 cm s^{-1}). In the wet season of May-September, the discharge increased to > 10 $m^3 s^{-1}$, and the current velocity reached > 60 cm s^{-1}. These facts might explain why cyanobacteria and chlorophytes were observed more frequently in winter when the current velocity was slower. Moreover, typhoons and thunderstorms often bring floods in summer. Consequently, the discharge became 20 $m^3 s^{-1}$, and the current velocity reached 122 cm s^{-1}, which might have reset the attached algae communities to earlier successional stages (Oemke and Burton, 1986). The fast current velocity and changing flow regime have likely resulted in the dominance of small-sized diatoms such as *Achnanthes, Achnanthidium*, and *Cocconeis* in the streams especially in summer and fall. These small-sized diatoms are generally characterized by prostrate or crustose forms which tightly adhere to the substrate to resist detachment by flooding (Leland and Porter, 2000).

Despite this, classification and MDS ordination of the epilithic algal communities in streams of the Wuling area clearly reflected the effects of agriculture in the catchment. The epilithic algal communities were primarily affected by NO_2+NO_3 concentrations in the streams resulting from agricultural runoff, and our conclusion is similar to the findings of Rosemond et al. (1993) and Dodds et al. (2002). High proportions and abundances of *A. minitissimum* were observed in association with extremely high NO_2+NO_3 concentrations in Yousheng Stream. Correlation with environmental variables also showed that the presence of *A. minitissimum* was positively correlated with NO_2+NO_3 concentrations in the streams. As a matter of fact, *A. minitissimum* is known to have a high demand for N (Fairchild et al., 1985; Carriok and Lowe, 1988) and is considered to be a pollution-tolerant species in many temperate streams (Krstic' et al., 1997; Kwandrans et al., 1997; Soininen and Niemelä, 2002). Correlation with environmental variables also showed that *Nostoc* spp., *D. vulgaris*, *E. minutum*, *N. sinuate* var. *tabellaria, R. sinuate*, and *S. ungeriana* var. *pseudogaillonii* were positively correlated with NO_2+NO_3 concentrations. *E. minutum* has been observed in areas with high and low nutrient concentrations (Rier and Stevenson, 2006). In this study, however, *E. minutum* was only observed in regions with high NO_2+NO_3 concentrations. These species might also be considered to be N-tolerant taxa (Fairchild et al., 1985; Rott et al., 1998; Winter and Duthie, 2000; Winter et al., 2003).

TP was suggested as being an important factor influencing the abundance and composition of diatoms in streams (Soininen and Könönen, 2004). Todd et al. (1996) found that phosphate enrichment increased the proportions of smaller algae. In this study, TP concentrations were not a primary factor structuring the epilithic algal communities in the streams. However, the abundance of *C. placentula* was found to be positively correlated with increased TP concentrations. *C. placentula* is typical of meso- or eutrophic taxon, and the optimum concentration of TP for growth was 27-396 μgL^{-1} (Van Dam et al., 1994; Soininen and Niemelä, 2002; Kovács et al., 2007). Although TP concentrations did not differ significantly among any regions, a clear seasonal pattern did emerge, especially in summer and fall, when the discharge increased. At that time, *C. placentula* replaced *A. atomus* and became the most dominant species in this region. However, the abundance of *C. placentula* quickly decreased in winter when the discharge and TP concentrations in the stream dropped.

Oscillatoria was frequently observed in streams with high nutrient loading and slower current velocities. *Oscillatoria* is also considered to be a pioneer taxon after flooding (DeNicola and McIntire, 1990a; Stevenson, 1996). In the Wuling area, current velocity was slower and NO_2+NO_3 concentrations were higher in Yousheng Stream. However, *Oscillatoria* was not the dominant taxon in Yousheng Stream. Instead, *Oscillatoria* was found to be more abundant in the lower reach of Cijiawan Stream, especially in winter. The growth of *Oscillatoria* has been found to be suppressed in high light conditions (DeNicola and McIntire, 1990b). The removal of riparian vegetation from Yousheng Stream might have increased the amount of sunlight reaching the stream surface and thus the water temperature. In the lower reach of Cijiawan Stream, nevertheless, the higher riparian canopy and NO_2+NO_3 concentrations were more suitable for the growth of *Oscillatoria*. This suggests that *Oscillatoria* is not a sensitive bioindicator for monitoring agriculture in tropical/subtropical streams.

In addition to the influence of agriculture, the abundance of many diatoms was negatively correlated with grazer density. Grazer density was also identified as one of the major factors affecting spatial changes in epilithic algal community. This suggests a top-down control of epilithic algae by aquatic insects in the stream. Nevertheless, Colletti et al. (1987) indicated that mayflies had little effect on algal assemblages at an insect density of < 1000 individual m^{-2}. In this study, the mean grazer density was only 261-839 individual m^{-2} (Table 1). However, a higher proportion of caddisflies, a grazer, was observed in the streams (Kuo and Chiu, 2005). The mouthparts of caddisflies can scrape attached algae off hard surfaces more effectively than the brush-like mouthparts of most mayfly nymphs (Peterson et al., 1998; Holomuzki and Biggs, 2006). This may be the reason that grazing effects on the abundance of epilithic algae were detected in the streams despite the low density of grazers. Grazing effects on the community composition of epilithic algae need to be further examined.

CONCLUSIONS

The effects of agriculture on the subtropical streams of the Wuling area were significant and varied with the extent of agriculture in the catchment. The epilithic algal communities were primarily affected by NO_2+NO_3 concentrations in the streams resulting from agricultural runoff. The epilithic algal biomass increased with NO_2+NO_3 concentration. Correlation analyses further identified the cyanobacteria *Nostoc* spp. and the diatoms *A. minitissimum*, *A. atomus, D. vulgaris*, *E. minutum*, *N. sinuata* var. *tabellaria*, *R. sinuate* and *S. ungeriana* var. *pseudogaillonii* as N-tolerant taxa. The diatoms *C. placentula*, *G. tergestinum* var. *tergestinum*, and *Gomphonema* sp.1 were more-closely related to increased TP concentrations. Changes in abundance and community structure of epilithic algae can be used to monitor the effects of agriculture in tropical/subtropical mountain streams.

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LITERATURE CITED

Carriok, H.J. and R.L. Lowe. 1988. Response of Lake Michigan benthic algae to in situ enrichment with Si, N and P. Can. J. Fish. Aquat. Sci. **45:** 271-279.

Chételat, J., F.R. Pick, A. Morin, and P.B. Hamilton. 1999. Periphyton biomass and community composition in rivers of different nutrient status. Can. J. Fish. Aquat. Sci. **56:** 560-569.

Chung, L.C., H.J. Lin, S.P. Yo, C.S. Tzeng, C.H. Yeh, and C.H. Yang. 2008. Relationship between the Formosan landlocked salmon *Oncorhynchus masou formosanus* population and the physical substrate of its habitat after partial dam removal from the Kaoshan Stream, Taiwan. Zool. Stud. **47:** 25-36.

Clarke, K.R. and R.M. Warwick. 1994. Change in marine communities: an approach to statistical analysis and interpretation. PRIMER-E Ltd, UK.

Clarke, K.R. and R.N. Gorley. 2001. PRIMER v5: User Manual / Tetorial. PRIMER-E Ltd, UK.

Clesceri, L. S., A. E. Greenberg and A. D. Eaton. 1998. Standard Methods for the Examination of Water and Wastewater 20th edition. American Public Health Association, Washington DC.

Colletti, P. J., D. W. Blinn, A. Pickart and V. T. Wagner. 1987. Influence of different densities of the mayfly grazer Heptagenia criddlei on lotic diatom communities. J. N. Am. Benthol. Soc. **6:** 270-280.

Cushing, C.E., K.W. Cummins, and G.W. Minshall. 1995. Ecosystems of the world 22–River and stream ecosystems. Elsevier Science B. V, Netherlands.

DeNicola, D.M. and C.D. McIntire. 1990a. Effects of substrate relief on the distribution of periphyton in laboratory streams: I Hydrology. J. Phycol. **26:** 624-633.

DeNicola, D.M. and C.D. McIntire. 1990b. Effects of substrate relief on the distribution of periphyton in laboratory streams : II Interactions with irradiance. J. Phycol. **26:** 634-641.

Detenbeck, N.E., C.M. Elonen, D.L. Taylor, L.E. Anderson, T.M. Jicha, and S.L. Batterman. 2003. Effects of hydrogeomorphic region, catchment storage and mature forest on baseflow and snowmelt stream water quality in second-order Lake Superior Basin tributaries. Freshwater Biol. **48:** 912-927.

Dodds, W.K., J.E. Jones, and E.B. Welch. 1998. Suggested classification of stream trophic state: distributions of temperate stream types by chlorophyll, total nitrogen, and phosphorus. Wat. Res. **5:** 1455-1462.

Dodds, W.K., V.H. Smith, and K. Lohman. 2002. Nitrogen and phosphorus relationships to benthic algal biomass in temperate streams. Can. J. Fish Aquat. Sci. **59:** 865-874.

Downing, J.A., M. McClain, R.J. Twilley, M. Melack, J, Elser, N.N. Rabalais, W.M. Lewis, Jr R.E. Turner, J. Corredor, D. Soto, A. Yanez-Arancibia, J.A. Kopaska, and R.W. Howarth. 1999. The impact of accelerating land-use change on the N-cycle of tropical aquatic ecosystems: current conditions and projected changes. Biogeochemistry **46:** 109-148.

Ekholm, P., K. Kallio, S. Salo, O.P. Pietiläinen, S. Rekolainen, Y. Laine, and M. Joukola. 2000. Relationship between catchment characteristics and nutrient concentrations in an agricultural river system. Water Res. **34:** 3709-3716.

Fairchild, G.W., R.L. Lowe, and W.B. Richardson. 1985. Algal periphyton growth on nutrient-diffusing substrates: an in situ bioassay. Ecology **66:** 465-472.

Hill, W.R. and A.W. Knight. 1988. Nutrient and light limitation of algae in two northern California streams. J. Phycol. **24:** 125-132.

Holomuzki, J.R. and B.J.F. Biggs. 2006. Food limitation affects algivory and grazer performance for New Zealand stream macroinvertebrates. Hydrobiologia **561:** 83-94.

Hornung, M. and M.D. Newson. 1986. Upland afforestion: influences on stream hydrology and chemistry. Soil Use Manage. **2:** 61-65.

Inwood, S.E., J.L. Tank, and M.J. Bernot. 2005. Patterns of denitrification associated with land use in 9 midweatern headwater streams. J. N. Am. Benthol. Soc. **24:** 227-245.

Johnson, L.B., C. Richards, G.F. Host, and J.W. Arthur. 1997. Landscape influences on water chemistry in Mid western stream ecosystem. Freshwater Biol. **37:** 193-208.

Kao, S.J., F.K. Shiah, and J.S. Owen. 2004. Export of dissolved inorganic nitrogen in a partially cultivated subtropical mountainous watershed in Taiwan. Water Air Soil Pollut. **156:** 211-228.

Kiffney, P.M. and J.P. Bull. 2000. Factors controlling periphyton accrual during summer in headwater streams of southwestern British Columbia, Canada. J. Freshw. Ecol. **15:** 339-351.

Kishi, D., M. Murakami, S. Nakano, and Y. Taniguchi. 2004. Effects of forestry on the thermal uabitat of Dolly Varden. Ecological Res. **19:** 283-290.

Kovács, C.S., K. Buczkó, É. Hajnal, and J. Padisák. 2007.

Epiphytic, littoral diatoms as bioindicators of shallow lake trophic status: trophic diatom index for lakes (TDIL) developed in Hungary. Hydrobiologia **589:** 141-154.

Krammer, K. and H. Lange-Bertalot. 1997. Bacillariophyceae. Spektrum Akademischer Verlag Heidelberg, Berlin.

Krebs, C.J. 1999. Ecological Methodlogy, 2nd edn. Addison-Welsey Educational Publishers, Inc, Canada.

Krstic', S., Z. Levkov, and P. Stojanovski. 1997. Saprobiological characteristics of diatom microflora in river ecosystems in the Pepublic of Macedonia as a parameter for determination of the intensity of anthropogenic influence. *In* J. Prygiel (ed.), Use of algae for monitoring rivers III. Agence. De. I' Eau. Artois-Picardie, pp. 145-153.

Kunikane, S. and Y. Magara. 1984. Fundamental considerations on nitrogen pollution of ground water and its causes. Proc. Environ. Eng. Res. **20:** 121-130.

Kuo, M.H. and M.C. Chiu. 2004. Community structure of aquatic insects monitoring in streams of Wuling area. Final report to Shei-Pa National Park.

Kuo, M.H. and M.C. Chiu. 2005. Community structure of aquatic insects monitoring in streams of Wuling area. Final report to Shei-Pa National Park.

Kwandrans, J., P. Eloranta, B. Kawecka, and K. Wojtan. 1997. Use of benthic diatom communities to evaluate water quality in rivers of southern Poland. *In* J. Prygiel (ed.), Use of algae for monitoring rivers III. Agence. De. I'Eau. Artois-Picardie, pp. 154-164.

Leland, H.V. and S.D. Porter. 2000. Distribution of benthic algae in the upper Illinois River basin in relation to geology and land use. Freshwater Biol. **44:** 279-301.

Lin, H.J., L.Y. Hsieh, and P.J. Liu. 2005. Seagrasses of Tongsha Island, with descriptions of four new records to Taiwan. Bot. Bull. Acad. Sin. **46:** 163-168.

Lobban, C.S., D.J. Chapman, and B.P. Kemer. 1988. Experimental Phycology a Laboratory Manual. Cambridge University Press, USA.

Mosisch, T.D., S.E. Bunn, and P.M. Davies. 2001. The relative importance of shading and nutrients on algal production in subtropical streams. Freshwater Biol. **46:** 1269-1278.

Oemke, M.P. and T.M. Burton. 1986. Diatom colonization dynamics in a lotic system. Hydrobiologia **139:** 153-166.

Pan, Y., R.J. Stevenson, B.H. Hill, P.R. Kaufmann, and A.T. Herlihy. 1999. Spatial patterns and ecological determinants of benthic algal assemblages, stream slope, TP, TN and riparian canopy coverage. J. Phycol. **35:** 460-468.

Patrick, R. and C.W. Reimer. 1966. The Diatoms of the United States, Vol. 1. Monographs, Academy of National Sciences, Philadelphia.

Patrick, R. and C.W. Reimer. 1975. The Diatoms of the United States, Vol. 2. Monographs, Academy of National Sciences, Philadelphia.

Pekárová, P. and J. Pekár. 1996. The impact of land use on stream water quality in Slovakia. J. Hydrol. **180:** 333-350.

Rekolainen, S. 1989. Phosphorus and nitrogen load from forest and agriculatural areas in Finland. Aqua Fenn. **19:** 95-107.

Peterson, C.G., K. Vormittag, and H.M. Valett. 1998. Ingestion and digestion of epilithic algae by larval insects in a heavily grazed mountain stream. Freshwater Biol. **40:** 607-623.

Rhodes, A.L., R.M. Newton, and A. Pufall. 2001. Influences of land use on water quality of a diverse New England watershed. Environ. Sci. Technol. **35:** 3640-3645.

Rier, S.T. and R.J. Stevenson. 2006. Response of periphytic algae to gradients in nitrogen and phosphorus in streamside mesocosms. Hydrobiologia **561:** 131-147.

Rosemond, A.D., P.J. Mulholland, and J.W. Elwood. 1993. Top-down and bottom-up control of stream periphyton: effects of nutrients and herbivores. Ecology **74:** 1264-1280.

Rott, E., H.C. Duthie, and E. Pipp. 1998. Monitoring organic pollution and eutrophication in the Grand River, Ontario, by means of diatoms. Can. J. Fish. Aquat. Sci. **55:** 1143-1453.

Round, F.E., R.M. Crawford, and D.G. Mann. 1990. The Diatoms-biology and morphology of the genera. Cambridge University Press, UK.

Round, F. E. and L. Bukhtiyarova. 1996. Four new genera based on *Achnanthes* (*Achnanthidium*) together with a re-diffinition of *Achnanthidium*. Diatom Res. **11:** 345-361.

Sabater, S., X. Tomas., J. Cambra, and Lange-Bertalot. 1990. Diatom flora of the Cape of Creus peninsula Catalonia, N. E. of Spain. Nova Hedwigia **5:** 165-195.

Soininen, J. and P. Niemelä. 2002. Inferring the phosphorus levels of rivers from benthic diatoms using weighted averaging. Arch. Hydrobiol. **154:** 1-18.

Soininen, J. and K. Könönen. 2004. Comparative study of monitoring South-Finnish rivers and streams using macroinvertebrate and benthic diatom community structure. Aquat. Ecol. **38:** 63-75.

Soranno, P.A., S.L. Hubler, and S.R. Carpenter. 1996. Phosphorus loads to surface waters: a simple model to account for spatial pattern of land use. Ecol. Appl. **6:** 865-878.

Squires, L.E. and N.S. Saoud. 1986. Effects of water quality and season on diatom community structure in the Damour River, Lebanon. Hydrobiologia **133:** 127-141.

Stevenson, R.J. 1996. The stimulation and drag of current. *In* R.J. Stevenson, M.L. Bothwell and R.L. Lowe (eds.), Algal ecology: Freshwater benthic ecosystem. Academic Press, USA, pp. 321-340.

Todd, A.W., B.R. Russell, and J.V. Ward. 1996. Importance of light and nutrients in structuring an algal community in a Rocky Mountain streams. J. Freshw. Ecol. **11:** 399-413.

Van Dam, H., A. Mertens, and J. Sinkeldam. 1994. A coded checklist and ecological indicator values of freshwater diatoms from the Netherlands. Neth. J. Aquat. Ecol. **28:** 117-133.

Vyverman, W. 1991. Diatoms from Papua New Guinea. Bibliotheca Diatomologica, 22. Gebrder Borntraeger, Berlin.

Wang, C.M. 1989. Environmental Quality and Community

Ecology in an Agricultural Mountain Stream System of Taiwan. PhD Thesis, Iowa State University, Iowa.

Wilby, R.L., L.E. Cranston, and E.J. Darby. 1998. Factors governing macrophyte status in Hampshire Chalk stream ; implications for catchment management. J. Inst. Water. Environ. Manage. **12:** 179-187.

Winter, J.G. and H.C. Duthie. 2000. Epilithic diatoms as indicators of streams total N and total P concentration. J. N. Am. Benthol. Soc. **19:** 32-49.

Winter, J.G., P.J. Dillon, C. Peterson, R.A. Reid, and K.M. Somers. 2003. Impacts of golf course construction and operation on headwater streams: bioassessment using benthic algae. Can. J. Bot. **81:** 848-858.

Yamagishi, T. 1992. Plankton Algae in Taiwan (Formosa). Uchida Rokakuho, Tokyo.

Yeh, C.H. 2006. Long-term ecological monitoring and ecosystem modeling in the Wuling area–the study of stream morphology and physical habitat change on the environmental factors. Technical report, Shei-Pa National Park Administration, Miaoli, Taiwan. (in Chinese).

農業活動對於亞熱帶台灣高山溪流石附生藻類豐度及群集之影響

于淑芬　林幸助

國立中興大學 生命科學系

武陵地區溪流是瀕臨滅絕台灣櫻花鉤吻鮭的唯一棲地。本研究目的為瞭解該溪流主要初級生產者－石附生藻類之豐度及群集結構，同時探討沿岸農業活動對於石附生藻類之影響。研究發現本區石附生藻類生物量有明顯之季節變化，在春、冬季較高，夏、秋季較低，且具高度農業活動之有勝溪，藻類生物量明顯較其他溪流為高。本區石附生藻類 85% 是矽藻，其中以 *Achnanthidium* 數量最多。石附生藻類群集亦明顯呈現時空變化。以 BIOENV 分析，發現水溫、導電度、NO_2+NO_3 與 SiO_2 濃度及流速與石附生藻類群集的季節變化最為相關，而影響藻類群集空間分布差異之主要因子為 NO2+NO_3 與 SiO_2 濃度以及藻食者密度。本研究顯示石附生藻類之豐度及群集結構變化可用來監測熱帶及亞熱帶地區高山溪流農業活動的影響。

關鍵詞： 武陵 ； 矽藻 ；*Achnanthidium*；NO_2+NO_3； 流速 ； 藻食者密度。