African Journal of Biotechnology Vol. 11(18), pp. 4168-4179, 1 March, 2012
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB11.3350
ISSN 1684–5315 © 2012 Academic Journals

Full Length Research Paper

Effect of environmental factors on distribution of stream macroalgae in Niangziguan Spring in Shanxi Province, North China

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Accepted 16 February, 2012

A survey of the spatial and temporal distribution of macroalgae in a stream system in Shanxi Province, North China, was undertaken from March, 2006 to January, 2007. The percent cover, biomass of macroalgae and several environmental factors were monitored along a 20 m stretch at each of seven sites, every 2 months during 1 year. All the measured environmental factors had seasonal fluctuations in different extent, but only air temperature and P^{3+} showed significant seasonality. In terms of temporal characterization of environmental factors, they also showed some differences among different sampling sites. Seventy-nine (79) species of macroalgae were found, with a predominance of Chlorophyta (38 species, 48.10%). Bacillariophyta and Charophyta represented the smallest proportion (3 species, 3.80% and 2 species, 2.53%, respectively). Three macoralgae species were the most widespread, occurring in all seven sampling sites. Thirty-five (35) species were found at only one site each. In terms of seasonality, 17 species occurred throughout the year, whereas 27 species were found in only one season each. The most key factor that affected the stream macroalgae was current velocity. We calculated Sorensen similarity indices to compare our study with other continent-wide surveys of stream macroalgae, but the similarity indices were all very low. This study also showed that macroalgae in different locations had significant reproductive isolation.

Key words: China, distribution, environmental factors, spatial, temporal, stream macroalgae.

INTRODUCTION

Macroalgae were considered to be any algae (filaments, tufts or mats) visible to the naked eyes and recognizable in the field (Holmes and Whitton, 1977). Stream macroalgae can be defined as those species occurring in flowing freshwaters and having a mature thallus, which are benthic and have a discrete structure recognizable with the naked eyes (Sheath and Cole, 1992). Frequently, their composition and seasonal dynamics change in response to factors such as physical and chemical composition of the water (Hynes 1970; Whitton, 1975). Recently, more algal scholars pay attention to the study on the stream macroalgae. The studies were concentrated on North America (Sheath and Burkholder, 1985; Sheath et al., 1986a, 1986b, 1988, 1989; Sheath and Cole, 1992, 1996; Sherwood and Sheath, 1999; Sherwood et al., 2000), South America (Branco and Necchi, 1996, 1998; Necchi, 1992; Necchi and Pascoaloto, 1993; Necchi et al., 1991, 1994, 1995, 2000, 2003), Europe (Holmes and Whitton, 1977, 1981; Whitton, 1975, 1984; Whitton et al., 1991; Johansson, 1982; John and Moore, 1985; Kawecka, 1980, 1981) and

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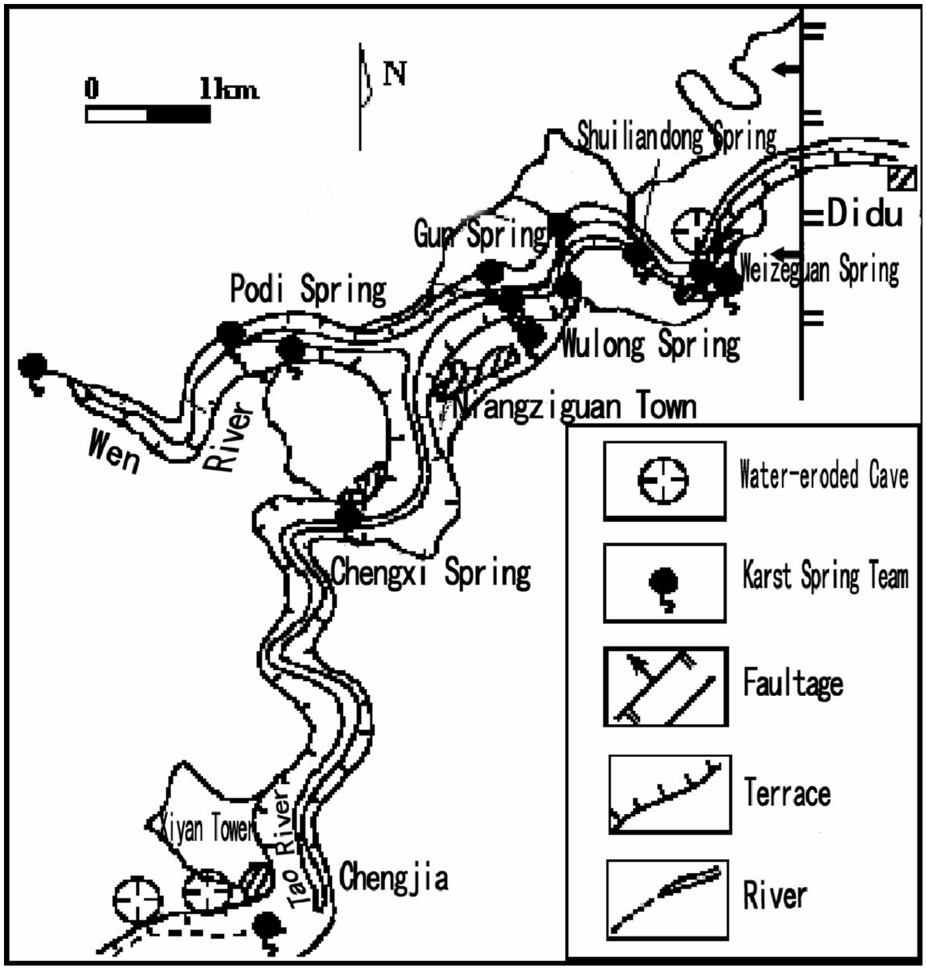


Figure 1. Location of the sampling area.

Australia (Biggs and Price, 1987; Entwisle, 1989). In China, the distribution of stream is widespread, but the research of stream algae was very poor (Shi et al., 2003; Hu et al., 2004, 2005; Xin et al., 2004; Hu and Xie, 2006). The present study examined the effect of environmental factors on distribution of stream macroalgae in Niangziguan Spring, Shanxi Province, North China.

Niangziguan Spring is the largest cold spring in North China and it is also among the largest spring in the world, 37°20′ to 38°20′ N, 113 to 114° E, situated in Pingding county. It lies in the middle of Taihang Mountain, and belongs to mid-low mountain landscape, continental climate. The area of the spring is almost 3.6×10^3 km^2 (Figure 1 and Table 1).

MATERIALS AND METHODS

Field work

Stream macroalgal samples were collected seasonally during one year (2006 to 2007), (March and May, Spring; July, summer; September and November, fall; January, winter) at seven stations.

At each station, samples were collected manually by snorkeling and SCUBA diving at 20 m intervals along the stream segment. A 1 m^2 quadrat was used as sampling unit to estimate macroalgal biomass. This quadrat size has been shown to be the best for obtaining a good sample of the species present and their biomass (De Wreede, 1985; Vázquez and González, 1995). Samples were fixed in a 4% solution of formaldehyde in freshwater.

The following environmental factors were measured: water temperature, air temperature, maximum width, maximum depth, current velocity, specific conductance, pH, NO_3^-, NO_2^-, Ca^{2+}, Mg^{2+}, HCO_3^-, P^{3+} and total rigidity. Water temperature was measured with digital JPB-607 equipment. Specific conductance was measured with a model DDB-303A digital conductivity meter. The pH was measured with a digital pH meter, model pH-4. Current velocity was determined from an average of three times required for a label to travel through a 1 m stream length. Maximum width and maximum depth were measured with tape. Negative ions were measured with UV-265 Spectrophotometer and positive ions were measured with flame photometer.

Statistical analysis

Differences in means for stream macroalgae and environmental

Table 1. Location of stream segments.

Stream segment	Location
1#	Wulong Spring, located at the middle of Niangziguan Spring
2#	Shuiliandong Spring, located at the lowest elevation of Niangziguan Spring
3#	Gun Spring, located at south central direction of Niangziguan Spring
4#	Weizeguan Spring, located at several kilometers away from Niangziguan Spring
5#	Chengxi Sandbanke, located at the mouth of Chengxi Spring
6#	Pingyang River, located at downwater of Mianhe in Niangziguan Spring
7#	Podi Spring, located at the neighbor of power plant in Niangziguan Spring

factors were tested by one-way analysis of variance (ANOVA) and Newman-Keuls multiple comparison test. Grey incidence analysis evaluated relationships between stream macroalgae and environmental factors. The relationships between the stream macroalgae and the environmental parameters were analyzed by Pearson's correlation with SPSS 13.0 software, and partial redundancy analysis (RDA) was carried out with the CANOCO 4.5 software.

RESULTS

Spatial-temporal characterization of environmental factors

The results of one-way ANOVA showed that the measured environmental factors all had seasonal fluctuations in different extent, but only air temperature ($F=92.97$, $P^{**}<0.01$) and P^{3+} ($F=6.52$, $P^{**}<0.01$) showed significant seasonality.

In terms of temporal characterization of environmental factors, they also showed some differences among different sampling sites (Figure 2).

Composition and spatial-temporal distribution of the stream macroalgae

The survey of macroalgal species in Niangziguan Spring resulted in 79 species (Table 2), with a predominance of Chlorophyta (38 species = 48.10%). The second was Cyanophyta (25 species = 31.65%). The following was Rhodophyta (seven species = 8.86%). The lower proportions were Xanthophyta (four species = 5.06%), Bacillariophyta (three species = 3.80%) and Charophyta (two species = 2.53%).

The genera *Ulotrix*, *Microspora* (Chlorophyta) and *Osicillatoria* (Cyanophyta) were the best represented with 10, eight and eight species, respectively (Table 2).

In terms of spatial distribution, there were three stream macroalgae being the most widespread, *Osicillatoria agardhii* Gomont, *O. tenuis* Agardh (Cyanophyta) and *Melosira varians* Agardh (Bacillariophyta), occurring in all the seven sampling segments. On the other hand, 35 species were found at only one segment. The number of species were different in the seven sampling segments, 1# (39 species) > 6# (34 species) > 3# (31 species) > 7# (26 species) > 4# (24 species) = 5# (24 species) > 2# (12 species).

In terms of temporal distribution, 17 species occurred throughout all the sampling seasons, whereas 27 species were found in only one season. The number of species were different in different sampling season, March (56 species) > May (42 species) > January (38 species) > September (37 species) > July (36 species) > November (26 species). Meanwhile, the average biomass showed the same trend seasonality, May > March > January > November > September >July.

Relationship between macroalgal seasonal variations and environmental factors

From the results of grey incidence analysis, we could see that the most key factor affected the average percent cover, average biomass and average species number of stream macroalgae was current velocity. The second key factor was Ca^{2+} (excepted average percent cover, which was HCO_3^-). The third key factors were NO_3^-, maximum width and air temperature, respectively (Table 3).

In the RDA model (Figure 3), the number of species of Cyanophyta was related positively with water temperature, air temperature, specific conductance, significantly positively with P^{3+} and HCO_3^- and negatively with current velocity and pH. The number of species of Chlorophyta, Bacillariophyta, and Xanthophyta related positively with maximum width and maximum depth, while those of Rhodophyta were positive with maximum width and current velocity. Spearman correlation analysis also showed that above environmental variables were all related with the number of species of each divisions.

DISCUSSION

We observed several environmental conditions in Niangziguan Spring, among them, only air temperature and P^{3+} showed significantly seasonal fluctuation, and to some extent, others varied only by a small amount over the sampling period and showed little seasonality.

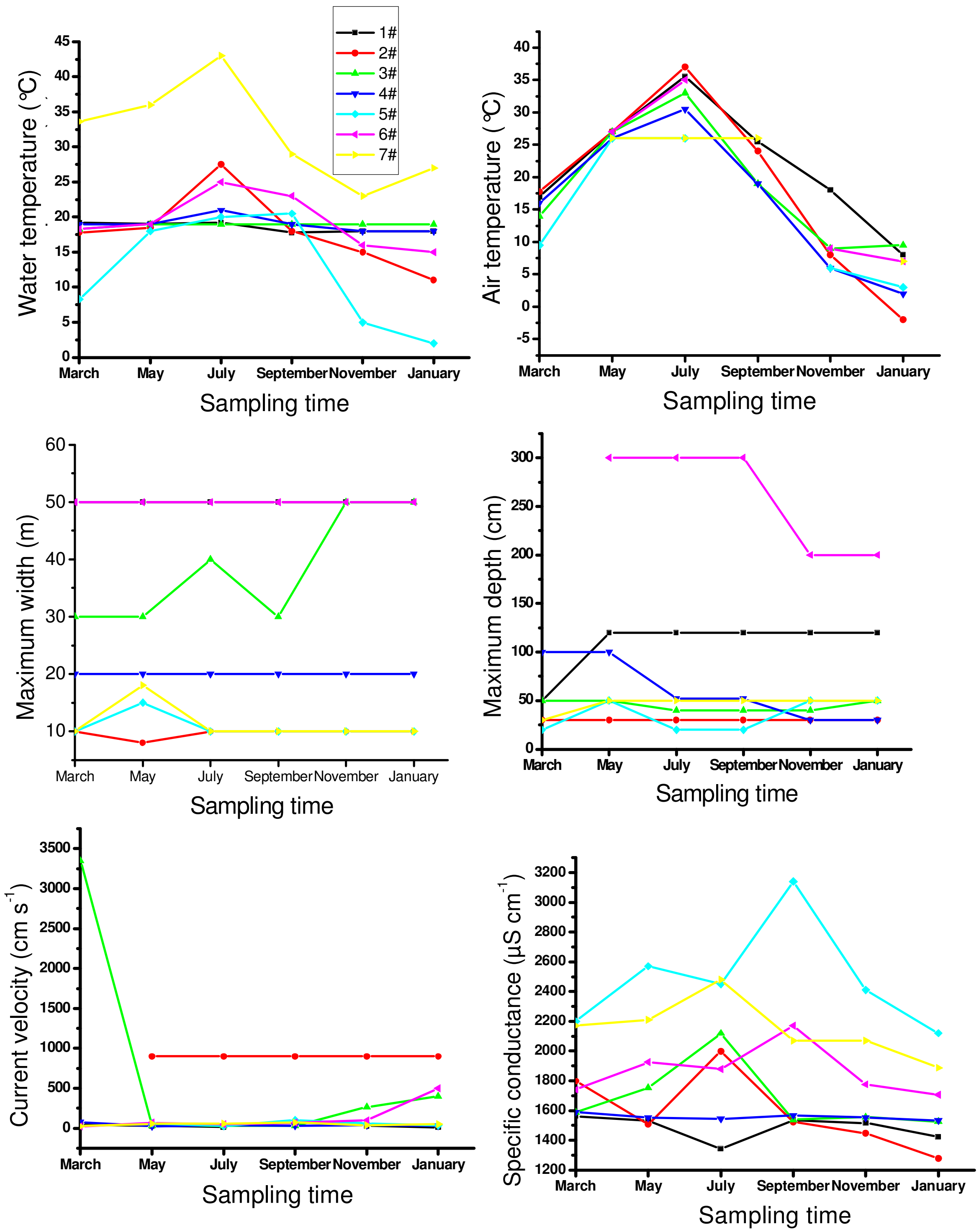
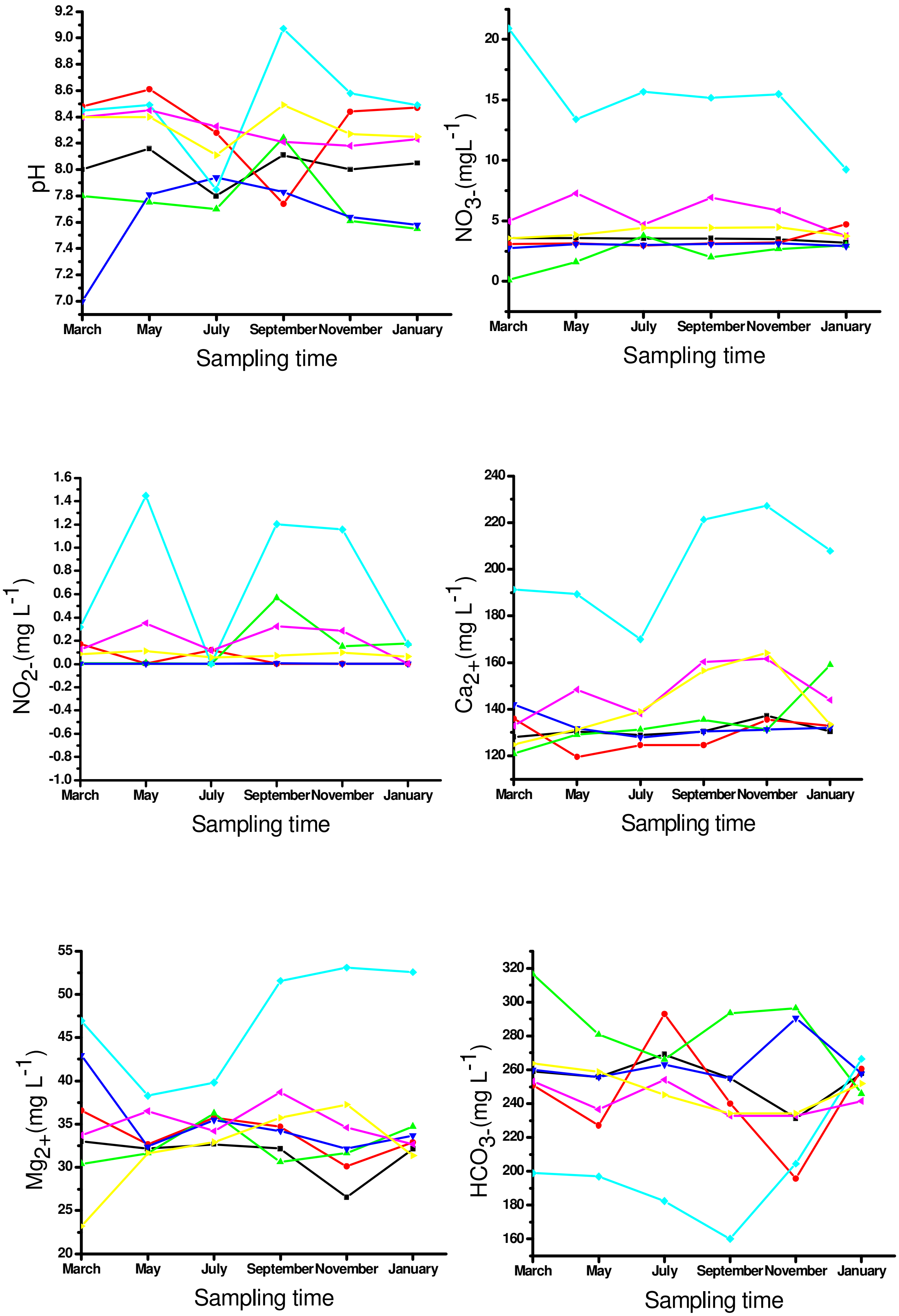


Figure 2. Spatial and temporal variation of water environmental factors in Niangziguan Spring.

In terms of temporal distribution, the stream macroalgae showed significant seasonality, spring > winter > summer > fall. This was similar to the previous studies (Necchi, 1993).

The results of grey incidence analysis concluded that the most key factor which affected the average percent cover, average biomass and average species number of stream macroalgae was current velocity. This was in accordance with the previous studies which indicated that some factors were very important in controlling stream



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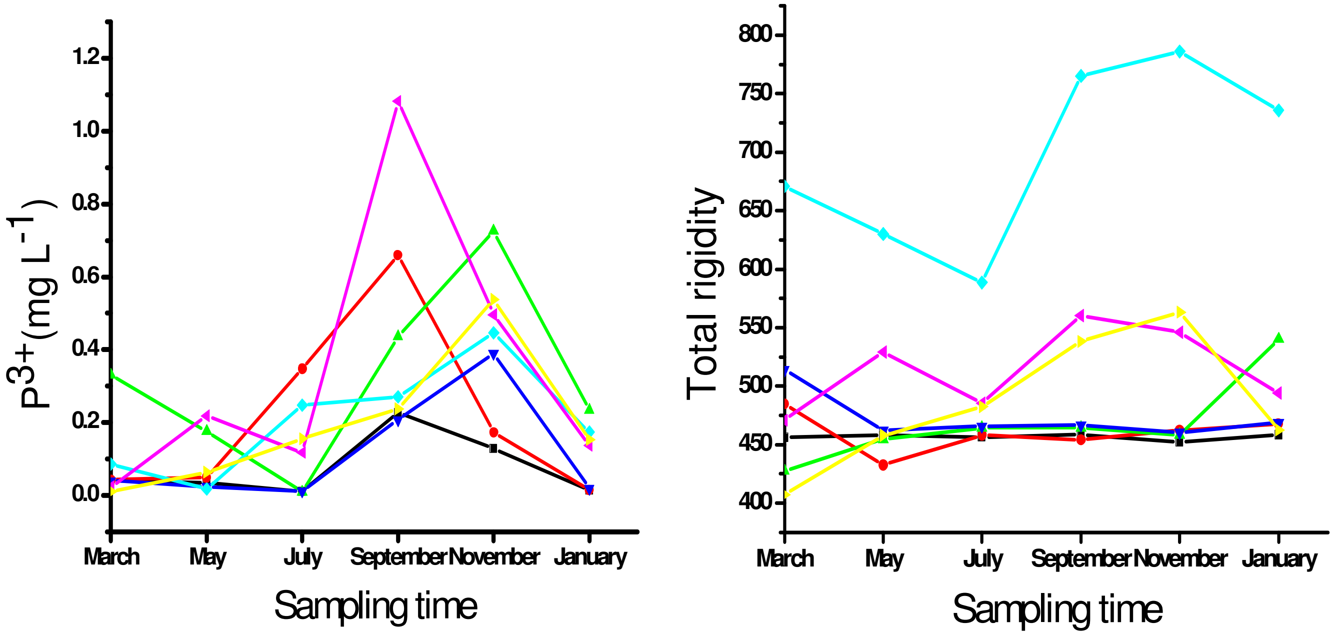

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algal growth, such as temperature, light, current velocity, substratum, water chemistry and grazing (Hynes, 1970; Whitton, 1975). Similarly, RDA and Pearson correlation analyses all showed that the number of species of each division was related with different environmental variables. Additionally, there were correlations between biotic factors, for example, Cyanophyte were negatively related with Rhodophyte, Xanthophyte positive with Bacillariophyte and Chlorophyte. In Niangziguan Spring, the dominant genera were *Ulotrix*, *Microspora* (Chlorophyta) and *Osicillatoria* (Cyanophyta). In spite of fewer representatives in number of species, Rhodophyta presented the highest values for percent cover. This fact corroborated Sheath (1984) who stated that in contrast to the generally low contribution of red algae to freshwater algal floras, its productivity and frequency might be important. The red algae were always found in the study sites 1#, 2#, 4# and 6#. In these sites, their water temperatures was 11.0 to 27.5℃, pH 7.0 to 8.61. Our study mainly shows no difference with the previous surveys. Batrchospermales were always growing well in the temperature 9 to 27℃ and pH 4 to 9 (Sheath, 1984).

Comparing the stream macroalgae in Niangziguan Spring and other areas, we could see that the total species numbers varied between 15 to 79 (Table 4). The green algae are the most predominant (except in Fiji Island and Shuishentang Spring, where the Cyanophyte are the most). The water quality of Niangziguan Spring was clean, and species of Chlorophyta were diverse and dominant. Meanwhile, RDA model and Pearson correlation analysis all showed that Chlorophyte were mainly related positively with maximum width and maximum depth and these two environmental factors were comparatively constant during the sampling period.

So, Chlorophyte were distributed widespread and stable at each site. We also found that the Cyanophyte, Rhodophyte and Charophyte predominated in different areas in some extent. The Chrysophyte and Bacillariophyte appeared in several areas, but they were few. From this comparison, we could see that there were no obvious differences between our study and previous surveys (Sheath and Cole, 1996; Sherwood and Sheath, 1999; Vis et al., 1994; Necchi et al., 1994; Hu and Xie, 2006). Calculating the values of Sorensen similarity indice (Santhanam et al., 1975) to compare our study with other continent wide surveys of stream macroalgae, we could see that the similarity indices were all very low (Table 3). It varied from 0.021 to 0.314. It was relatively higher between Niangziguan Spring and Xin'an Spring (0.314), Niangziguan Spring and Shuishentang Spring (0.189), and Niangziguan Spring and Ji'nan Spring (0.082), might be because they both lay in North China. This is also expected, because we know that the stream water comes out of the underneath and near the mouth of spring, so they cannot easily cross with each other like river or lake. This study also shows that the macroalgae in the different location have significant reproductive isolation.

In summary, the macroalgal flora in Niangziguan Spring is diverse. Of course, further research is needed.

ACKNOWLEDGEMENTS

The authors greatly appreciated the staff of our laboratory

Table 2. Occurrence of macroalgal species per sampling site and season in Niangziguan Spring.

Taxa	Sampling points and time						
	1#	2#	3#	4#	5#	6#	7#
Cyanophyta							
Aulosira laxa Kirchn. ex Born.			7				7
Calothrix epiphytica W. et G. S. West				5			
C. fusca Born. et Flah.							5,1
Cylingrospermum majus Kuetzing							7
C. stagnale (Kuetzing) Born. Et Flah.			9				
Homeothrix fluviatillis Jao			7				
H. Juliana (Monegh) Kirch.	7						1
Lyngbya major Meneghini			11,1	3			
L .martensiana Meneghini	7		3,7,9,1	5	7	9	7,9
L. limnetica Lemmermann			3,5,11,1	3,7,9		3	5,7
Microcoleus vaginatus (Vauch.) Gomont			9		9		7
Oscillatoria agardhii Gomont	3,7	5	3,5,7,9,11,1	3,5,11	5,9	3,5	5,7,9
O. amoena (Kuetz.) Gomont			5	3,5			
O. amphibian C. agardh	7		3				
O. formosa Bory	9,11		5,7,9,11,1	3,7,9,11	9	3	7,1
O. princeps Vaucher	3		3,5,9	3	3,7,9	5	5,7,9,11,1
O. sancta Kuetzing			5,7,9	3	9		7,9
O. splendida Greville	3,7,11		3,5				
O. tenuis Agardh	3,9,11	5	3,5,7,11,1	3,5,7,9	3,9	3,7,9	3,5,9,11,1
Porphyrosiphon corium (Ag.) Gomont	7						5,7
P. favosum (Bory) Gomont							9
P. foveolarum (Mont.) Gom.		9				3,7,9	7
P. notarisii Kuetzing				3		3	
P. tenue(Menegh.) Gom.	3		1				7
Rivularia jaoi Chu							1
Rhodophyta							
Audouinella chalybea (Roth) Bory	3,5,7	9,11,1			3	3,5,7,9,11,1	5
A. sinensis Jao	3,5,7,9,11,1						
A. vaga (Drew) Garbary		3,5,7,9,11,1		3,5		5	
Batrachospermum arcuatum Kylin emend. Vis et al.				3,5,11,1			
B. atropurpurea (Roth) C. Agardh		3,5,7,9,11,1					
B. gelatinosum (Linnaers) De Candolle	3,5,1						
Compsopogon coeruleus (Ag.) Montagne						3,5,7,9,11,1	

Table 2. Contd.

Taxa	Sampling points and time						
	1#	2#	3#	4#	5#	6#	7#
Xanthophyta							
Tribonema affine G. S. West						3,5	
T. ulothrichoides Pascher						3,5	
T. viride Pascher						3,5	
Vaucheria biateralis Jao	3		11,1		5	3,5,11	5
Bacillarlophyta							
Diatoma vulgure Norger	3,5,7,9			5	3	3,5	
Melosira granulate (Ehr.) Ralfs		9			3,5,1	3,5,7,9,11,1	
M. varians Agardh	3,5,7,9	9	3,5,7,9,11,1	3,5	3,5,9,1	3,5,7,9,11	3
Chlorophyta							
Cladophora glomerata Kuetz.	3,5,7,9,1	3,5,7,9,11,1	5,9,11,1	11	3,5,11,1	5,7,9,11	
Cloniophora macrocladia (Nordst.) Bourrelly	11		3,9		3,7	7,9	
C. shanxiensis Ling et Xie	3						
C. spicata (Schm.) Islam	9	9	1		9,11	3,5,9,1	
Draparnaldia mulabilis (Roth)	1						
Geminella minor (Nag.) Heering	3						
G.. protogenita (Kuetz.) G. S. West						3	
Gloeotila caldaria Kuetzing						3	
Klebsormidium rivulare (Kuetz.) Morrisen et Sheath			3				
Microspora abbreviata (Rab.) Lagerheim	3						
M. floccosa (Vauch.) Thuret						3	
M. irregularis (W. et G. S. West) Wichmaun	7,9						
M. membranacea Wang	9,11		11	5,7,9			
M. quadrata Kuetzing	3						
M. stagnorum (Kuetz.) Lagerheim			9		3		
M. tumidula Hazen					1	5	
M. willeana Lagerheim			9				3
Oedogonium Link			1		5,9	3,5,11,1	
Spirogyra borealis Zheng et Ling					9	3,9	
S. longata (Vauch.) Kuetzing	3		5,1				9
S. singularis Nordstedt	3,5,7,9,11,1			3		3	
S. weberi Kuetzing	3,5,7,9,11,1						

Table 2. Contd.

Taxa	Sampling points and time						
	1#	2#	3#	4#	5#	6#	7#
Stigeoclonium aestivale (Hass.) Collins			9				
S. amoenum Kuetz.			9				
S. elongatum (Hass.) Kuetzing	1				1		
S. nanum (Dillw.) Kuetzing			5	7	5,11,1	7	1
S. subsecundum (Kuetz.) Kuetzing							1
S. variabilis Naegeli	9	9	9	9	3,5,7,9,11,1	7,9	
Ulothrix aequalis Kuetzing				7			
U. cylindricum Prescott				3			
U. geminata Jao	3						
U. oscillatoria Kuetzing	1	9			3	9,1	
U. roroda Thuret						5	
U. subconstricta G..S. West	3				3		
U. tenerrima Kuetzing	3			3			3
U. tenuissima Kuetzing	3,5						
U. variabilis Kuetzing	3,5,1					5	5
U. zonata (Web. et Mohr.) Kuetzing	1					5	
Charophyta							
Chara inconnexa Allen				3,5,7,9, 11,1			
C .vulgaris Linn	3,5,7,9,1						

Table 3. Correlative degree and order about the stream macroalgae and the environmental factors in Niangziguan Spring.

Parameter	Average percent cover		Average biomass		Average species number	
	Correlative degree	Order	Correlative degree	Order	Correlative degree	Order
Water temperature	0.896116	9	0.969891	9	1.00589	6
Air temperature	0.705515	14	0.94426	11	1.02888	3
Maximum width	0.96977	8	0.984873	3	0.874919	13
Maximum depth	0.847859	11	0.948827	10	0.958503	9
Current velocity	1.16667	1	1.13721	1	1.16304	1
Specific conductance	0.779882	13	0.869796	14	0.843131	14
pH	0.993063	4	0.97413	6	0.923013	11
NO_3^-	0.999149	3	0.971797	7	0.981408	7
NO_2^-	0.992532	6	0.974222	5	0.926849	10
Ca^{2+}	0.84528	12	0.991222	2	1.07358	2
Mg^{2+}	0.988459	7	0.971556	8	1.01304	4
HCO_3^-	1.09153	2	0.941878	12	1.0072	5
P^{3+}	0.851585	10	0.883041	13	0.886833	12
Total rigidity	0.992989	5	0.974327	4	0.965941	8

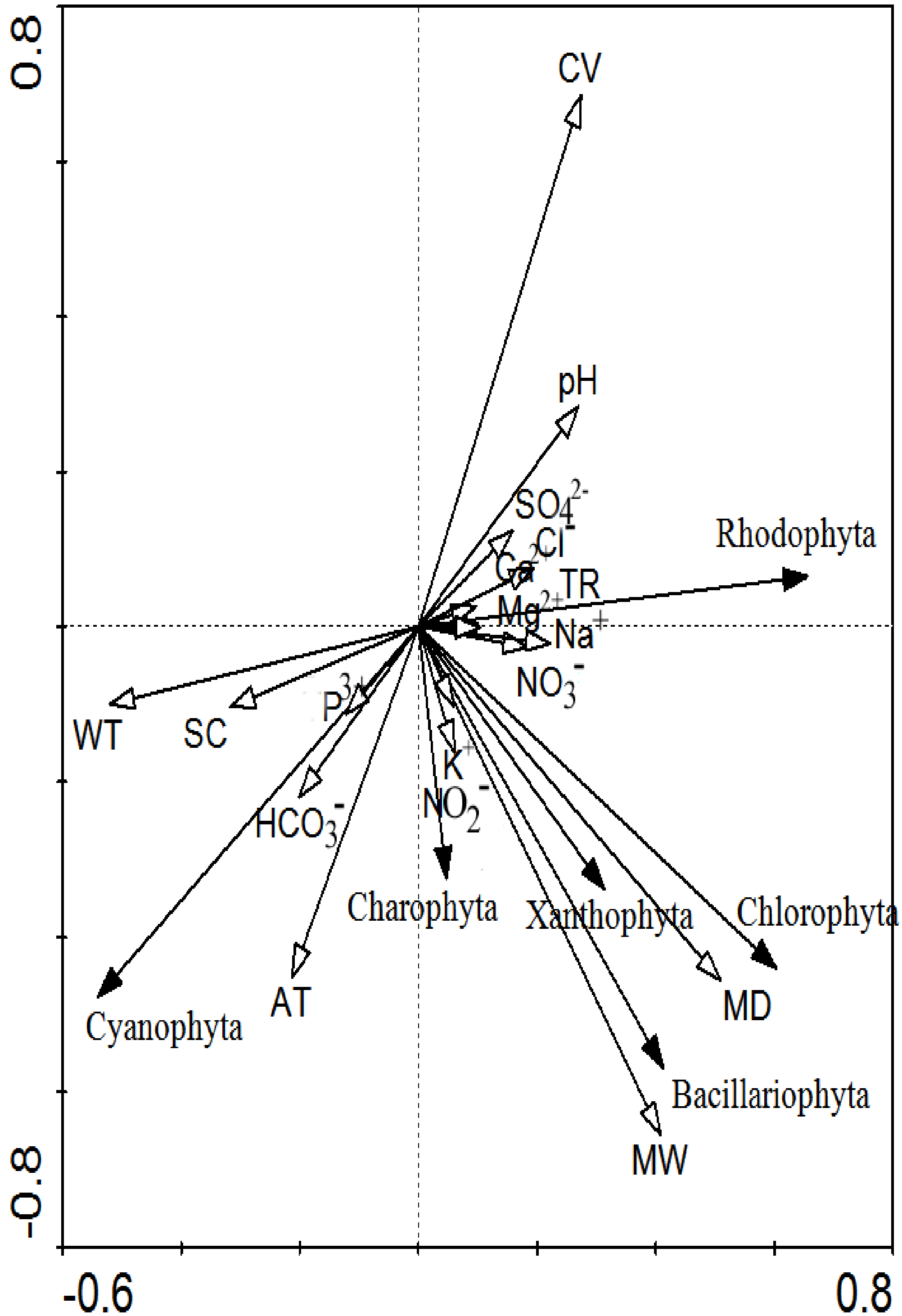

Figure 3. RDA analysis of the relationship between the species number of each division and environmental factors in Niangziguan Spring. CV, Current velocity; WT, water temperature; AT, air temperature; SC, specific conductance; MW, maximum width; MD, maximum depth; TR, total rigidity.

with the field work. This work was funded by the National Natural Science Foundation of China (31100264, 30970187), the Natural Science Foundation of Shanxi Province, China (2010021027-1, 2009021034-2) and high-tech industrialization projects of Shanxi Province, China (2010019).

Table 4. Composition and comparison with other areas about stream macroalgae in Niangziguan Spring.

Area	Cyanophyta (%)	Xanthophyta (%)	Rhodophyta (%)	Bacillariophyta (%)	Chlorophyta (%)	Charophyta (%)	Chrysophyta (%)	Total number	Similarity indice
Fiji Island (Sheath and Cole, 1996)	46.7	0	13.3	0	40.0	0	0	15	0.021
Texas (Sherwood and Sheath, 1999)	18.6	3.70	25.9	3.70	40.7	7.40	0	27	0.038
Hawaiian Islands (Vis et al., 1994)	36.7	3.30	16.7	0	40.0	0	3.30	30	0.055
South-eastern Braizl (Necchi et al., 1994)	17.9	7.10	17.9	0	35.7	21.4	0	28	0.068
Ji'nan (Xin et al., 2004)	21.1	0	15.8	10.5	42.1	10.5	0	19	0.082
Shuishentang Spring (Hu et al., 2004)	43.8%	6.20	0	12.5	31.3	6.20	0	16	0.189
Xin'an spring (Hu and Xie, 2006)	16.7	11.9	2.38	4.76	61.9	2.38	0	42	0.314
Niangziguan Spring	31.7	5.06	8.86	3.80	48.1	2.53	0	79	100.0

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