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Distribution patterns of benthic diatoms during summer in the Niyang River, Tibet, China*

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Abstract The aim of this study was to investigate the distribution, density, community structure and biodiversity characteristics of benthic diatoms, and to analyze whether differences in species composition and abundance exist in different regions of the Niyang River, Tibet. Among the 157 taxa observed in 15 sampling sites in the main river and tributary, most were casual species (>100), the relative abundance of the genera *Achnanthes* and *Fragilaria* was 67% of the total relative abundance. *Achnanthes minutissima* was the most important species and dominated the whole river reaches (average relative abundance was 30%); the average diatom densities were 7.4×10^5 cell/cm^2 at all sites, and increased slowly from the upper section to downriver. The significant indicator taxa with higher relative abundance were *Achnanthes biasolettiana* (18.0%) and *Fragilaria arcus* (18.2%), *Fragilaria capucina* var. *vaucheriae* (31.2%), *Fragilaria construens* var. *venter* (11.3%) and *Cymbella affinis* (11.0%) in the upper, tributary and mid-river sections, respectively. *Achnanthes minutissima* was the most abundant species (56%) in the downriver section. Biodiversity indices showed a gradual decrease from the up- to down-river section, and dominant species were more abundant in the upper and mid-river sections than in the downriver section. A two-way indictor species analysis (TWINSPAN) of diatom composition clearly showed four different groups, namely the upper, mid, lower and tributary sections. Detrended correspondence analysis (DCA) supported the results of TWINSPAN, and the characteristics of site distribution and species composition in the Niyang River supported the spatial structure of diatom assemblages. This study indicates that bio-assessment programs utilizing benthic diatoms could clearly benefit lotic water with regional stratification.

Keyword: benthic diatoms; diatom density; biodiversity; bio-assessment; Niyang River

1 INTRODUCTION

The Niyang River is one of the largest major tributaries of the mid-upper Brahmaputra at an altitude of over 3 000 m a.s.l., and has a very diverse range of hydrological and biological characteristics (TETCAS, 1983). It is a pristine or near-pristine clear river, and relatively well preserved; and provides a useful baseline for understanding the structure of biological communities. However, with the development of travel and intensification of water source exploitation, the impacts of anthropogenic activities have gradually increased in the Niyang River systems. Researchers have successfully used benthic diatoms as indicators to monitor water quality change and evaluate the ecological intactness of lotic systems (Stevenson et al., 1996; Kilroy et al., 2006; Jüttner et al., 2003). Soininen et al. (2004) reported that diatom assemblages had intensive spatial structure, in different parts of the country. Ponader et al. (2007) indicated that nutrient concentrations had a significant influence on the variation in diatom taxa composition. However, riverine benthic algal studies in China are at the initial stages (Wang and Zhang, 2004; Tang et al., 2004; Wu et al., 2009), and information on

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diatom composition and distribution in the Niyang River is scarce; but these studies are necessary to develop suitable management measures in the river system (Fabricius et al., 2003). The aim of the present study was to obtain basic biotic data on the distribution, abundance and community composition of benthic diatoms in the Niyang River. In addition, the identification of individual species which could potentially be used as indicators of different environmental regions and act as potential water quality indicators were determined.

2 MATERIAL AND METHOD

2.1 Study area

The Niyang River (Fig.1) is 286 km long and its watershed has a surface area of 1 780 km^2. It has an average gradient of 7.27% and a natural fall of more than 2 080 m There are many tributaries within the Niyang River system, and it subsequently joins the Brahmaputra. The river basin has an Indian Ocean warm climate, with average annual temperatures of 7.6°C, and the average annual rainfall is approximately 673 mm, 88.8% of which occurs during May–October. The upper river section is characterized by a steep slope, with cobbles and gravel as the riverbed substrata, the slope then decreases and small gravel or sand become the dominant substrata in the middle and lower sections of the river. The river is constrained by high gullies which initially create shifting meanders and later braided channels, with riffle alternating with pool in all sections.

2.2 Sample collection and processing

Benthic diatom sampling was performed at 15 sites (Fig.1) in the Niyang River system during August 2009, between the altitudes of 4 244 and 2 927 m a.s.l. The river temperature varied between 7.6 and 16.4°C, and decreased from the upper Songduo spring site (13R) to the Brahmaputra River join lower site (2R) during the study period. R and T were used to show the location of the sampling points in the main river (R) and tributary (T), respectively. These tributary sites join the Niyang River in the mid section. Diatom samples were collected from each representative substratum at each site avoiding shaded sites. To collect a single composite sample that represented the benthic diatom community in each reach, diatoms were collected from all available substrates and habitats. Diatom samples were qualitatively collected from three to five stone surfaces randomly chosen from a defined transect at each site and the algae were thoroughly removed from the exposed surfaces within a 2.7 cm diameter corer with a scalpel and nylon toothbrush using a total of 200 mL distilled water. The samples were preserved in 4% formalin. Permanent diatom slides were prepared following acid digestion of the samples. The relative abundance of diatom taxa per sample was analyzed by counting at least 300 valves

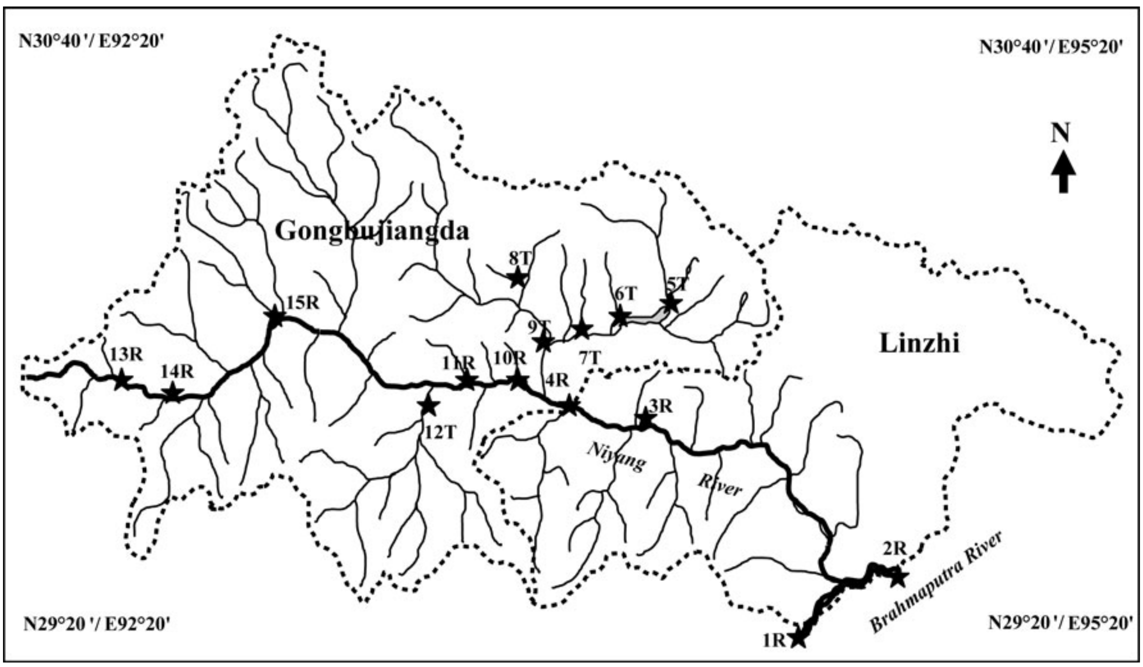

Fig.1 Location of sampling sites in the Niyang River system (stars indicate the sampling sites)

per slide. Identification of taxa followed Krammer and Lange-Bertalot (1986–1991) and Zhu and Chen (2000).

2.3 Data analysis

We adopted two statistics in common use, the Shannon-Weaver index H (Shannon and Weaver, 1949) and the evenness index J (Pielou, 1966). The program calculated information-theory diversity according to the following formula: $H=-\sum p_i \ln p_i$, where p_i is the relative abundance of the i^{th} taxon. Evenness was calculated using the following formula: $J=H/H_{max}$, where $H_{max}=\ln S$. The number of taxa in a count (S) was used as a measure of species richness (R). Analysis of variance (ANOVA) was employed to estimate differences between sites with respect to diatom density and biodiversity indices. To investigate the variations in diatom community composition at the different sites, two-way indicator species analysis (TWINSPAN) and a detrended correspondence analysis (DCA) were performed. Rare diatom species (at less than 1% in one or more sites) were excluded in the TWINSPAN analyses.

3 RESULT

3.1 Species composition and distribution

A total of 157 diatom taxa were identified in the Niyang River from the 15 samples collected during the study. The relative abundance of the majority of taxa was low, 25 taxa accounted for 5% of the relative abundance in at least one sample, representing 16% of the total number of taxa. The genera *Achnanthes* and *Fragilaria* together comprised almost 67% of all observed taxa, and *Achnanthes minutissima* was the numerically dominant diatom (average relative abundance of 30%) throughout the whole Niyang River. *Achnanthes biasolettiana*, *Cymbella sinuate*, *Fragilaria arcus*, *Diatoma vulgare* var. *linearis* were the dominant diatoms in the upper section of the river; *Achnanthes convergens*, *Cymbella affinis*, *Fragilaria capucina* var. *vaucheriae* were characteristic species in the mid section; several taxa of the genus *Achnanthes* dominated the diatom community in the downriver section.

The frequency of benthic diatom taxa appearance showed that about 100 species occurred in less than two of the 15 sites. The six most common species (*Achnanthes minutissima*, *Cocconeis placentula*, *Cymbella affinis*, *Diatoma moniliformis*, *Fragilaria capucina* var. *vaucheriae*, *Gomphonema angustum* and *Cymbella silesiaca*) appeared at more than 10 sites during the study period. *Achnanthes minutissima* was frequent at all sites.

3.2 Diatom density analysis

The overall average diatom density for the 15 sites was 7.4×10^5 cell/cm^2 (Fig.2), the maximum diatom density was found at site 3R (15×10^5 cell/cm^2), and the minimum was observed at site 9T (1.1×10^5 cell/cm^2). In contrast, total diatom density in the main river sites was more than twice that in the tributary sites. The calculated average density in the Niyang River showed that diatom density increased gradually from the upper section to downriver, and diatom density was significantly negatively correlated with altitude ($R=-0.72$, $P<0.05$). *Achnanthes minutissima* was the most abundant species with an average density of approximately 2.4×10^5 cell/cm^2, and was more than 32% of the total abundance. However, this diatom was more abundant in the lower section than in the mid and upper sections ($P<0.05$).

3.3 Characteristics of the diatom assemblages

TWINSPAN segregated the sites into groups and identified indicator species for the five different conditions in the upper, mid-upper, mid, low and tributary sections of the Niyang River (Fig.3). Species whose relative abundance was more than 1% were used in the TWINSPAN analyses. Distribution of the main species in the different TWINSPAN groups (Fig.3) showed that species were associated with the upper (group 1 included 13R, 14R, 15R) and mid-upper (group 2 included 10R, 11R, 12T) river sections (e.g. *Achnanthes biasolettiana* and *Fragilaria arcus*) on the right-hand side. A further division in the left hand branch separated the lower (group 5 included 1R, 2R) section (e.g. *Achnanthes minutissima*) from the

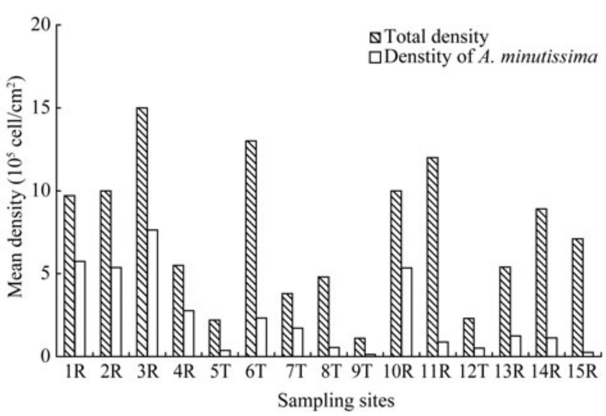

Fig.2 Mean values of total density of benthic diatoms and *Achnanthes minutissima* density in all sites

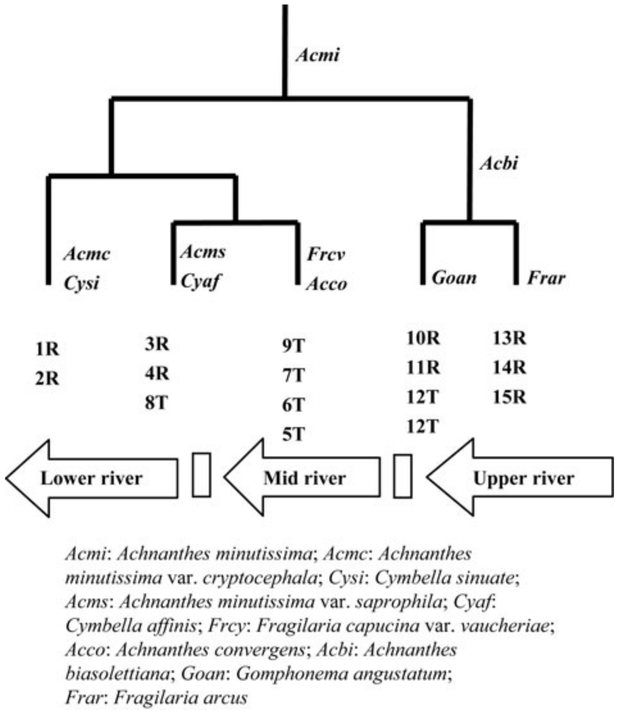

Fig.3 Dendrogram showing the TWINSPAN group of sites and indicator species for the main divisions of the 15 sampling sites

mid (group 4 included 3R, 4R, 8T) section (e.g. *Achnanthes minutissima* var. *saprophila*), the second division separated the mid section from the tributary (group 3 included 5T, 6T, 7T, 9T) section (e.g. *Fragilaria capucina* var. *vaucheriae*).

DCA analysis was concordant with the results of the TWINSPAN analysis and suggested five groups of sites (Fig.4). The TWINSPAN groups were rather

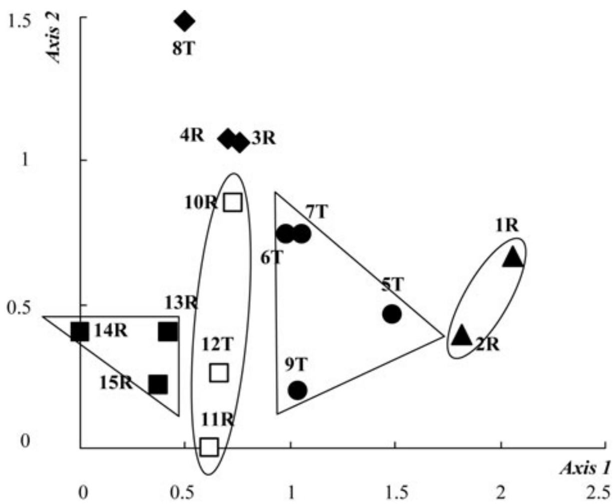

Fig.4 Detrended correspondence analysis of diatom assemblages in the Niyang River

Symbols: ■ = the first group; □ = the second group; ♦ = the third group; ● = the fourth group; ▲ = the fifth group.

well separated in the first DCA axis, from left to right, and DCA axis 1 scores at the upper, tributary, mid-upper, mid and lower sites, and the first axis was correlated with altitude.

Diatom assemblage composition differed in the four groups, these main species, which represented the taxonomic composition in each group by assessing mean relative abundance ≥6% of the sixteen taxa, are summarized in Fig.5. Groups 1, 2, 3, 4, and 5 represent the upper, mid-upper, tributary, mid, and lower sections, respectively.

Achnanthes minutissima occurred in all sites, the average relative abundance reached ≥22.4% in each group (Fig.5). The upper and mid-upper groups contained sites 13R, 14R, 15R, 10R, 11R and 12T, respectively; the upper group was a well-defined group with the highest number of significant indicator taxa of all the groups. The important species characterizing this group, such as *Diatoma vulgare* var. *linearis* (6.2%) and *Fragilaria arcus* (18.2%) indicated oligotrophic, circumneutral waters. *Achnanthes biasolettiana* was a characteristic species of the upper and mid-upper groups, and other indicator species included *Achnanthes convergens* (4.0%), *Cymbella sinuate* (2.2%), *Fragilaria capucina* var. *rumpens* (3.2%), *Diatoma moniliformis* (3.0%) and *Gomphonema angustatum* (2.1%) in the mid-upper group.

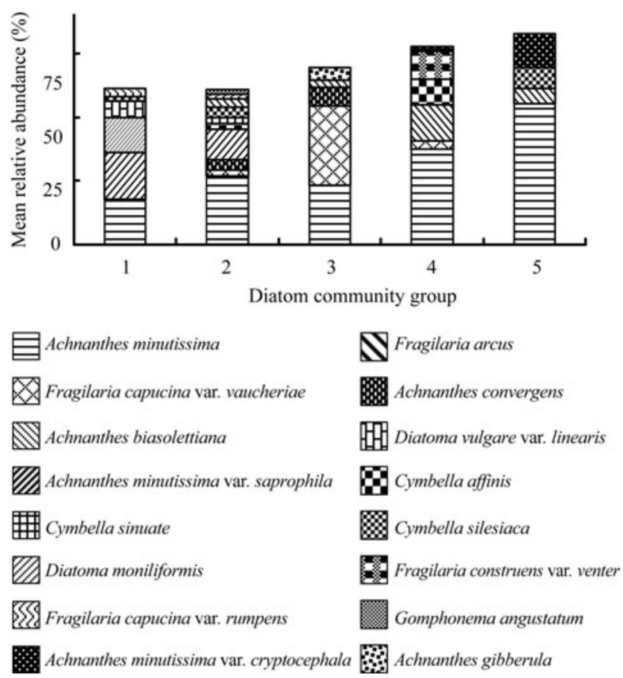

Fig.5 Relative abundance of indicator diatoms in the TWINSPAN group

The tributary group consisted of sites 5T, 6T, 7T and 9T, which joined at the mid section of the Niyang River, and sites 5T, 6T were close to an adjacent lake. The best indicator species in this group were *Fragilaria capucina* var. *vaucheriae* (31.2%) and *Achnanthes gibberula* (4.9%), both *Achnanthes convergens* and *Diatoma moniliformis* were conspicuous at these sites.

The mid group included sites 3R, 4R and 8T, and four of the most characteristic species represented 74% of all species. The most abundant species was *Achnanthes minutissima* (37.5%); *Achnanthes minutissima* var. *saprophila* (14.3%), *Fragilaria arcus* var. *venter* (11.3%) and *Cymbella affinis* (11.0%) were the most indicative taxa at these sites.

The lower group was composed of sites 1R and 2R, the water was clear and slightly alkaline or circumneutral at these sites and characterized by species of the genus *Achnanthes*, with one or two species significantly dominant. The relative abundance of *Achnanthes minutissima* and *Achnanthes minutissima* var. *cryptocephala* were 56% and 13.5%, respectively. *Achnanthes minutissima* var. *saprophila* was common in the lower section sites.

3.4 Biodiversity indices

The average species richness (*R*), evenness (Pielou's *J*) and Shannon-Weaver diversity (*H*) index of sites 11R and 1R were 50, 0.86, 4.9 and 25, 0.47, 2.2, respectively (Fig.6). Contrast biodiversity indices showed clear differences between the upper and downriver sites in evenness ($P<0.007$) and Shannon–Weaver diversity ($P<0.007$). The average species richness in the upper sites was highest (37 species) in four groups, and was similar in the other three groups. Further analysis showed that species richness, evenness and Shannon-Weaver diversity indices were positively correlated with altitude, and correlation coefficients were 0.54, 0.60 and 0.62, respectively.

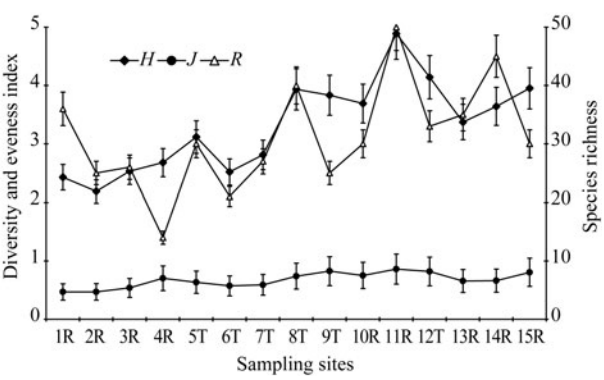

Fig.6 Mean values of Shannon-Weaver, evenness, and richness of benthic diatoms in each site

4 DISCUSSION

4.1 Species distribution

Many benthic diatoms (*Achnanthes minutissima*, *Cocconeis placentula*, *Cymbella affinis*) occurred at most sites. As the most abundant species, *Achnanthes minutissima* was ubiquitous throughout the Niyang River, but was not the most important taxa in differentiating characteristics and distinguishing the four groups and ideal indicators in individual sections. *Achnanthes minutissima* is found in water of different pollution levels (Van Dam et al., 1994). Although many taxa in our study occur in many parts of the world, some taxa were not commonly found. For example, *Achnanthes biasolettiana*, and *Cymbella sinuate* were common in the diatom communities at the upper sites at high elevation; *Cymbella minuta* was found at fewer damaged upper and mid section sites. Our findings are in agreement with Ndiritu et al. (2006), whose data supported the argument that diatom communities are strongly spatially structured. In addition, Soininen et al. (2004) reported different taxonomic compositions along the riverine gradient. Diatom species distribution may be affected by various environmental parameters, including temperature, flow rate, light availability and nutrient availability (Forster et al., 2006; Frankovich et al., 2006). Clearly, our data support the view that diatom communities exhibit a strong spatial component, with distinctly different communities in different sections of the river. It was obvious that these factors had a combined influence on benthic algal communities and should be considered together. The aim of this investigation was to determine the pattern of benthic diatoms without considering chemical factors at this stage. During the study period, the water temperature in the river sections varied between 8°C and 17°C. The 13R site in the upper section in the headwaters and the 2R site in the lower section had the lowest (8°C) and the highest (17°C) temperature, respectively. The mean turbidity of the major river (5.4 NTU) was lower than that of the tributary (8.2 NTU), and the downriver section had the highest turbidity (62.7 NTU). Fallu et al. (2002) proposed that water turbidity was responsible for diatom distribution across broad geographic regions in low mineral content, oligotrophic freshwater systems. The landscape, terrain and climate conditions of the Niyang River are very complex. A variety of drainage systems cross from the headwaters to join the Brahmaputra River, and there are many tributaries of different types in the regional sections. The upper section exhibited little within-region environmental variability, but the habitat heterogeneity increased significantly in the lower section. The river was characterized by a gentle slope, high drainage density, and no obvious major river, thus it formed extremely complex habitats in the downriver section. Potapova and Charles (2002) found that altitudinal variation was one of the most important factors (one-third of the total explainable variation) in the distribution of benthic diatoms in rivers in the USA, and the significant affect of altitude on diatom communities in the Niyang River was consistent with their results.

TWINSPAN analyses defined the diatom taxa connected with the five groups under different environmental conditions which proved to be similar to findings previously reported (Lobo et al., 1995; Fabricius et al., 2003). There were several common indicator species (*Achnanthes biasolettiana*, *Cymbella silesiaca* and *Fragilaria capucina* var. *rumpens*) in the upper and mid-upper groups, however, the high relative abundance of *Diatoma vulgare* var. *linearis* and *Fragilaria arcus* separated the upper from the mid-upper stream sites. The upper sites were closer to Songduo hotspring than the mid-upper sites, which may have induced different dominant species in the upper and mid-upper groups. The results of DCA showed that physical factors contributed to site classification, because most of the sites in each group were located within a restricted geographical area (Fig.4). Given the strong latitudinal patterns in community composition, it seems apparent that bio-assessment programs using benthic diatoms would benefit from geographical stratification. Since local in-river factors were more influential than spatial factors in explaining diatom distributions (Potapova and Charles, 2002), the predominance of groups rather than species might reduce some of the problems caused by uncertainly and variational taxonomy, and functional groups have been used successfully for benthic algae (Leland and Porter, 2000). Therefore, a combination of regional stratification and predictive modeling based on local environmental features might provide a powerful framework for diatom-based bio-assessment of the Niyang River.

4.2 Species diversity

During this study, the water of the upper section was clear, oligotrophic, and low-density residential, and high species richness and diversity were observed at the upper to mid-river sites. Those areas suffered low level pollution from industrial and agricultural sources and small scale human settlement, however, with tributary and residential density increasing, the disturbance level in the lower section was higher than that of the upper sites Nather Khan (1991). The maximum diversity of benthic diatoms was typical for low to intermediate levels of disturbance and nutrient supply (Lobo et al., 1995; Jüttner et al., 2003). Although these authors also found that diatom assemblages had low diversity, species richness and high cell densities in heavily polluted waters, these trends did not always apply to the 74 sites in our study. The response of particular taxa to water chemistry may vary between geographical regions, thus some indices might not exactly reflect water quality (Jüttner et al., 2003). High species richness and diversity observed in assemblages in the upper section and high diatom densities in the lower section agreed with the findings of Jüttner et al. (2003) and Biggs (1996); a decrease in biodiversity and changes in species composition from the upper to the lower section might be related to changes in water quality, altitude and increasing disturbance. In a study of riverine landscape and its relation to biodiversity patterns and disturbances, Ward (1998) indicated that the river routeways connected biotic niches with environmental gradients. The results on benthic diatom abundance and community composition in the Niyang River provide important information for identifying water quality indicators.

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