African Journal of Biotechnology Vol. 10(38), pp. 7416-7426, 25 July, 2011
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.2289
ISSN 1684–5315 © 2011 Academic Journals

Full Length Research Paper

Phytoplankton community characteristics of the icebound season and its relationship to the environmental variables in the Zhalong Wetland, China

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Accepted 3 June, 2011

The taxonomic structure and spatial variability of phytoplankton abundance in the icebound season was obtained from the Zhalong Wetland. A total of 109 taxa were identified in all samples, 92 taxa occurring in at least two samples or the percentages over 1% in at least one sample were utilized in further study. The algal population of the Zhalong Wetland was extremely scarce under the ice-cover condition, with a mean density of 3.11×10^7 ind./L (ranged from 1.11×10^6 ind./L to $1.99\times10^8\times$ind./L). Principle component analysis (PCA) displayed two major groups in environmental variables, that is, (1) ion and organic matters; (2) physical characters and non-organic matters. The relationship between phytoplankton community and environmental variables was analyzed from the inhalant and core region of the Zhalong Wetland. The detrended correspondence analysis (DCA) examined all sites positioned in the range of the DCA biplot and the largest gradient length (13.7 standard deviation units) evoked a strong unimodal response modal. Canonical correspondence analysis (CCA) with forward selection and a Monte Carlo permutation test revealed that nitrate (NO_3-N) and TN mostly affected the distribution of algae.

Key words: Phytoplankton, icebound season, canonical correspondence analysis (CCA), Zhalong Wetland.

INTRODUCTION

Wetlands are the most productive ecosystems in the world compared with rainforests and coral reefs. It plays an integral role which is essential to both human society and the ecological system of the nature world (Toet et al., 2005). Scientists are beginning to realize that atmospheric maintenance may be an additional wetlands function. The Zhalong Wetland, which is situated in the Northeastern China, as a national nature reserve area, is known for its importance as a natural resource. The Zhalong nature reserve is the biggest nature reserve in China that aims to protect cranes and the wetland ecology. Six endangered crane species are living in here. Above one third of 1000 red-crowned cranes occurring worldwide are existing in the Zhalong Wetland, moreover, there are other 35 species of key protected birds to perch here (Wang et al., 2006). It is striking to note that Zhalong Wetland is recognized as important features in the landscape that provides numerous beneficial services for fish, wildlife and even man.

However, in recent years, the Zhalong Wetland has been facing more threats from both intensified human exploitation and recent climate change. The usefulness of algae in evaluating present and past conditions of water quality and environmental change is increasingly being recognized world-wide, which results in renewed interest in using these organisms in surface water quality monitoring (Zhou et al., 2008; Coogan et al., 2007; Katharyn et al., 2005). The physical, chemical and biological conditions of the water present large spatial variations, determining changes in phytoplankton composition, abundance and diversity over different spatial scales

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Abbreviations: PCA, Principle component analysis; **DCA,** detrended correspondence analysis; **CCA,** canonical correspondencs analysis.

(Priddle et al., 1994; Walsh et al., 2001; Moore and Abbott, 2002). This variability in the structure of the plankton community has important implications for the entire ecosystem, since the phytoplankton community, as the autotrophic component of the aquatic ecosystem, affects the structure and efficiency of the food web and the global biogeochemical cycles (Smetacek, 1996; Walsh et al., 2001).

Algae are the dominant component of the biomass of the freshwater ice communities, but there are substantial and metabolically active populations of heterotrophic microbes in the ice community (Hill et al., 2005; Sukhanova et al., 2009; Melnikov, 1998). Despite the extreme environmental conditions of temperature and light, a highly specialized phytoplankton community has developed and adapted to live within the aquatic channel system (Søreide et al., 2008; Gradinger, 2009). These algae in the ice support specialized biotic communities including cold-tolerant animals as reported from Himalayan (Yoshimura et al., 1997) and Patagonian glaciers (Koshima et al, 2007). The importance of the ice-associated production may be greater than its share of total production would suggest, due to its time of occurrence and spatially concentrated nature (Søreide, 2008). The succession of the sea ice algae is mainly controlled by abiotic parameters (Gradinger et al., 1999).

Algal cells released from ice are a possible source for spring phytoplankton assemblages, but evidence for this origin has been equivocal. The need to understand the processes crucial to their sustainability is intense, but, the wintertime cold and ice adds difficulties to their investigation. For the research on ice-cover, wetland requires expensive and highly sophisticated logistics, for example, ice-breaking technology or driving on ice-cover experience. Thus, biological studies on the freshwater especially the wetland solid aquatic systems are rare.

The purpose of this study was to determine for the first time the phytoplankton composition systematically and the environmental characteristics of the wintertime in the Zhalong Wetland. Another objective of this study was to investigate the influence of some environmental parameters on the phytoplankton composition and discuss which variables play the main role in establishing different communities through icebound period in the Zhalong Wetland. By analyzing the relationship between these biological and environmental parameters, we attempt to understand the relative importance of the environmental factors in the icebound season on this temperate zone phytoplankton community. The ecological information can form the basis for future management strategies on the restoration of such threatened fragile ecosystems.

MATERIALS AND METHODS

Study area and sampling design

The Zhalong Wetland is a national natural protection area (covers 210, 000 hm^2), which is connected to western Song-Nen Plain and the lower Wuyuer River. It is located in the inner flow area between 46°52′ to 47°32′N to 123°47′ to 124°37′E (Figure 1). Annually, this region is characterized by 6 months-long icebound season usually from November to April. From the month of November, water in the Zhalong Wetland becomes semi-frozen making the region inaccessible. A month later, the semi-frozen wetland becomes well or completely frozen and remains in that state until February. This is followed by another one or two months semi-frozen state before the ice completely turns back to water.

The samples were collected in 12th to 14th February, 2009. According to the ecology of the wetland and influence of water flow area, three zones were identified; inhalant region, core region and exhalant region. 12 sampling stations were set up in the Zhalong Wetland covering these zones with several stations in each of the main areas. However, there was no exhalant region due to the lack of water. Samples were obtained from each station at two different depths: ice undersurface and 20 cm above the bottom (1.5 m the shallowest station and 3.5 m the deepest). The sampling design considered samples taken from each station, which is also replicated within each zone. All field sampling was done between 09:00 and 15:00, sampling in all the stations were done in the same order. Water samples were collected using a 2.5 L volume bottle. Simultaneously, water temperature (WT), pH value, dissolved oxygen (DO), turbidity and chlorophyll a (Chla) were determined with a portable instrument (YSI 6600) and SD was also obtained in the field. Net hauls (54 mm mesh size) were used at each sampling site. It took about 5 min to obtain phytoplankton material (only for taxonomic determination). Then, 1 L water sample from each station was preserved in lugol solution for later phytoplankton identification and counting. Samples for chemical oxygen demand (COD_{Mn}) analysis were stored in glass containers and samples for other analysis were transported to the laboratory in plastic containers at the temperature of 4°C.

Laboratory analysis

In the laboratory, 22 chemical variables, including total phosphorus (TP), total nitrogen (TN), chemical oxygen demand COD_{Mn}, silicon dioxide (SiO_2), suspend solid (SS), fluoride (F), cyanide (CN), ammonia (NH_3-N), nitrate (NO_3-N) and nitrite (NO_2-N) and ionic concentrations, magnesium (Mg), manganese (Mn), natrium (Na), lead (Pb), zinc (Zn), calcium (Ca), chromium (Cr), copper (Cu), iron (Fe), kalium (K), bicarbonate (HCO_3^-), phosphate (PO_4^{3-}) and sulfate (SO_4^{2-}) were determined using standard techniques (MEPPRC, 2002). The evaluation of water sample nutrient level was based on the nutrient score, which was obtained from 5 routine indices of TP, TN, Chla, SD and COD (Jin, 1995).

Phytoplankton identification and counts

Prior to quantitative analyses, a preliminary taxonomic survey was performed to identify phytoplankton species in each station. The lugol preserved samples were gently shaken and poured into 30 ml sedimentation chambers allowing them to settle for 24 h before cell count. Phytoplankton species were identified under a light microscope (Olympus BH×2) - by phase contrast and oil immersion lens. This was done at a magnification of 100× or 400×. Three crossed diameter transects were observed in each sample. When sparse cells occurred, additional strips were counted until the count reached 400 cells of the most frequent species. For identification, we mainly consulted taxonomical identification based on Hustedt (1930), Patrick and Reimer, (1966), Lange-Bertalot (2001), Lange-Bertalot and Krammer, (2000, 2002) and Hu et al. (2006).

Data analysis

PCA was applied to search for a general pattern in the studied

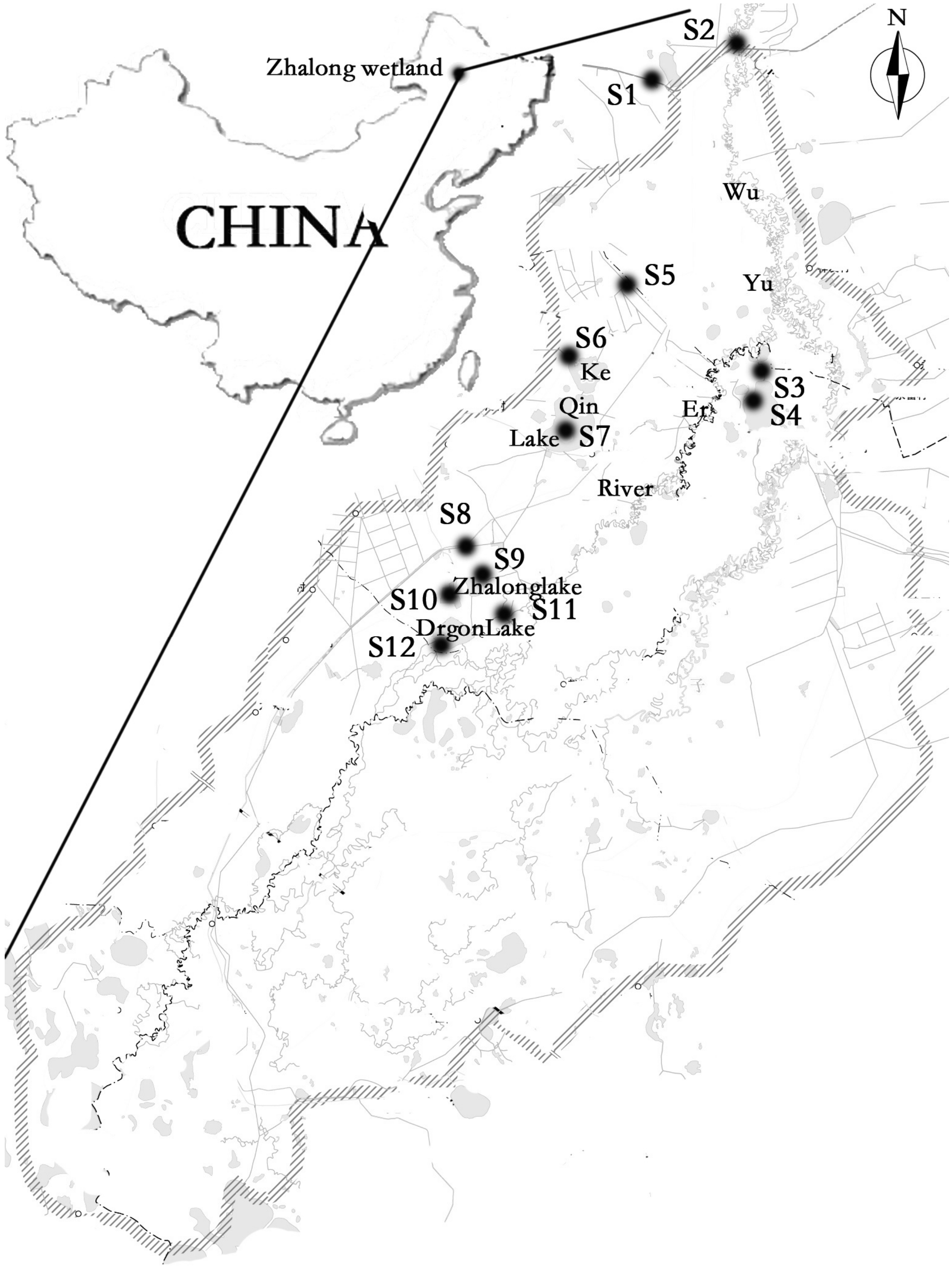

Figure 1. Location of study sites in the Zhalong Wetland. S1-S5 in inhalant region, S6-S12 in core region.

environmental variables. Two types of species-data ordination techniques were applied to explore the relationship between environmental variables and phytoplankton compositions. First, unconstrained ordination (DCA) was used to find major gradients in species composition, which describes the linear or unimodal response model of the species data to environmental axes which could be examined before further analysis. The other technique is constrained ordination (CCA). This was used to assess the relative importance of first and second major gradients of environmental variables in explaining the species distribution patterns (Naqinezhada et al., 2008). 28 constrained variables from both regions were involved in the analysis. Species weight and species

Table 1. Variation of physical and chemical characteristics and the nutrient scores in the Zhalong Wetland during the studied period.

Site	TN	NO_3-N	WT	DO	Chla	Tur	pH	SiO_2	TP	COD_{Mn}	Fe	TLI
S1	9.39	0.33	0.27	72.10	7.10	8.90	7.65	23.36	0.10	12.72	3.28	57.67
S2	1.27	0.24	0.05	8.00	3.00	2.00	8.00	1.13	0.25	6.40	0.83	48.49
S3	2.17	0.30	0.05	59.40	8.80	4.50	6.88	13.08	0.08	10.88	0.70	52.37
S4	1.35	0.26	0.14	61.00	21.40	3.00	8.42	15.02	0.85	14.80	0.34	62.23
S5	0.64	0.10	0.28	67.60	33.00	8.60	11.00	28.91	0.08	5.68	0.60	49.33
S6	1.44	0.28	0.13	144.30	94.40	62.00	10.17	24.47	0.30	28.00	1.34	67.79
S7	1.20	0.10	0.06	116.30	12.80	14.80	9.11	19.47	0.42	11.04	1.24	57.47
S8	2.07	0.29	0.33	81.40	59.80	28.00	9.02	17.52	0.34	46.40	6.92	69.28
S9	2.27	0.31	0.30	51.80	9.40	4.20	8.20	7.69	0.01	32.00	1.60	51.65
S10	1.80	0.19	0.11	50.30	24.40	1.70	7.95	8.63	0.07	33.60	0.57	59.98
S11	1.97	0.28	0.07	33.50	6.20	4.70	7.94	8.91	0.03	27.20	2.27	52.68
S12	3.53	0.14	0.17	8.40	8.70	2.20	5.51	11.97	0.10	32.00	3.41	59.64

TN, Total ntrogen; WT, water temperature; DO, dissolve oxygen; Chla, chlorophyll a; Tur, turbidity; SiO_2, silicon dioxide; TP, total phosphorus; COD, chemical oxygen demand; NO_3-N,nitrate.

fit on both canonical axes were used for the selection of the species shown in the resulting biplots. A global Monte Carlo test and forward selection in CCA were performed to determine the significance of the correlations between the environmental and biological variables in CANOCO (ter Braak et al., 2002).

Species with a frequency of less than 1% of all samples were excluded in the analysis in order to eliminate their influence on the ordination results (Yang et al., 2005). The relative abundances were square root-transformed and the rare species were down-weighted before matrix analysis. To achieve normality, For WT, DO, Chla, Tur, SiO_2 and COD_{Mn} with values <10, square-root transformation was applied. For TN, TP, NO_3-N and Fe, we change the unit to "µg/l" then use $\log_{10}$ (x+1) transformed prior to analysis. The analyses were performed using the CANOCO software package, version 4.5 (ter Braak et al., 2002).

RESULTS

Water environmental characteristics

The inflation of physical and chemical parameters and the nutrient scores of the Zhalong Wetland during the studied period is given in Table 1. The concentrations of TP and TN ranged from 0.01 to 0.85 mg/l and from 0.64 to 9.39 mg/l, respectively. Turbidity and Chla had their highest values at site 6 while all sites had a low level during the studied period. pH value had a wide span from 5.51 to 10.17. SiO_2 content at all sites changed little. P and TLI reached a maximum value at S8 and so the concentration for Fe did. In core region, S6-S12 had a higher COD_{Mn} value than the inhalant region (S1-S5).

Most of the values determined at different region had similar importance in PCA and are strongly inter-correlated. According to the results of PCA (Figure 2), the first axis of PCA explained 57.5% variance of environmental variables and the 27.6% variance of the environmental data was explained by the second axis. pH, CN and TP was clearly related to the first axis. The concentration for heavy metal ion (Zn, Cr, Pb, Cu) showed a strong positively correlation with the second axis while the data for ion (Mg, Fe, K, Ca, Na, HCO_3^-) and Mn, Fe, COD_{Mn}, showed a negative correlation with it.

Phytoplankton communities

A total of 109 taxa were identified in the 12 studied sites, 92 taxa occurring in at least two samples were present or over 1% in at least one sample (Figure 3), which belonged to 6 phyla, 8 classes, 16 orders, 26 families and 43 genera. During the sampling period, the algal of the Zhalong Wetland was extremely scarce, with a mean density of 3.11×10^7 ind./L (ranged from 1.11×10^6 ind./L to $1.99\times10^8\times$ind./L).

In general, species diversity increased from meso-trophic to mesoeutrophic waters, but decreased in eutrophic ones. The lowest number of species was obtained from eutrophic and mesotrophic waters. Only 2 species were observed from S6 and S11, but 21 species were observed from S12 (Figure 4). However, its density was essentially limited to *Cryptophyta* (Figure 5) which was observed mainly at S2 and S4, while *Bacillariophyta* and *Chlorophyta* had the highest species quantity (Figure 6). *Euglenophyta*, *Bacillariophyta* and *Chlorophyta* were common communities with high frequency. The most common phytoplankton taxa occurring with the frequency over 25% in all sites include *Ankistrodesmus*, *Cryptomonas* and *Euglena*. Examples of such species include *Ankistrodesmus angustus* (S1,2,4,8), *Cryptomonas erosa* (S2,3,4,5), *Euglena acus* (S1,6,8,9,10,11), *Euglena oxyuris* (S1,8,12) and *Gymnodinium aeruginosum* (S2,3,4,9). *C. erosa* was particularly dominant in S2 and S4 with 83.63 and 96.35%, respectively. *Kirchneriella contorta* had the absolute advantage number at S7 with 55.41%. *E. acus*

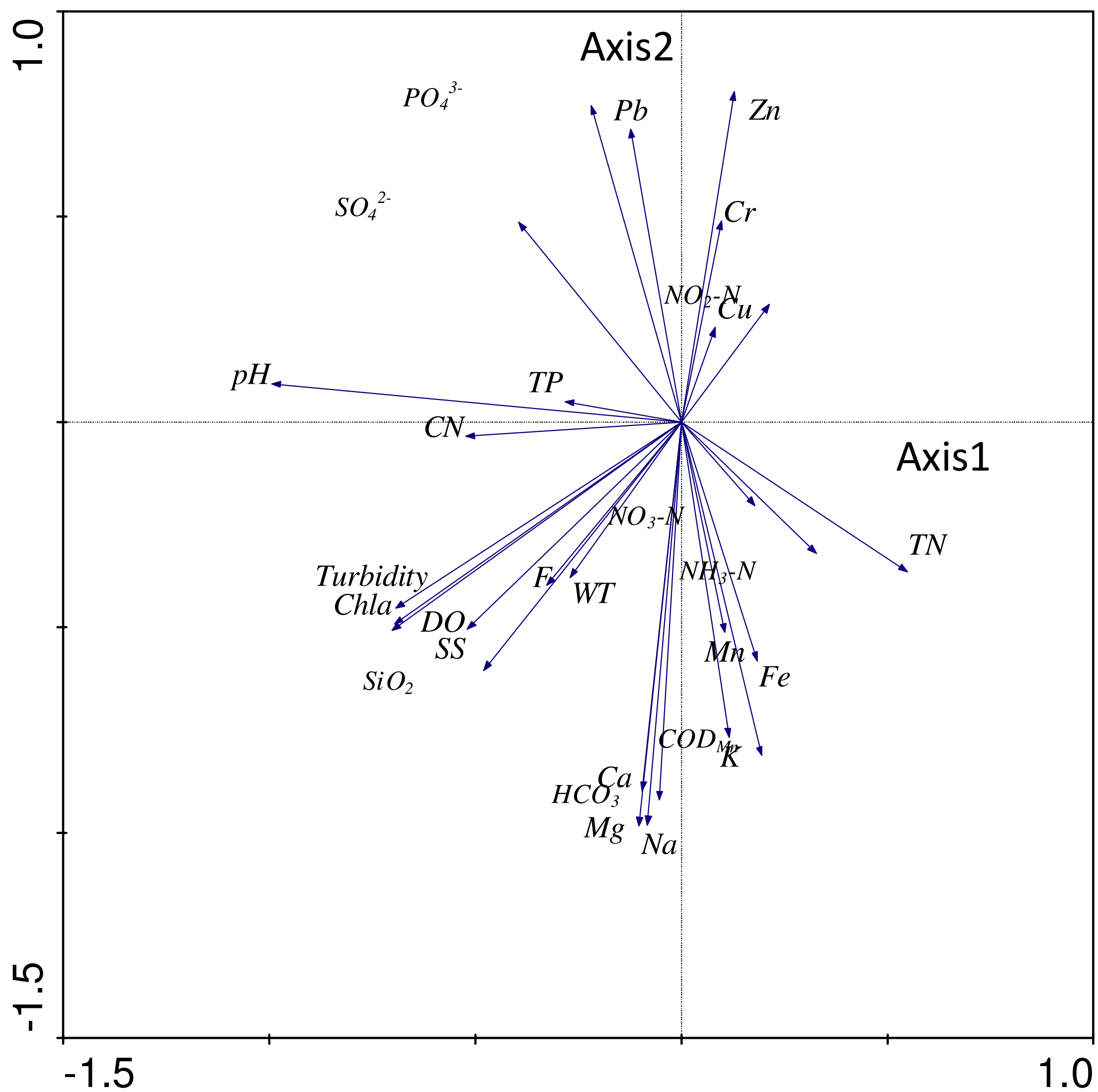

Figure 2. PCA ordination of environmental variables of the Zhalong Wetland during the icebound period.

was the dominant taxa at S11 with *Chlamydomonas* sp. and so did it with *Synedra ulna* at S6. Other taxa such as *Euglena caudata*, *Lyngbya* sp., *Microcystis flosaquac* were also abundant in this study (Figure 3; Appendix 1).

Relationship between environmental parameters and phytoplankton

In order to determine the gradient length for species data, the DCA analysis was required. When the gradient length was larger than 4 standard deviation units, the unimodal context CCA is most useful (ter Braak et al., 2002). The DCA ordination of the 12 sites showed that the first axis Eigen value (0.947) was larger than the second axis (0.81), capturing 13.3% variance of phytoplankton data. The largest gradient length was 13.7 standard deviation units, evoking a strong unimodal response modal in the data that can be used for further CCA ordination. The DCA also examined all sites positioned in the range of the DCA biplot and all of them could be used in further analysis.

The forward selection with the Monte Carlo permutation test identified that the only variable NO_3-N and TN explained significant specific proportions ($P < 0.05$) of the species composition, which were used in final CCA ordination. Figure 7 shows the influence of the two environmental variables on the distribution of algae in the study sites, as determined by CCA. TN was related to axis 1, while NO_3-N was closely related to axis 2, suggesting an obvious nutrient gradient along the two axis. Some indicator of nutrient-tolerant species such as *Euglena polymorpha*, *E. caudate*, *Phacus agilis* and *Phacus pyrum* were located at the high end of TN. Some species occurred at the high end of NO_3-N such as *Cyclotella meneghiniana* and *G. aeruginosum*.

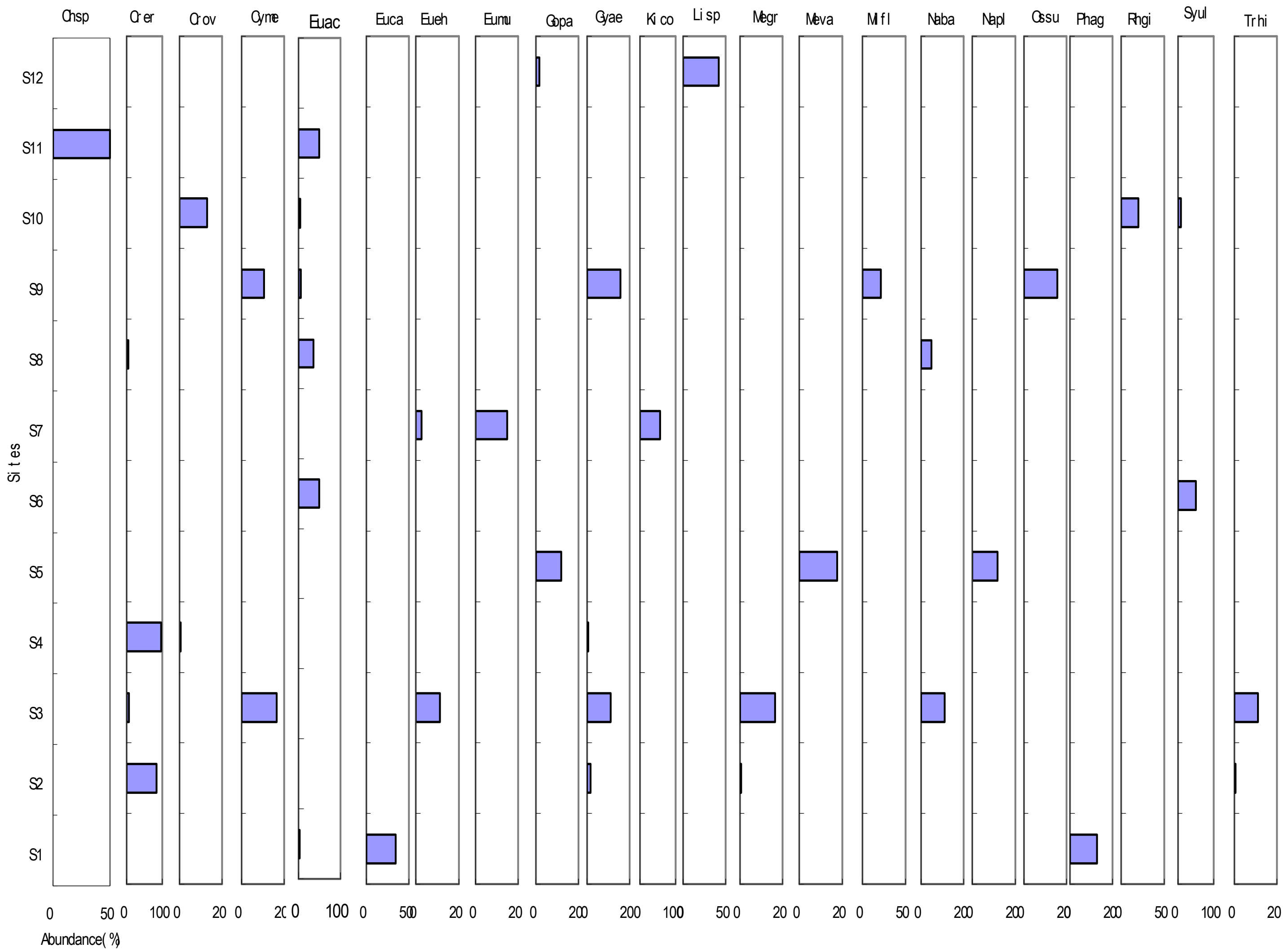

Figure 3. Species abundance with a frequency of more than 10% in at least one sample of the Zhalong Wetland at the present study. Taxa abbreviation see appendix.

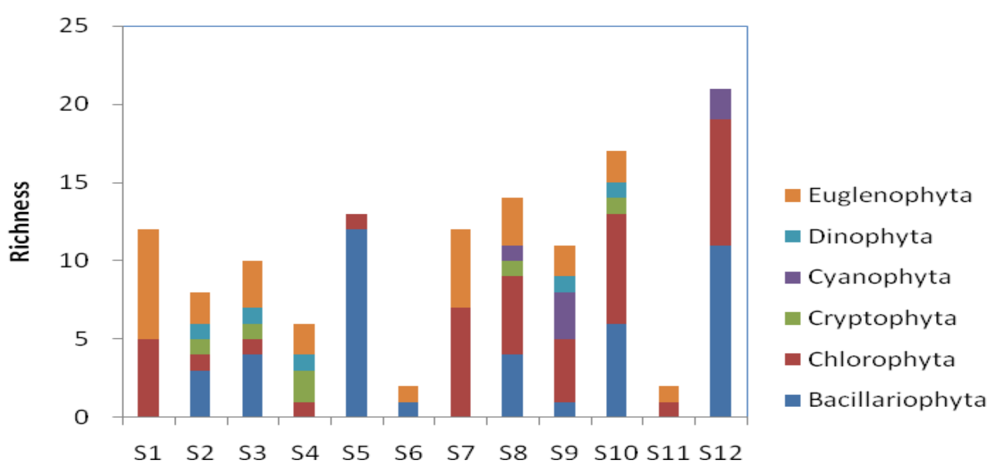

Figure 4. Species richness of phytoplankton species during the studied period including those taxa with a relative proportion of 1% or occurring more in at least one sample.

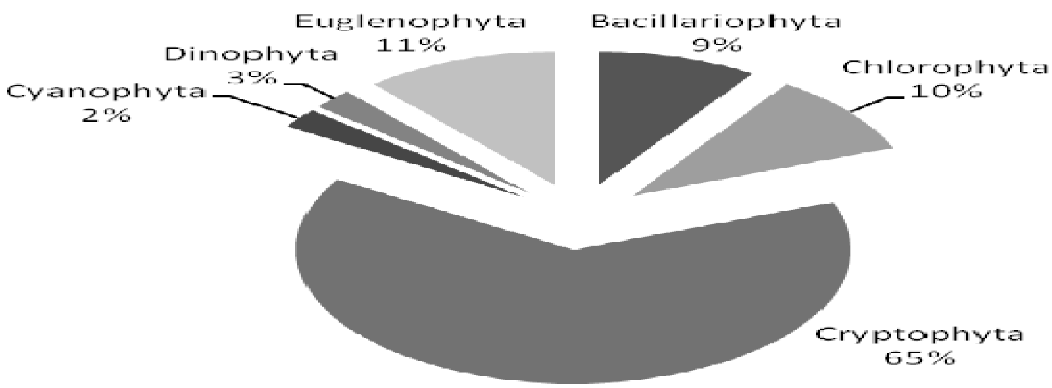

Figure 5. Variation of total phytoplankton biomass and percentages of the main algae groups during the studied period.

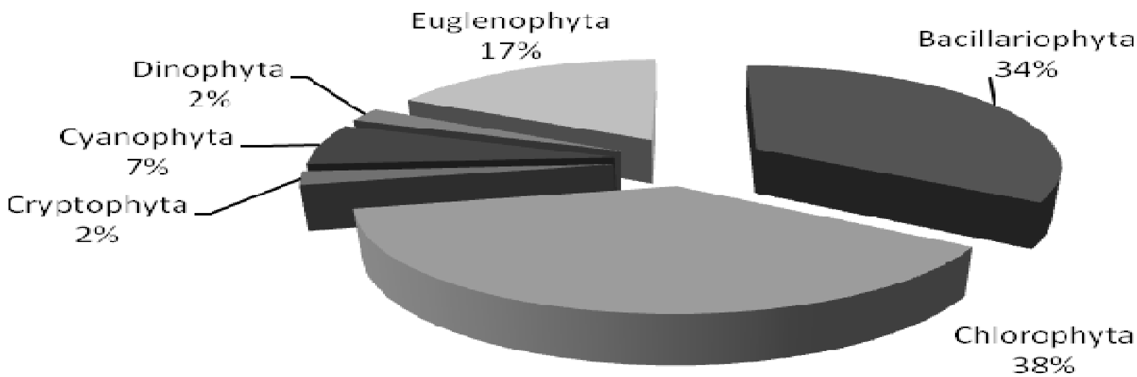

Figure 6. Variation of species composition and percentages of the main algae groups during the studied period.

DISCUSSION

As is shown from TSI, the nutrient value of the Zhalong Wetland ranged from 48.48 to 69.27 with 5 mesotrophic, 5 mesoeutrophic and 2 eutrophic samples not high during the icebound period. *E. acus*, *Gomphonema parvulum*, *Navicula cryptocephala*, *E. oxyuris* and *G. parvulum* appeared abundantly, which indicates that our study region was attributed to β-middle pollution. (El-Sheekh et al., 2010; Barinova et al., 2004; Alves-da-Silva et al., 2007). There was a peak value for TN and NO_3-N at the entrance of the Zhalong Wetland (S1) and other sites did not show significant variations for TN. In wintertime, the WT of collected samples in the Zhalong Wetland was about 0℃. The sample were collected under ice face, while DO was higher. Moreover, as shown from the results of PCA (Figure 2), the environmental parameters were classified into two major groups: (1) ionic and organic matters; (2) physical characters and inorganic matters.

The phytoplankton community in our work presented lower diversity and abundances. In general, a reduction of light energy results in extreme decline of algal biomass. This is because the low winter temperatures restrict phytoplankton assemblage production; this explains why some species produce resting state(Sommer et al, 1986). Thus, some widespread species were found frequently, such as *A. angustus*, *C. erosa, E. acus, E. oxyuris*, *G. aeruginosum*. Algal density in our studied region was essentially limited to *Cryptophyta* (not common in all the sites) and observed at S2 and S4. However, seen from the species composition for all samples, the Zhalong Wetland with the highest diversities in the studied region could be *Bacillariophyta-Chlorophyta* species. This description is in agreement with the findings of Leira and Sabater, (2005) on the plant assemblage distribution in relation to chemical and physiographical factors. The research of Garibottia et al. (2005) and Varela et al. (2002) indicated that small unidentified phytoflagellates, diatoms and cryptophytes are the main phytoplankton groups, contributing the major proportion of total phytoplankton cell abundance and biomass concentration in their cold studied region. Some studies report that similar

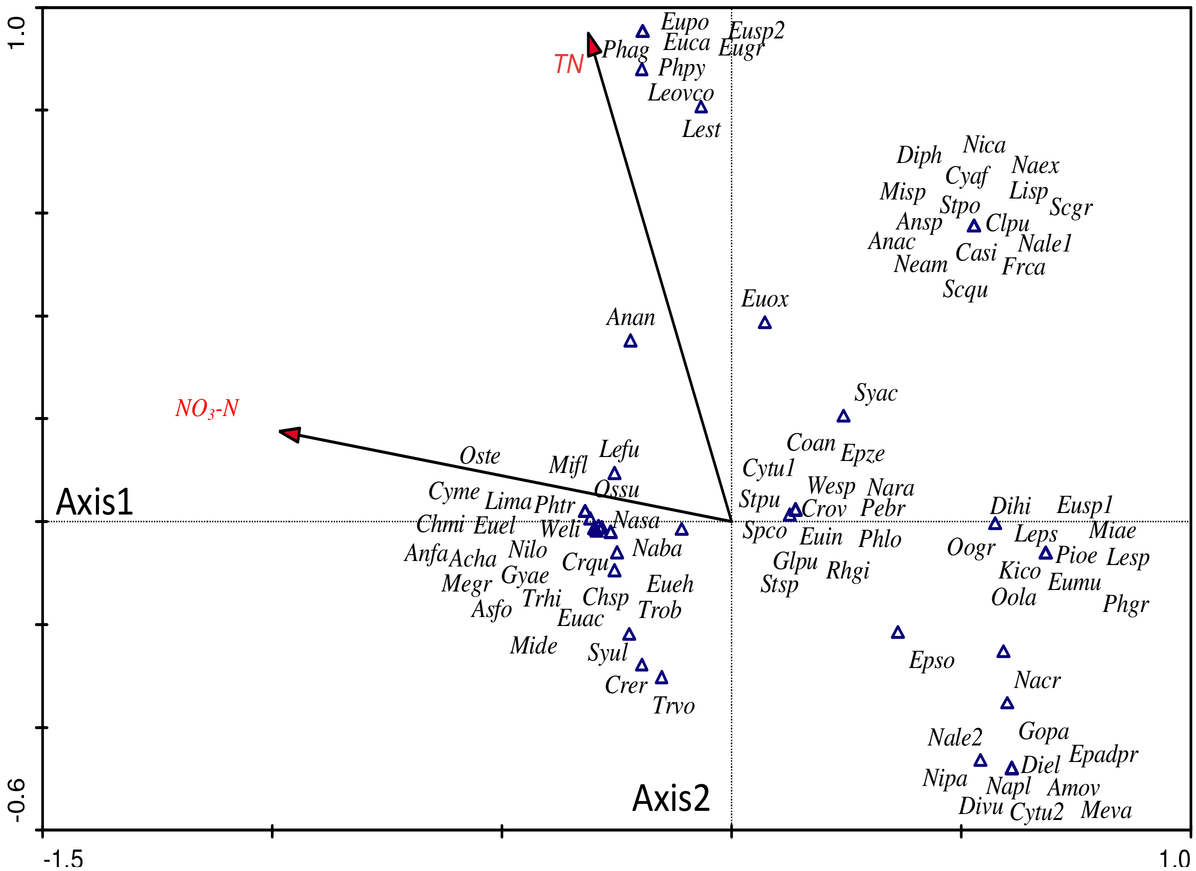

Figure 7. CCA biplot of the phytoplankton distribution and 2 environmental variables in the Zhalong Wetland during the ice-cover period. For taxa abbreviation, see appendix.

Cryptophyte-enriched assemblages develop after a sea-ice edge diatom bloom and consider them as a secondary stage of the seasonal phytoplankton succession (Kang and Lee, 1995; McMinn et al., 2000; Bode et al., 2002). In our study, Figure 5 shows that *Cryptophyta* and *Bacillariophyta* presented a divergent distribution through the area. In fact, peaks of *Cryptophyta* and diatoms standing stock were found simultaneously in S2, S3 and S4, but as the diatoms concentrated in S5 and S12, the *Cryptophyta* disappeared in the transect. The observed spatial variability is also consistent with the previous discussion that c*ryptophytes* versus diatom standing stock clearly showed an inverse relationship for the three studied periods (Garibotti et al., 2005). Furthermore, it is considered that c*ryptophytes* are competitors of diatoms for nutrients and light. Consequently, the diatom disappearance facilitates a cryptophytes bloom (Walsh et al., 2001).

The CCA performed on the data displayed that the phytoplankton abundances and diversity was mainly affected by an abiotic interaction between physical and chemical factors. The drainage basin of Wuyuer River which the Zhalong Wetland water comes from, small rural properties is characterized by an intense agricultural activity, as well as intensive livestock breeding (Zhao, 2005). Thus, the run-off into the Zhalong Wetland leads to nutrient content accumulation. This explains the high values recorded for nutrients especially TN and NH_3-N at S1 the entrance of the Zhalong Wetland. Consequently, some species such as *Euglena ehrenbergii*, *E. acus*, which were inclined to a mass of organic matter water body, occurred in our studied sites (Jiang, 2006).

The CCA biplots revealed a strong correlation among each environmental parameter, suggesting that these parameters were interconnected and showed some common information of species data. This is in agreement with some researchers (Yang et al., 2005). Consequently, some species such as *Oscillatoria tenuis* is situated at the intermediate region (Figure 7).

Organic matter may contribute to phytoplankton dynamics in aquatic ecosystems (Aké-Castillo et al., 2008). Nutrient limitation is also a common characteristic in others study (Abrantes et al., 2006). The competition for phosphate leads to replacement of green algae by large Bacillariophyceae and later the nitrogen depletion favours a shift to nitrogen-fixing of filamentous Cyanobacteria. Nevertheless, the fact that the average ratio of TN: Si: TP is 6:13:1 in our study, should be the limitation for nitrogen (Paul et al., 2008). Then, the present region of the Zhalong Wetland still belonged to *Bacillariophyta -Chlorophyta* type which indicated that there was competition for phosphate in the studied area.

In the 12 sites sampled during the icebound season, the algae community was found to distribute regularly along a nutrient gradient. Along nutrient axis, the phytoplankton assemblage dominated by sensitive and clean water species was replaced by nutrient-tolerant phytoplankton taxa, indicating that algae growth was affected mainly by nutrient status. It indicated that a good relationship existed between phytoplankton community and winter water quality parameters.

However, in cold region like the Zhalong Wetland with icebound season, though there was a higher TN and TP and the nutrient scores ranged from 48.48 to 69.27, the large scale eutrophic state did not occur, even in summer. The reason may be that they could not assemble by physical function under ice during winter. The standard of cold region should be different from that warmer region research. To solve this problem, the supplement of some oligotrophic and oligomesotrophic region is needed in order to enlarge the nutrient coverage in this algae dataset. Classification and ordination methods generated results that were complementary and ecologically meaningful.

Acknowledgments

This research was supported by the Key Scientific and Technological Projects in Heilongjiang Province (GB07C20303) and the National Water Pollution Control and Management Technology Major Projects (2008ZX07207).

REFERENCES

Abrantes N, Antunes SC, Pereira MJ, Gongalves F (2006). Seasonal Succession of Cladocerans and Phytoplankton and their Interactions in a Shallow Eutrophic Lake (Lake Vela, Portugal). Acta. Oecol. 29(1): 54-64.

Aké-Castillo J, Vázquez G (2008). Phytoplankton Variation and its Relation to Nutrients and Allochthonous Organic Matter in a Coastal Lagoon on the Gulf of Mexico. Estuar. Coast. Shelf Sci. 78: 705-714.

Alves-da-Silva SM, Hermany G, Oliveira MA (2007). Diversity and Ecological Considerations on Pigmented Euglenophyceae in the State Park of the Jacuí Delta, Rio Grande Do Sul, Southern Brazil. Biociências, Porto Alegre. 15(1): 8-20.

Barinova SS, Anissimova OV, Nevo E, Jarygin MM, Wasser SP (2004). Diversity and Ecology of Algae from the Nahal Qishon river, Northern Israel. Plant Bios. 138(3): 245- 259.

Bode A, Castro CG, Doval MD, Varela M (2002). New and Regenerated Production and Ammonium Regeneration in the Western Bransfield Strait Region (Antarctica) during Phytoplankton Bloom Conditions in Summer. Deep-Sea Res. II. 49: 787-804.

ter Braak CJF, Šmilauer P (2002). CANOCO Reference Manual and CanoDraw for Windows User's Guide: Software for Canonical Community Ordination (version 4.5). Microcomputer Power, Ithaca, NY, USA.

Coogan MA, Edziyie RE, Lapoint TW, Venables BJ (2007). Algal Bioaccumulation of Triclocarban, Triclosan, and Methyl-Triclosan in a North Texas Wastewater Treatment Plant Receiving Stream. Chemosphere, 67: 1911-1918.

El-Sheekh MM, Deyab MAI, Desouki SS, Eladl M (2010). Phytoplankton Compositions as a Response of Water Quality in El Salam Canal Hadous Drain and Damietta Branch of River Nile Egypt. Pak. J. Bot. 42(4): 2621-2633.

Garibottia IA, Vernetb M, Ferrarioc ME (2005). Annually Recurrent Phytoplanktonic Assemblages during Summer in the Seasonal Ice Zone West of the Antarctic Peninsula (Southern Ocean). Deep-Sea Res. I. 52: 1823-1841.

Gradinger R (2009). Sea-ice algae: Major Contributors to Primary Production and Algal Biomass in the Chukchi and Beaufort Seas during May/June 2002. Deep-Sea Res. II. 56: 1201-1212.

Gradinger R, Friedrich C, Spindler M (1999). Abundance, Biomass and Composition of the Sea Ice Biota of the Greenland Sea Pack Ice. Deep-Sea Res. II, 46: 1457-1472.

Hill V, Cota G (2005). Spatial Patterns of Primary Productionon the Shelf, Slope and Basin of the Western Arcticin 2002. Deep-Sea Res. II. 52: 3354-3369.

Hu HJ, Wei YX (2006). The Freshwater Algae of China-Systematics, Taxonomy and Ecology. Sci. Press. Beijing, China.

Hustedt F (1930). Bacillariophyta (Diatomeae). In: Pascher A. Die Süsswasser Flora Mitteleuropas. GFV Jena, Germany.

Jin XC (1995). Lake Environment in China. Ocean press. Beijing, China.

Kang SH, Lee SH (1995). Antarctic Phytoplankton Assemblage in the Western Bransfield Strait Region, February 1993: Composition, Biomass, and Mesoscale Distributions. Mar. Ecol. Prog. Ser. 129: 253-267.

Katharyn E, Boyer T, Peggy F (2005). Macroalgal-Mediated Transfers of Water Column Nitrogen to Intertidal Sediments and Salt Marsh Plants. J. Exp. Mar. Biol. Ecol. 321: 59-69.

Kohshima S, Takeuchi N, Uetake J, Shiraiwa T, Uemura R, Yoshida N, Matoba S, Godoi MA (2007). Estimation of net accumulation rate at a Patagonian glacier by ice core analyses using snow algae. Global Planetary Change, 59: 236-244.

Lange-Bertalot H (2001). Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats. Koeltz Sci. Books. Koenigstein, Germany.

Lange-Bertalot H, Krammer K (2000). Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats. Koeltz Sci. Books. Koenigstein, Germany.

Lange-Bertalot H, Krammer K (2002). Diatoms of Europe: Diatoms of the European Inland Waters and Comparable Habitats. Koeltz Sci. Books. Koenigstein, Germany.

Leira M, Sabater S (2005). Diatom Assemblage Distribution in Catalan Rivers, NE Spain, in Relation to Chemical and Physiographical Factors. Water Res. 39: 73-82.

McMinn A, Bleakley N, Steinburner K, Roberts D, Trenerry L (2000). Effect of Permanent Sea Ice Cover and Different Nutrient Regimes on the Phytoplankton Succession of Fjords of the Vestfold Hills Oasis, Eastern Antarctica. J. Plankton Res. 22(2): 287-303.

Melnikov IGA (1998). Winter Production of Sea Ice Algae in the Western Weddell Sea. J. Marine Syst. 17: 195-205.

Ministry of Environmental Protection of the People's Republic of China (2002). Standared Methods for the Examination of Water and Wastewater. Environ. Sci. Press. Beijing, China.

Moore JK, Abbott MR (2002). Surface Chlorophyll Concentrations in Relation to the Antarctic Polar Front: Seasonal and Spatial Patterns Fromsatellite Observations. J. Mar. Syst. 37: 69-86.

Naqinezhada A, Hamzeh B, Attarb F (2008). Vegetation-Environment Relationships in the Alderwood Communities of Caspian Lowlands. N. Iran (toward an ecological classification) Flora, 203: 567-577.

Patrick R, Reimer CW (1966). The diatoms of the United States. Monographs Acad. Nat. Sci. Phila. Philadelphia, USA.

Paul JT, Ramaiah N, Sardessai S (2008). Nutrient Regimes and their Effect on Distribution of Phytoplankton in the Bay of Bengal. Mar. Environ. Res. 66: 337-344.

Priddle J, Brandini F, Lipski M, Thorley MR (1994). Pattern and Variability of Phytoplankton Biomass in the Antarctic Peninsula Region: an Assessment of the Biomass Cruises. In: El-Sayed SZ

(Ed.), Southern Ocean Ecology: The Biomass Perspective. Cambridge University Press, New York.
Smetacek V (1996). Biodiversity and Production in the Water Mass. In: Hempel G (Ed.). The Ocean and the Poles. GFV, Jena, Germany.
Sommer U, Gliwicz M, Lampert W, Duncan A (1986). The PEG-model of Seasonal Succession of Planktonic Events in Fresh Waters. Arch. Hydr. Biol. 106: 433-471.
Søreide JE, Falk-Petersen S, Hegseth EN, Hop H, Carroll ML, Hobson KA, Blachowiak-Samolyk K (2008). Seasonal Feeding Strategies of Calanus in the High-Arctic Svalbard Region. Deep-Sea Res. II. 55: 2225-2244.
Sukhanova IN, Flint MV, Pautova LA, Stockwell DA (2009). Phytoplankton of the Western Arctic in the Spring And Summer of 2002: Structure And Seasonal Changes. Deep-Sea Res. II. 56: 1223-1236.
Toet S, Richard SP, Logtestijn V, Schreijer M, Kampf R, Verhoeven JTA (2005). The Functioning of a Wetland System Used for Polishing Effluent from a Sewage Treatment Plant. Ecol. Eng. 25: 101-124.
Varela M, Fernandez E, Serret P (2002). Size-fractionated Phytoplankton Biomass and Primary Production in the Gerlache and South Bransfield Straits (Antarctic Peninsula) in Austral Summer 1995-1996. Deep-Sea Res. II. 49: 749-768.
Walsh JJ, Dieterle DA, Lenes J (2001). A Numerical Analysis of Carbon Dynamics of the Southern Ocean Phytoplankton Community: the Roles of Light and Grazing in Affecting Both Sequestration of Atmospheric CO_2 and Food Availability to Larval Krill. Deep-Sea Res. I. 48: 1-48.
Wang MY, Shu LF, Zhao FJ (2006). Reed Fires in Zhalong Nature Wetland Reserve in Heilongjiang Province. IFFN. 34: 85-88.
Yang XD, Dong XH, Gao G, Pan HX, Wu JL, Tian XR (2005). Relationship Between Surface Sediment Diatoms and Summer Water Quality in Shallow Lakes of the Middle and Lower Reaches of the Yangtze River. J. Integr. Plant Biol. 47(2): 153-164.
Zhao X (2005). Water Environment and Sustainable Development of the Zhalong Wetlands. Wetland Sci. 3(4): 286-291.
Jiang JG (2006). Development of a New Biotic Index to Assess Freshwater Pollution. Environ. Pollut., 139: 306-317.
Yoshimura Y, Kohshima S, Ohtani S (1997). A community of snow algae on a Himalayan glacier: change of algal biomass and community structure with altitude. Arct. Alp. Res. 29(1): 126-137.
Zhou QF, Zhang JB, Fu JJ, Shi JB, Jiang GB (2008). Biomonitoring: An Appealing Tool for Assessment of Metal Pollution in the Aquatic Ecosystem. Anal. Chim. Acta. 606: 135-150.

Appendix 1.

Taxa	Abbreviation	Taxa	Abbreviation	Taxa	Abbreviation
Actinastrum hanstzschii	*Acha*	*Euastrum insulare*	*Euin*	*Neidium ampliatum*	*Neam*
Amphora ovails	*Amov*	*Euglena mutabilis*	*Eumu*	*Nitzschia capitellata Hust*	*Nica*
Ankistrodesmus acicularis	*Anac*	*Euglena oxyuris*	*Euox*	*Nitzschia longissima*	*Nilo*
Ankistrodesmus angustus	*Anan*	*Euglena polymorpha*	*Eupo*	*Nitzschia palea*	*Nipa*
Ankistrodesmus falcatus	*Anfa*	*Euglena* sp.1	*Eusp1*	*Navicula placentula*	*Napl*
Anabaena sp.	*Ansp*	*Euglena* sp.2	*Eusp2*	*Oocystis granulata*	*Oogr*
Asterionella formosa	*Asfo*	*Fragilaria capucina*	*Frca*	*Oocystis lacustis*	*Oola*
Caloneis silicula	*Casi*	*Glenodinium pulvisculua*	*Glpu*	*Oscillatoria subbrevis*	*Ossu*
Chroococcus minutus	*Chmi*	*Gomphonema parvulum*	*Gopa*	*Oscillatoria tenuis*	*Oste*
Chlamydomonas sp.	*Chsp*	*Gymnodinium aeruginosum*	*Gyae*	*Pediastrum branri*	*Pebr*
Closterium pulchellum	*Clpu*	*Kirchneriella contorta*	*Kico*	*Phacus agilis*	*Phag*
Cosmarium anisochondrum	*Coan*	*Lepocinclis fusiformis*	*Lefu*	*Phacus granum*	*Phgr*
Cryptomonas erosa	*Crer*	*Lepocinclis ovum* var.conica	*Leovco*	*Phacus longicauda*	*Phlo*
Cryptomonas ovata	*Crov*	*Lepocinclis pseudo*-texta	*Leps*	*Phacus pyrum*	*Phpy*
Crucigenia quadrata	*Crqu*	*Lepocinclis* sp.	*Lesp*	*Phacus triqueter*	*Phtr*
Cymbella affinis	*Cyaf*	*Lepocinclis steinii*	*Lest*	*Pithophora oedogomia*	*Pioe*
Cyclotella meneghiniana	*Cyme*	*Lyngbya martensiana*	*Lima*	*Rhopalodia gibba*	*Rhgi*
Cymbella turgida	*Cytu1*	*Lyngbya* sp.	*Lisp*	*Scenedesmus granulatus*	*Scgr*
Cymbella tumida	*Cytu2*	*Melosira granulata .*	*Megr*	*Scenedesmus quadricauda*	*Scqu*
Diploneis elliptia	*Diel*	*Melosira varians*	*Meva*	*Spiroggyra communis*	*Spco*
Diatoma hiemale	*Dihi*	*Microcystis aeruginosa*	*Miae*	*Staurastrum polymorphum*	*Stpo*
Dictyosphaerium pulchellum	*Diph*	*Microcystis densa*	*Mide*	*Staurastrum punctulatum*	*Stpu*
Diatoma vulgare	*Divu*	*Microcystis flosaquac*	*Mifl*	*Staurastrum sp*	*Stsp*
Epithemia adnata var.proboscidea	*Epadpr*	*Microcystis* sp.	*Misp*	*Synedra acus*	*Syac*
Epithemia sorex	*Epso*	*Navicula bacillum*	*Naba*	*Synedra ulna*	*Syul*
Epithemia zebra	*Epze*	*Navicula cryptocephala*	*Nacr*	*Trachelomonas hispida*	*Trhi*
Euglena acus	*Euac*	*Navicula exigua*	*Naex*	*Trachelomonas oblonga*	*Trob*
Euglena caudata	*Euca*	*Navicula leptostriata*	*Nale1*	*Trachelomonas volvocina*	*Trvo*
Euglena ehrenbergii	*Eueh*	*Navicula lesmonensis*	*Nale2*	*Westellopsis linearis*	*Weli*
Eudorina elegans	*Euel*	*Navicula radiosa*	*Nara*	*Westellopsis* sp.	*Wesp*
Euglena gracilis	*Eugr*	*Navicula salinarum*	*Nasa*		