

## DIVERSITY OF FRESHWATER GREEN MACROALGAE IN THE PUNJAB AND NEIGHBOURING AREAS OF PAKISTAN

A. ZARINA<sup>1</sup>, MASUD-UL-HASAN<sup>2</sup> AND MUSTAFA SHAMEEL<sup>3</sup>

<sup>1</sup>*Department of Botany, Federal Urdu University of Arts, Science & Technology,  
Gulshan-e-Iqbal Campus, Karachi-75300*

<sup>2</sup>*Department of Botany, Government College University, Kachehri Road, Lahore-54000*

<sup>3</sup>*Department of Botany, University of Karachi, Karachi-75270, Pakistan*

*Corresponding author: zarinaali2006@yahoo.com*

### Abstract

Altogether 139 species of planktonic, edaphic, epioikotic, epiphytic and epilithic algae belonging to 3 phyla, 5 classes, 13 orders, 14 families and 26 genera have been collected from various freshwater habitats in several districts of the Punjab Province of Pakistan as well as certain areas of NWFP and Azad Kashmir during December 2003 and July 2005. All of them were taxonomically known species, but are recorded for the first time from their area of collection. Among them 6 genera and 82 species are first reports from Pakistan. Members of the phylum Chlorophycota with 22 genera and 127 species were found to be more prevalent than other two phyla, and the Zygnemophyceae appeared to be the largest class with 7 genera and 91 species. At ordinal level, Zygnemales was most commonly distributed with 5 genera and 65 species, and *Spirogyra* with 42 species was the most commonly occurring genus. An overwhelming amount of species was found in the planktonic condition, followed by epiphytes and rest in the edaphic and epilithic habitats. Largest number of species was found in Lahore district among 12 localities. The algae were found to grow in all the four seasons, but the largest proportion of their collection was made in spring. Their frequency of occurrence remained almost the same during summer and winter but was smallest in autumn.

### Introduction

Randhawa (1936) was the first phycologist to make a taxonomic investigation of freshwater Chlorophycota from Lahore and other areas of the Punjab now included in Pakistan. Much later Masud-ul-Hasan (1978a, b, 1980) and his students worked on the taxonomy of green algae from Punjab Province of Pakistan (Masud-ul-Hasan & Batool, 1987; Masud-ul-Hasan & Yunus, 1989). Apart from that no study was carried out on the algal flora of this area. It appeared that vast areas of the Punjab and its neighbouring region in Pakistan were devoid of such studies. Therefore, this study was undertaken to make a detailed survey of grass-green, stonewort and yellow-green algae from these areas.

### Materials and Methods

Several surveys were made in various districts of the Punjab Province *eg.*, Gujranwala, Jauharabad, Jhang, Kasur, Lahore, Pasrur, Sargodha, Sheikhpura and Sialkot, certain areas of Attock and Swat in North-Western-Frontier Province (NWFP) like Bahrain and Kalam of Pakistan, as well as Chenari, Muzzaffarabad and Neelum Valley in Azad Kashmir during December 2003 and July 2005. For this purpose green macroalgae were collected from pools, ditches, lakes, irrigation canals, riverin ponds, rivers and other water reservoirs. The collected material was preserved in 4 % formalin

solution to which a little glycerine was added and was brought to the laboratory at Karachi. For investigation semi-permanent slides were made in glycerine and sealed with nail polish. The specimens were examined under photographic microscope (BH 2 Olympus, Japan) and various species of green algae were taxonomically determined with the help of standard literature (eg., Pascher, 1925; Venkataraman, 1961; Mattox & Bold, 1962; Pal *et al.*, 1962; Prescott, 1962; Hoek, 1963; Ramanathan, 1964; Biswas, 1975; Akiyama & Yamagishi, 1981; Nizamuddin & Gerloff, 1982; Krause, 1997; Wehr & Sheath, 2003; John *et al.*, 2005 etc.).

## Results and Discussion

One hundred and thirty-nine species of planktonic (free-floating), edaphic, epioikotic (attached with artificial substrata), epiphytic and epilithic green algae belonging to 3 phyla, 5 classes, 13 orders, 14 families and 26 genera have been collected. On the basis of their morphological and cytological characteristics an attempt was made to identify the collected specimens up to species level (Table 1). They have been identified, taxonomically described and systematically arranged according to the recently proposed classification (Shameel, 2001, 2008). Although, all of them appeared to be taxonomically known species but are recorded for the first time from their area of collection. Among them, 6 genera and 82 species (marked by an asterisk) are first report from Pakistan.

## Taxonomic diversity

As a result of taxonomic studies, members of the phylum Chlorophycota with 22 genera and 127 species were found to be more prevalent than other two phyla of green algae, while phylum Vaucherophycota included 3 genera and 10 species. The phylum Charophycota contained only 1 genus with 2 species and thus appeared to be the smallest phylum in diversity (Table 1). Similar observations were made on algal diversity recently studied in Peshawar Valley of Pakistan (Nawaz & Sarim, 2004; Zaman & Sarim, 2005; Zaman & Hussain, 2006).

The class Zygnemophyceae with its new concept (Shameel, 2006), appeared to be the largest class with 7 genera and 91 species and exhibited the largest diversity. It was followed by the class Ulvophyceae with 11 genera and 25 species. It is quite obvious, because several genera of this class are marine while the former one is exclusively freshwater (Sze, 1996; Lee, 1999; Graham & Wilcox, 2000; Hoek *et al.*, 2002; John *et al.*, 2005; Wahid & Khan, 2006). The Siphonocladophyceae appeared to be the least distributed class of the phylum Chlorophycota having 4 genera and 8 species and contained only 5 % of the total collected algae. This is due to the fact that this class is mainly found in the marine environment (Shameel & Tanaka, 1992; Silva *et al.*, 1996; Akatsuka, 1994; Dawes, 1998).

The class Vaucherophyceae with 3 genera and 10 species was not commonly represented in the collected material, although it overwhelmingly occurs in the freshwater environment (Goetz, 1897; Brown, 1929; Li, 1936; Randhawa, 1939, 1942; Venkataraman, 1961; Faridi & Hussain, 1977). Among all the classes, Charophyceae with 1 genus and 2 species was least represented in the present collection. In the previous studies also it was observed that charophytes are not so commonly represented in Pakistan (Faridi, 1955; Pal *et al.*, 1962; Sarim, 1991; Langangen & Leghari, 2001; Shameel 2002, 2005).

**Table 1. Occurrence of green, stonewort and yellow-green algae in different areas of the north-eastern region of Pakistan and Azad Kashmir.**

Algal taxa	Habitat	Localities											
		1	2	3	4	5	6	7	8	9	10	11	12
<b>Chlorophycota</b>													
<b>Ulvophyceae</b>													
<b><i>Binuclearia</i>*</b>													
<i>B. tectorum</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<b><i>Geminella</i>*</b>													
<i>G. ordinata</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<b><i>Heterothrichopsis</i>*</b>													
<i>H. viridis</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<b><i>Ulothrix</i></b>													
<i>U. aequalis</i>	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<i>U. cylindrica</i> *	Epilithic	-	-	-	-	-	-	+	-	-	-	-	-
<i>U. flacca</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	+
<i>U. moniliformis</i> *	Planktonic	-	-	-	-	+	-	-	-	+	-	-	-
<i>U. tenerrima</i>	Epiphytic	-	+	+	-	-	+	-	-	+	-	-	-
<i>U. tenuissima</i>	Planktonic	-	-	-	-	-	+	-	-	+	-	-	+
<i>U. variabilis</i>	Edaphic	-	-	-	-	-	+	-	-	-	-	-	-
<i>U. zonata</i>	Planktonic	-	-	-	-	-	-	-	-	-	-	+	+
<b><i>Uronema</i></b>													
<i>U. confervicola</i>	Epilithic	-	-	-	-	-	-	-	-	-	+	-	-
<i>U. gigas</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<b><i>Cylindrocapsa</i></b>													
<i>C. involuta</i> *	Planktonic	-	-	-	-	-	-	-	-	+	+	-	-
<b><i>Microspora</i></b>													
<i>M. floccosa</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<i>M. loefgrenii</i> *	Epiphytic	-	-	-	+	-	-	-	-	-	-	-	-
<i>M. tenerrima</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<i>M. tumidula</i>	Planktonic	-	-	-	-	+	-	-	-	-	+	-	-
<i>M. wittrockii</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<b><i>Chaetophora</i></b>													
<i>C. attenuata</i>	Epiphytic	-	-	-	-	-	+	-	-	-	-	-	-
<b><i>Stigeoclonium</i></b>													
<i>S. elongatum</i> *	Epiphytic	-	-	-	-	-	+	-	-	-	+	-	-
<i>S. lubricum</i>	Epiphytic	-	-	-	-	-	+	+	-	-	-	-	+
<i>S. nanum</i> *	Epiphytic	-	+	-	-	-	-	-	-	-	-	-	-
<i>S. tenue</i>	Epiphytic	-	-	-	-	-	+	-	-	+	+	-	-
<b><i>Aphanochaete</i></b>													
<i>A. polychaete</i> *	Epiphytic	-	+	-	-	-	-	-	-	-	-	-	-
<i>A. repens</i>	Planktonic	+	-	-	-	-	-	-	-	-	-	-	-
<b><i>Coleochaete</i></b>													
<i>C. pulvinata</i> *	Epiphytic	-	-	-	-	-	+	-	-	-	-	-	-
<i>C. scutata</i>	Planktonic	-	+	-	-	+	-	-	-	-	-	-	-
<b>Zygnemophyceae</b>													
<b><i>Bulbochaete</i></b>													
<i>B. intermedia</i> *	Epiphytic	-	+	-	-	-	-	-	-	-	-	-	-
<i>B. mirabilis</i>	Epiphytic	-	-	-	-	-	+	-	-	-	-	-	-

Table 1. (Cont'd.).

Algal taxa	Habitat	Localities											
		1	2	3	4	5	6	7	8	9	10	11	12
<b>Oedogonium</b>													
<i>O. argentum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. cardiacum</i> *	Epiphytic	-	-	-	-	-	+	-	-	-	-	-	-
<i>O. curtum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. curvum</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>O. exospirale</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. foveolatum</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	+	-
<i>O. globosum</i> *	Epilithic	-	-	-	-	-	+	-	-	-	-	+	-
<i>O. grande</i> *	Epilithic	-	-	-	-	+	-	-	-	-	-	-	-
<i>O. indicum</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>O. inerme</i> *	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-
<i>O. irregulare</i>	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<i>O. leave</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. nanum</i> *	Epiphytic	-	-	-	-	+	-	-	-	-	-	-	-
<i>O. obsoletum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. pachydermum</i> *	Edaphic	-	-	-	-	-	+	-	-	-	-	-	-
<i>O. pithophorae</i> *	Edaphic	-	-	-	-	-	+	-	-	-	+	-	-
<i>O. plagiostomum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-
<i>O. plusiosporum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. pseudoboscii</i>	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<i>O. pyriforme</i> *	Epilithic	-	-	-	-	-	+	-	-	-	-	+	-
<i>O. rufescens</i>	Planktonic	+	+	-	-	-	+	-	-	-	+	-	-
<i>O. sociale</i>	Epiphytic	-	-	-	-	-	-	+	-	+	+	+	-
<i>O. suecicum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. tyrolicum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. urbicum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>O. vaucheri</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<b>Hallasia</b> *													
<i>H. reticulata</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<b>Mougeotia</b>													
<i>M. calcarea</i>	Planktonic	-	-	-	-	-	-	-	+	-	-	-	-
<i>M. elegantula</i>	Epiphytic	-	-	-	-	-	-	-	-	-	+	-	-
<i>M. genuflexa</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-
<i>M. sphaerocarpa</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	+
<b>Spirogyra</b>													
<i>S. arta</i> *	Planktonic	-	-	-	+	-	-	-	-	-	-	-	-
<i>S. borgeana</i>	Planktonic	-	-	-	-	+	-	-	-	-	-	-	+
<i>S. buchetii</i>	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-
<i>S. chenii</i>	Planktonic	-	-	-	-	-	-	-	-	-	-	-	+
<i>S. communis</i>	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. crassa</i>	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. crassoidea</i> *	Planktonic	-	+	-	-	+	-	-	-	-	-	-	-
<i>S. dacimina</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. daedlea</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-

Table 1. (Cont'd.).

Algal taxa	Habitat	Localities											
		1	2	3	4	5	6	7	8	9	10	11	12
<i>S. dubia</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. farlowii</i> *	Epiphytic	-	+	-	-	-	-	-	-	-	-	-	-
<i>S. fennica</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. fragilis</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. gibberrosa</i> *	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-
<i>S. gracilis</i>	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<i>S. hyalina</i>	Planktonic	-	-	-	+	-	-	-	-	+	-	-	+
<i>S. intorta</i> *	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-
<i>S. irregularis</i>	Planktonic	-	-	-	+	-	-	-	-	-	+	-	+
<i>S. jaoi</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. juergensii</i>	Planktonic	-	+	-	+	+	+	+	-	-	-	-	-
<i>S. kaffirita</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	+
<i>S. luteriana</i> *	Planktonic	-	-	-	-	-	+	-	-	+	-	+	-
<i>S. majuscula</i>	Planktonic	-	-	-	-	-	+	-	-	-	+	-	-
<i>S. mirabilis</i>	Planktonic	-	-	-	-	-	-	+	-	-	-	-	-
<i>S. nyctigama</i>	Planktonic	+	-	+	-	-	-	-	-	-	-	-	-
<i>S. oudhensis</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<i>S. paludosa</i>	Planktonic	+	-	+	-	-	-	-	-	-	-	-	-
<i>S. papulata</i>	Planktonic	+	-	+	-	-	-	-	-	-	-	-	-
<i>S. parvula</i>	Planktonic	-	-	-	-	-	-	-	-	+	-	-	+
<i>S. peipingensis</i>	Planktonic	-	+	-	-	-	-	-	-	-	+	-	-
<i>S. polymorpha</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. pratensis</i>	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. pseudospreeiana</i> *	Planktonic	-	-	-	-	-	-	+	-	-	-	-	-
<i>S. reflexa</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>S. semiornata</i> *	Planktonic	-	+	-	-	-	-	-	-	-	-	-	-
<i>S. silvicola</i> *	Planktonic	-	-	-	+	-	-	-	-	-	-	-	-
<i>S. singularis</i>	Planktonic	-	-	-	+	+	+	-	-	+	-	-	+
<i>S. submarina</i>	Planktonic	-	-	-	+	-	-	-	-	-	-	-	+
<i>S. subsalsa</i> *	Epilithic	-	-	-	-	-	-	-	-	-	-	-	+
<i>S. tandae</i>	Planktonic	-	+	-	-	-	-	-	-	-	-	-	-
<i>S. teodoresci</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>S. varians</i> *	Epiphytic	-	+	-	-	-	-	-	-	+	+	-	-
<b>Zygnema</b>													
<i>Z. cyaneum</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	+
<i>Z. czurdae</i>	Planktonic	-	-	-	-	-	-	-	-	-	-	-	+
<i>Z. fanicum</i> *	Epiphytic	-	-	-	-	-	-	-	-	+	-	-	+
<i>Z. gangeticum</i>	Planktonic	-	-	-	-	+	-	-	-	-	+	-	-
<i>Z. himalayense</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-
<i>Z. insigne</i>	Epiphytic	+	+	-	-	-	+	-	-	-	+	-	-
<i>Z. kashmirensis</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	+	-
<i>Z. khannae</i> *	Planktonic	-	-	-	+	-	-	-	-	-	-	-	-
<i>Z. normani</i>	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-
<i>Z. subcruciatum</i> *	Planktonic	-	-	-	-	-	-	+	-	-	-	-	-

Table 1. (Cont'd.).

Algal taxa	Habitat	Localities												
		1	2	3	4	5	6	7	8	9	10	11	12	
<b>Zygnemopsis</b>														
<i>Z. hesaragattense</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	-	+
<i>Z. indica</i>	Planktonic	-	+	-	-	-	-	-	-	-	-	-	-	-
<i>Z. lahoulense</i> *	Planktonic	-	+	+	-	-	-	-	-	-	-	-	-	-
<i>Z. saravatiensis</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-	-
<i>Z. spirilis</i> *	Planktonic	-	-	-	-	-	-	-	-	+	-	-	-	-
<i>Z. splendens</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	-	+
<b>Siphonocladophyceae</b>														
<b>Cladophora</b> *														
<i>C. aegagaropila</i> *	Epiphytic	-	-	-	-	-	+	-	-	+	-	-	-	+
<i>C. crispata</i> *	Planktonic	-	-	-	-	-	-	-	-	-	-	-	-	+
<b>Pithophora</b>														
<i>P. cleveana</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-	-
<i>P. oedogonia</i>	Planktonic	-	-	-	-	+	+	-	-	+	+	-	-	-
<b>Rhizoclonium</b>														
<i>R. fontatum</i>	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-	-
<i>R. hieroglyphicum</i>	Planktonic	-	-	-	-	+	-	-	-	+	+	-	-	-
<i>R. riparia</i> *	Planktonic	-	-	-	-	+	-	-	-	-	-	-	-	-
<b>Sphaeroplea</b>														
<i>S. annulina</i>	Planktonic	+	-	-	-	-	-	-	-	-	-	-	-	-
<b>Charophycota</b>														
<b>Charophyceae</b>														
<b>Chara</b>														
<i>C. aspera</i>	Epilithic	-	-	-	-	-	-	-	-	+	-	-	-	-
<i>C. globularis</i>	Epiphytic	-	-	-	-	-	-	-	-	+	-	-	-	-
<b>Vaucherophycota</b>														
<b>Vaucherophyceae</b>														
<b>Tribonema</b> *														
<i>T. pyranigerum</i> *	Planktonic	-	+	-	-	-	-	-	-	-	-	-	-	-
<i>T. vulgare</i> *	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-	-
<b>Botrydium</b>														
<i>B. granulatum</i>	Epiphytic	-	-	-	-	-	+	-	-	-	-	-	-	-
<b>Vaucheria</b>														
<i>V. amphibia</i>	Planktonic	-	+	-	-	-	+	-	-	-	-	-	-	-
<i>V. bursata</i>	Planktonic	-	-	-	-	-	-	+	-	-	-	-	-	-
<i>V. debaryana</i>	Planktonic	+	-	-	-	-	-	-	-	-	-	-	-	-
<i>V. discoidea</i>	Planktonic	-	-	-	-	-	-	-	-	-	+	-	-	-
<i>V. hamata</i> *	Edaphic	-	-	-	-	-	-	+	-	-	-	-	-	-
<i>V. longata</i>	Edaphic	-	-	-	+	-	-	-	-	-	-	-	-	-
<i>V. terrestris</i>	Planktonic	-	-	-	-	-	+	-	-	-	-	-	-	-

1 = Attock, 2 = Gujranwala, 3 = Jauharabad, 4 = Jhang, 5 = Kasur, 6 = Lahore, 7 = Pasroor, 8 = Sargodha, 9 = Sheikhpura, 10 = Sialkot, 11 = Swat, 12 = Azad Kashmir, + = Present, - = Absent,

\*= First report from Pakistan.

At ordinal level, Zygnemales was most commonly distributed with 5 genera and 65 species and showed the largest diversity. It was followed by the order Oedogonales with 2 genera and 28 species. While rest of the orders were represented very poorly among the collected population. Prasiolales, Sphaeropleales and Botrydales were the most poorly distributed orders with only 1 genus and 1 species each. As the orders Zygnemales and Oedogonales belong to the class Zygnemophyceae, it appeared to be the most highly distributed class as has already been described above. In previous studies, the orders Zygnemales and Oedogonales were found to be very widely and very well represented in the Indian Sub-continent (Rao, 1937; Randhawa, 1959) as well as in other parts of the world (Tiffany, 1930; Czurda, 1932; Transeau, 1951).

### Species diversity

*Spirogyra* with its 42 species was the most commonly occurring genus (Table 2). It was followed by the genera *Oedogonium* with 26 species and *Zygnema* with 10 species. Next common were the genera *Ulothrix* with 8 species and *Zygnemopsis* with 6 species, except *Ulothrix* all these genera belong to the class Zygnemophyceae. Such observations have also been made in several previous studies made on the specific diversity of these genera from Indian Sub-continent (Rao, 1937; Randhawa, 1948, 1959; Khan & Faridi, 1977; Ara & Faridi, 1978; Shameel, 1978, 1984; Faridi *et al.*, 1982; Hussain *et al.*, 1982) and other parts of the world (Hirn, 1900; Hazen, 1902; Heering, 1914; Tiffany, 1930; Czurda, 1932; Transeau, 1951; Mattox & Bold, 1962; Ramanathan, 1964).

Poorly distributed genera were *Binuclearia*, *Chaetophora*, *Cylindrocapsa*, *Geminella* and *Heterothrichopsis* among class Ulvophyceae, *Hallasia* among Zygnemophyceae, *Sphaeroplea* among Siphonocladophyceae and *Botrydium* among class Vaucherophyceae, which were represented by a single species each. While *Aphanochaete*, *Bulbochaete*, *Chara*, *Cladophora*, *Coleochaete*, *Pithophora*, *Tribonema* and *Uronema* were slightly better in their diversity, as each of them was represented by two species. Some of these genera have been observed to be poorly distributed at other places also (Wittrock, 1887; Tiffany, 1928; Fritsch, 1929; Wichmann, 1937; Palik, 1950; Hoek, 1963; Faridi & Haq, 1972).

### Habitat diversity

Out of the total investigated species in the present collection, an overwhelming amount was found in the free-floating or planktonic condition (Table 3). Most of such species were not real plankton, but they were found in the detached condition during collection as tychoplankton. In a previous study made on the occurrence of blue-green algae from the north-eastern areas of Pakistan, a similar observation was also made, where species of the Cyanophycota were predominantly found to occur in the planktonic condition (Naz *et al.*, 2009). No epipsammic or epipellic alga was observed in the present collection. Next category, in which individuals were collected, is the epiphytic condition. These were the two major habitats, in which collected algae commonly occurred, while in other habitats they were very poorly represented. Only a few species occurred in the edaphic, epilithic, and epioikotic habitats. The last mentioned was the least represented, habitat. In the above-mentioned previous study, the collected blue-green algae occurred in edaphic habitat in an appreciable amount (Naz *et al.*, 2009).

**Table 2. Species diversity of green, stonewort and yellow-green algae in different areas of the north-eastern region of Pakistan and Azad Kashmir.**

Algal taxa	Number of species												
	1	2	3	4	5	6	7	8	9	10	11	12	T
<b>Chlorophycota</b>	6	17	5	11	26	33	5	4	28	25	20	21	201
<b>Ulvophyceae</b>	1	5	1	3	2	12	1	-	6	6	2	4	43
<b>Ulotrichales</b>	-	2	1	-	1	5	1	-	3	2	2	3	20
<i>Binuclearia</i>	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>Geminella</i>	-	-	-	-	-	-	-	-	-	1	-	-	1
<i>Heterotrithopsis</i>	-	-	-	-	-	-	-	-	-	1	-	-	1
<i>Ulothrix</i>	-	2	1	-	1	4	1	-	3	-	1	3	16
<i>Uronema</i>	-	-	-	-	-	-	-	-	-	1	1	-	2
<b>Prasiolales</b>	-	-	-	-	-	-	-	-	1	1	-	-	2
<i>Cylindrocapsa</i>	-	-	-	-	-	-	-	-	1	1	-	-	2
<b>Microsporales</b>	-	-	-	1	1	2	-	-	1	1	-	-	6
<i>Microspora</i>	-	-	-	1	1	2	-	-	1	1	-	-	6
<b>Chaetophorales</b>	-	2	-	1	-	4	-	-	1	2	-	1	11
<i>Chaetophora</i>	-	-	-	-	-	1	-	-	-	1	-	-	2
<i>Stigeoclonium</i>	-	2	-	1	1	3	-	-	1	2	-	1	11
<b>Coleochaetales</b>	1	1	-	1	-	1	-	-	-	-	-	-	4
<i>Aphanochaete</i>	1	1	-	-	-	-	-	-	-	-	-	-	2
<i>Coleochaete</i>	-	-	-	1	-	1	-	-	-	-	-	-	2
<b>Zygnemophyceae</b>	4	12	4	8	21	18	4	4	19	16	18	15	143
<b>Oedogonales</b>	-	2	-	-	4	9	-	3	3	5	14	-	40
<i>Bulbochaete</i>	-	1	-	-	-	1	-	-	-	-	-	-	2
<i>Oedogonium</i>	1	1	-	-	4	8	-	3	3	5	14	-	39
<b>Zygnemales</b>	4	10	4	8	17	9	4	1	16	11	4	15	103
<i>Hallasia</i>	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>Mougeotia</i>	-	-	-	-	1	1	-	1	-	1	-	1	5
<i>Spirogyra</i>	3	7	3	7	14	6	3	-	7	8	3	9	70
<i>Zygnema</i>	1	1	-	1	2	1	1	-	2	2	1	3	15
<i>Zygnemopsis</i>	-	2	1	-	-	-	-	-	7	-	-	2	12
<b>Siphonocladophyceae</b>	1	-	-	-	3	3	-	-	3	3	-	2	15
<b>Cladophorales</b>	-	-	-	-	3	3	-	-	3	3	-	2	14
<i>Cladophora</i>	-	-	-	-	-	1	-	-	1	-	-	2	4
<i>Pithophora</i>	-	-	-	-	1	2	-	-	1	1	-	-	5
<i>Rhizoclonium</i>	-	-	-	-	2	-	-	-	1	2	-	-	5
<b>Sphaeropleales</b>	1	-	-	-	-	-	-	-	-	-	-	-	1
<i>Sphaeroplea</i>	1	-	-	-	-	-	-	-	-	-	-	-	1
<b>Charophycota</b>	-	-	-	-	-	-	-	-	2	-	-	-	2
<b>Charophyceae</b>	-	-	-	-	-	-	-	-	2	-	-	-	2
<b>Charales</b>	-	-	-	-	-	-	-	-	2	-	-	-	2
<i>Chara</i>	-	-	-	-	-	-	-	-	2	-	-	-	2
<b>Vaucherophycota</b>	1	2	-	1	-	4	2	-	-	-	-	-	10
<b>Vaucherophyceae</b>	1	2	-	1	-	4	2	-	-	-	-	-	10
<b>Tribonemales</b>	-	1	-	-	-	1	-	-	-	-	-	-	2
<i>Tribonema</i>	-	1	-	-	-	1	-	-	-	-	-	-	2
<b>Botrydales</b>	-	-	-	-	-	1	-	-	-	-	-	-	1
<i>Botrydium</i>	-	-	-	-	-	1	-	-	-	-	-	-	1
<b>Vaucherales</b>	1	1	-	1	-	2	2	-	-	1	-	-	8
<i>Vaucheria</i>	1	1	-	1	-	2	2	-	-	1	-	-	8
<b>Grand total</b>	7	19	5	12	26	37	7	4	30	26	20	21	214

1= Attock, 2= Gujranwala, 3= Jauharabad, 4= Jhang, 5= Kasur, 6= Lahore, 7= Pasroor, 8= Sargodha, 9= Sheikhpura, 10= Sialkot, 11= Swat, 12= Azad Kashmir, T=Total species.



**Table 3. Habitat diversity exhibited by the species of green, stonewort and yellow-green algae of the north-eastern region of Pakistan and Azad Kashmir.**

Algal taxa	Kashmir					
	Total species	Planktonic	Edaphic	Epioikotic	Epilithic	Epiphytic
<b>Chlorophycota</b>	<b>127</b>	<b>98</b>	<b>3</b>	<b>2</b>	<b>4</b>	<b>20</b>
<b>Ulvophyceae</b>	<b>28</b>	<b>16</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>9</b>
<b>Ulotrichales</b>	<b>13</b>	<b>9</b>	<b>1</b>	<b>1</b>	<b>1</b>	<b>1</b>
<i>Binuclearia</i>	1	1	-	-	-	-
<i>Geminella</i>	1	1	-	-	-	-
<i>Heterothrichopsis</i>	1	1	-	-	-	-
<i>Ulothrix</i>	8	5	1	-	1	1
<i>Uronema</i>	2	1	-	1	-	-
<b>Prasiolales</b>	<b>1</b>	<b>1</b>	-	-	-	-
<i>Cylindrocapsa</i>	1	1	-	-	-	-
<b>Microsporales</b>	<b>5</b>	<b>4</b>	-	-	-	<b>1</b>
<i>Microspora</i>	5	4	-	-	-	1
<b>Chaetophorales</b>	<b>5</b>	-	-	-	-	<b>5</b>
<i>Chaetophora</i>	1	-	-	-	-	1
<i>Stigeoclonium</i>	4	-	-	-	-	4
<b>Coleochaetales</b>	<b>4</b>	<b>2</b>	-	-	-	<b>2</b>
<i>Aphanochaete</i>	2	1	-	-	-	1
<i>Coleochaete</i>	2	1	-	-	-	1
<b>Zygnemophyceae</b>	<b>91</b>	<b>75</b>	<b>2</b>	<b>1</b>	<b>3</b>	<b>10</b>
<b>Oedogonales</b>	<b>28</b>	<b>18</b>	<b>2</b>	<b>1</b>	<b>2</b>	<b>5</b>
<i>Bulbochaete</i>	2	-	-	-	-	2
<i>Oedogonium</i>	26	18	2	1	2	3
<b>Zygnemales</b>	<b>63</b>	<b>57</b>	-	-	-	<b>5</b>
<i>Hallasia</i>	1	1	-	-	-	-
<i>Mougeotia</i>	4	3	-	-	-	1
<i>Spirogyra</i>	42	39	-	-	-	2
<i>Zygnema</i>	10	8	-	-	-	2
<i>Zygnemopsis</i>	6	6	-	-	-	-
<b>Siphonocladophyceae</b>	<b>8</b>	<b>7</b>	-	-	-	<b>1</b>
<b>Cladophorales</b>	<b>7</b>	<b>6</b>	-	-	-	<b>1</b>
<i>Cladophora</i>	2	1	-	-	-	1
<i>Pithophora</i>	2	2	-	-	-	-
<i>Rhizoclonium</i>	3	3	-	-	-	-
<b>Sphaeropleales</b>	<b>1</b>	-	-	-	-	-
<i>Sphaeroplea</i>	1	1	-	-	-	-
<b>Charophycota</b>	<b>2</b>	-	-	-	<b>1</b>	<b>1</b>
<b>Charophyceae</b>	<b>2</b>	-	-	-	<b>1</b>	<b>1</b>
<i>Chara</i>	2	-	-	-	1	1
<b>Vaucherophycota</b>	<b>10</b>	<b>7</b>	<b>2</b>	-	-	<b>1</b>
<b>Vaucherophyceae</b>	<b>10</b>	<b>7</b>	<b>2</b>	-	-	<b>1</b>
<b>Tribonemales</b>	<b>2</b>	<b>2</b>	<b>1</b>	-	-	<b>1</b>
<i>Tribonema</i>	2	2	-	-	-	-
<b>Botrydales</b>	<b>1</b>	-	-	-	-	<b>1</b>
<i>Botrydium</i>	1	-	-	-	-	1
<b>Vaucherales</b>	<b>7</b>	<b>5</b>	<b>2</b>	-	-	-
<i>Vaucheria</i>	7	5	2	-	-	-
<b>Grand total</b>	<b>139</b>	<b>105</b>	<b>5</b>	<b>2</b>	<b>5</b>	<b>22</b>

The above-mentioned conditions were mainly represented by the species of the phylum Chlorophycota, and its three classes behaved similarly except Siphonocladophyceae. In this class, no species was found in the epilithic, epioikotic or edaphic habitats. It is due to the fact that they are poorly represented in the freshwater environment (Dawson, 1966; Lüning, 1985; Shameel & Tanaka, 1992; Silva *et al.*, 1996; Dawes, 1998). The freshwater grass-green algae mostly occur in the free-floating condition (Round, 1973, 1981; Lüning, 1985; Lobban & Harrison, 1997). Under the phylum Vaucherophycota, no species was found in the epioikotic or epilithic condition. They usually occur in the free-floating and edaphic conditions (Li, 1936; Randhawa, 1939; Venkataraman, 1961). Apart from epilithic and epiphytic habitats all the other categories were missing among collected species of the Charophycota. But it is not so important, because only two species could be collected and therefore no valid generalization may be made with these data. Usually, they mainly grow in the benthic condition, attached at the bottom of slow running water channels (Wood, 1965; Krause, 1997; Langangen & Leghari, 2001; Shameel, 2002, 2005).

### **Diversity of localities**

In the present study collections were made from 12 different localities. Largest number of species was found in Lahore District. In a previous study, greatest diversity was exhibited by the collections of blue-green algae made at Lahore and its surroundings (Naz *et al.*, 2009). Other groups of freshwater algae were also found in abundance at Lahore (Masud-ul-Hasan, 1978a, b, 1980; Masud-ul-Hasan & Yunus, 1989). It was followed by the collections of Sheikhpura District. Similar observation was also made on the distribution of blue-green algae in the above-mentioned previous study (Naz *et al.*, 2009). These areas were further followed by Kasur and Sialkot districts.

The cold areas of Swat and Azad Kashmir also displayed an appreciable number of species. In other studies also a large number of algal species have been collected from these areas (Siddiqui & Faridi, 1964; Anjum *et al.*, 1982; Anjum & Faridi, 1985; Masud-ul-Hasan & Zeb-un-Nisa, 1986; Nawaz & Sarim, 2004; Zaman & Sarim, 2005; Zaman & Hussain, 2006). The areas of Attock and Pasroor were quite poor in the distribution of algae. A poor algal diversity was also observed at Attock by Faridi *et al.*, (1981). Smallest number of species was observed in Sargodha and Jauharabad districts with a very slight difference. A poor collection of different phyla of freshwater algae was also recorded for these districts in certain previous studies (Masud-ul-Hasan & Batool, 1987; Naz *et al.*, 2009).

Above mentioned observations are quite obvious regarding the species of the phylum Chlorophycota as a whole. Its class Zygnemophyceae was well represented at all the 12 localities, but the class Ulvophyceae was not found at Sargodha District. It is quite obvious, because this area previously showed the lowest diversity of algal growth (Masud-ul-Hasan & Batool, 1987; Naz *et al.*, 2009). However the class Siphonocladophyceae was not present at several localities, due to its poor representation in the freshwater environment (Shameel & Tanaka, 1992; Silva *et al.*, 1996; Lobban & Harrison, 1997; Dawes, 1998). Due to quite small number of species collected, the above-mentioned conditions are not clear among members of the phyla Charophycota and Vaucherophycota. Therefore, no valid conclusion may be drawn about them.

**Table 4. Seasonal diversity shown by the genera of green, stonewort and yellow-green algae in the north-eastern region of Pakistan and Azad Kashmir.**

Algal taxa	Azad Kashmir.			
	Spring	Summer	Autumn	Winter
<b>Chlorophycota</b>				
<b>Ulvophyceae</b>				
<b>Ulotrichales</b>				
<i>Binuclearia</i>	+	-	-	-
<i>Geminella</i>	+	-	-	-
<i>Heterothrichopsis</i>	-	+	-	-
<i>Ulothrix</i>	+	+	+	+
<i>Uronema</i>	+	+	-	-
<b>Prasiolales</b>				
<i>Cylindrocapsa</i>	+	-	-	-
<b>Microsporales</b>				
<i>Microspora</i>	+	+	-	+
<b>Chaetophorales</b>				
<i>Chaetophora</i>	-	-	+	-
<i>Stigeoclonium</i>	+	+	+	+
<b>Coleochaetales</b>				
<i>Aphanochaete</i>	-	-	-	+
<i>Coleochaete</i>	-	+	-	+
<b>Zygnemophyceae</b>				
<b>Oedogonales</b>				
<i>Bulbochaete</i>	+	-	-	+
<i>Oedogonium</i>	+	+	+	+
<b>Zygnemales</b>				
<i>Hallasia</i>	+	-	-	-
<i>Mougeotia</i>	+	+	+	-
<i>Spirogyra</i>	+	+	+	+
<i>Zygnema</i>	+	+	+	+
<i>Zygnemopsis</i>	+	-	-	+
<b>Siphonocladophyceae</b>				
<b>Cladophorales</b>				
<i>Cladophora</i>	+	+	+	-
<i>Pithophora</i>	+	+	+	+
<i>Rhizoclonium</i>	+	-	-	+
<b>Sphaeropleales</b>				
<i>Sphaeroplea</i>	-	-	-	+
<b>Charophycota</b>				
<b>Charophyceae</b>				
<b>Charales</b>				
<i>Chara</i>	-	-	+	-
<b>Vaucherophycota</b>				
<b>Vaucherophyceae</b>				
<b>Tribonemales</b>				
<i>Tribonema</i>	-	+	-	+
<b>Botrydiales</b>				
<i>Botrydium</i>	-	-	-	+
<b>Vaucherales</b>				
<i>Vaucheria</i>	+	+	-	+
<b>Total</b>	<b>18</b>	<b>14</b>	<b>10</b>	<b>15</b>

*Spirogyra* was the most commonly collected genus. Its different species were found growing at all investigated localities except Sargodha District. Next to it was *Zygnema*, which was further absent from Jauharabad District. Further next were *Oedogonium* and *Ulothrix* which were collected from 8 different localities. *Binuclearia*, *Botrydium*, *Geminella*, *Hallasia*, *Heterothrichopsis* and *Sphaeroplea* were the least occurring genera. They were collected from one locality only. While *Aphanochaete*, *Bulbochaete*, *Chaetophora*, *Chara*, *Coleochaete*, *Cylindrocapsa*, *Tribonema* and *Uronema* were slightly better, as they occurred at two different localities. Some of these genera were also found to be poorly distributed at other places (Tiffany, 1928; Wichman, 1937; Palik, 1950; Hoek, 1963; Faridi & Haq, 1972).

### Seasonal diversity

Collections of green algae were attempted throughout the year. They were found to grow practically in all the four seasons, but the largest number of their collections was made in spring season (Table 4). Their frequency of occurrence remained almost the same during summer and winter, they were found in smallest number in autumn. It appeared that they started growing in winter, thrived luxuriantly and reached to a maximum growth during spring, then they declined and began to disappear during autumn. Similar observations have been made about the occurrence of freshwater green algae at several other places as well (West, 1904; Pascher, 1925; Prescott, 1962; John *et al.*, 2005). They usually exhibit a bloom in their occurrence during spring (Round, 1981; Wehr & Sheath, 2003).

In the present collection, the seasonally resistant most common genera were *Stigeoclonium* and *Ulothrix* from the class Ulvophyceae; *Oedogonium*, *Spirogyra* and *Zygnema* among Zygnemophyceae and *Pithophora* under the class Siphonocladophyceae, which were found to grow in all the four seasons of the year. These genera were also of common occurrence at other places as well (Hirn, 1900; Fritsch, 1903; Heering, 1914; Cholnoky, 1932; Czurda, 1932; Islam, 1963; Khan & Faridi, 1977; Faridi *et al.*, 1982). It was interesting to observe that *Binuclearia*, *Cylindrocapsa*, *Geminella* and *Hallasia* were only collected during spring season, *Heterothrichopsis* was only found in summer, *Chaetophora* and *Chara* occurred only during autumn, while *Aphanochaete*, *Botrydium* and *Sphaeroplea* thrived only in winter. Species of all these genera could not be collected during other seasons; they appeared to be of very restricted occurrence and reflected a clear seasonality. Some of these genera have previously been observed to exhibit a restricted seasonal occurrence in our region (Faridi, 1955; Faridi & Haq, 1972; Sarim, 1991; Langangen & Leghari, 2001) as well as in other areas (Wittrock, 1887; Hazen, 1902; Fritsch, 1929; Palik, 1950; Krause, 1997). The remaining genera were found in certain seasons of the year but remained absent during others.

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(Received for publication 18 September 2008)