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Research Article

Study of seasonal influences on algal biodiversity in the River Yarqon (central Israel) by bio-indication and canonical correspondence analysis (CCA)

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Abstract: In our research conducted in the River Yarqon during 2003-2006, we identified 313 taxa of algae and cyanobacteria belonging to 8 taxonomical divisions. Out of these 313 taxa, 268 taxa (85.6%) were indicators of environmental conditions that characterised the river water as alkaline with medium mineralisation. In the rainy and dry seasons the algal taxonomic compositions were very different, with prevailing diatoms in the winter and cyabobacteria and greens in summer. Bio-indication shows that the taxonomic preference for the self-purification process was more intensive during the rainy season, while the low level of river water in the dry season stressed the algal community. By employing CCA analysis some indicators of highly mineralised water with high pH, anthropogenic pollution, and eutrophication were revealed. CCA analyses also helped to reveal various biosensor species sensitive to the advent of anthropogenic pollution. We therefore conclude that the combination of bioindicational methods with statistics is effective in the determination of the main factors influencing algal diversity. This combination is also helpful in indicating which biosensing species will influence the most important environmental parameters. The obtained results can be used for water quality assessment and in monitoring systems of Israeli and other Mediterranean coastal rivers.

Key words: Algae, biodiversity, ecology, CCA, seasonal, River Yarqon, Israel

Introduction

The algal diversity researched by our investigative team is very much influenced by changes in the environmental parameters of their habitats. We can use this influence in bio-indication methodology, which is widely used in European countries under the EU Framework Directive (Whitton et al., 1991; European Parliament, 2000; Dokulil, 2003; Foerster et al., 2004) as well as in the USA (Winter & Duthie, 2000; Ponader et al., 2007). However, major parameters used in bioindication are individual for each species. Our analysis is based on the taxonomical structure data and presents fluctuations of diversity in respect to seasonal activity of communities. On the other hand, a statistical approach helps us to connect all species diversity in communities with the river environment fluctuation. Therefore, our conclusion is based not only on the species autecology, but also

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on the community response to environment change. Moreover, whereas bioindicators can be specified autecologically, the species-biosensors of the major environmental variables are identifiable on the basis of CCA.

Therefore, we decided to study the reaction of the entire algal community present in the River Yarqon to changes in the water parameters affected by seasonal climate change. The main characteristic of Israeli climate is a short rainy season, which lasts from December to March. Therefore, on the one hand, we assumed that water quality before the rainy season represented the sum of influences during the dry season. On the other hand, the water quality at the end of the rainy season represented the sum of influences for the rainy season. In similar climatic conditions and floristic realms diatom algal communities were studied with respect to seasonal influences of environmental factors in Turkey (Aktan & Aykulu, 2005), Lebanon (Squires & Saoud, 1986), and Egypt (El-Awamri et al., 2007).

Our preliminary investigation examined the dynamics of indicator species and abundance of each species at the stations of the River Yarqon (Tavassi et al., 2004).

A possible method to reveal the many influences of species indicators is statistical ordination.

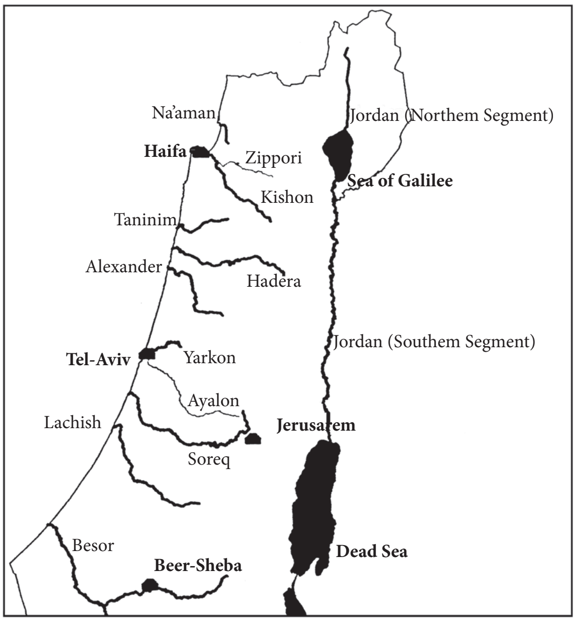

Figure 1. Israel's coastal rivers (Bar-Or, 2000).

Description of the study site

The River Yarqon is the southernmost perennial river in the Coastal Plain of Israel (Bar-Or, 2000) (Figure 1). This lowland river (gradient 0.06%) meanders along 29 km through the Tel-Aviv metropolitan region and drains into the Mediterranean. The Yarqon drainage basin covers an area of approximately 1800 km^2, with an average annual rainfall of about 600 mm. Based on the degree of perturbation and water quality of the River Yarqon, the basin can be divided into 3 segments (Gafny et al., 2000) (Figure 2): (a) an upper 7.5 km, relatively unperturbed, section with considerably high-water quality (Gasith, 1992) although immigration of pollutants, such as herbicides and nutrients, via the adjacent agriculture area during the rainy period (Ben-Hur et al., 2000) is possible. This unpolluted section ends at the confluence with the Qane tributary, where municipal effluents from a waste-water treatment plant (Kefar-Sava–Hod-Hasharon) enter the River Yarqon; (b) the central section, about 17.5 km, is severely impacted by pollution, mostly from municipal effluents (entering via the Qane tributary and the Ramat-Hasharon oxidation ponds); (c) the lowermost section, about 4 km, is under tidal influence and is therefore variably saline.

In the past 40 years the river has been severely influenced by human action. Fish kills occur along the polluted sections of the river fairly regularly (especially following winter floods) and when pollutants are discharged into the river (i.e. when the operation of waste-water treatment fails). These events attest to the serious ecological state of the River Yarqon. Presently, efforts are being made to rehabilitate the Yarqon and other coastal rivers in Israel (Gafny et al., 2000).

Materials and methods

For our study we collected 81 samples of planktonic and periphytonic algae during the period from August 2003 till February 2006. The samples where collected at 16 designated sampling stations along the River Yarqon (Figure 2).

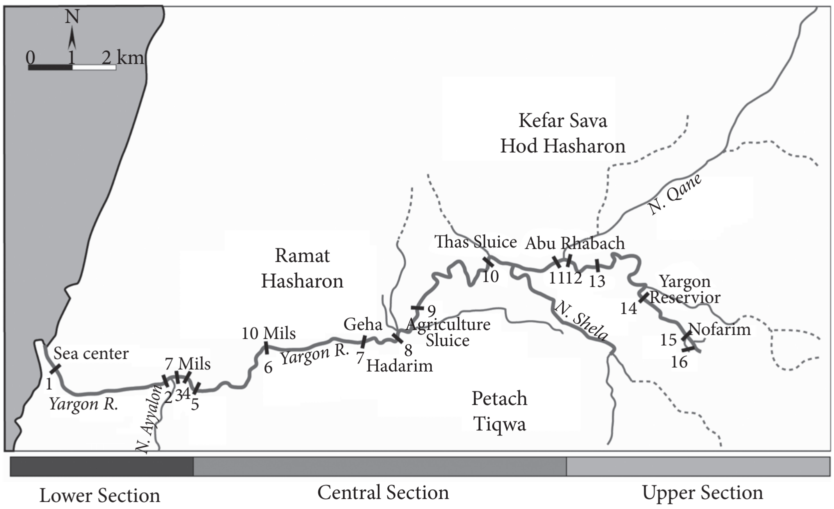

Figure 2. Study sampling stations along the River Yarqon.

The samples were obtained by scooping up for phytoplankton and by scratching for periphyton and fixing them in 3% formaldehyde. Algae were studied with a dissecting Swift microscope under magnifications of ×740-1850 and were photographed with the digital camera Inspector 1. Diatoms were prepared with the peroxide technique (Swift, 1967) modified for glass slides (Barinova, 1997).

In parallel with sampling for algae we measured conductivity, total dissolved solids (TDS), and pH with HANNA HI 9813 (Table 1). In addition to our sampling, we used data from chemical analyses regularly performed by the Ministry of Environment of Israel (2006), which are marked with asterisks in Table 1.

The taxonomy of this study mainly follows the systems adopted in the "Süswasserflora von Mitteleuropa" (Ettl, 1978; Komárek & Anagnostidis, 1998, 2005; Krammer & Lange-Bertalot, 1991a, 1991b, 1991c, 1991d; Starmach, 1983) and Green Algae by Mattox and Stewart (1984) with additions for individual taxa (Desikachary, 1959; Ettl & Gartner, 1988; Lenzenweger, 1996; Moshkova & Gollerbach, 1986; Perestenko, 1994).

Density scores were calculated using a 6-score scale (Korde, 1956) (Table 2). Ecological characteristics of the species are summed up in our database (Barinova et al., 2006).

Our ecological analysis revealed ecological groups of freshwater algae in respect to pH, salinity, and saprobity as well as temperature, streaming, and oxygenation. Each group was separately assessed according to its significance in bioindication. Species that respond predictably to these variables can be used as bioindicators reflecting the response of aquatic ecosystems to eutrophication, pH levels (acidification), salinity, and organic pollutants.

The distribution in the number of species between the groups under the different indicator systems shows the total range of environmental conditions in the river, on one hand, and the prevailing conditions, on the other. The summit of the trend line corresponds to the optimal conditions in respect to a given variable.

We quantified correlation of species composition and environmental variables using Canonical Correspondence Analysis (CCA) with CANOCO for Windows 4.5 package. Statistical significance of each variable was assessed using the Monte Carlo unrestricted permutation test involving 499 permutations (ter Braak, 1990). The abbreviated names of species are given in Table 3. The CCA biplot represents the overlap of species in relation to a given combination of environmental variables. Arrows represent environmental variables, with the maximal value for each variable located at the tip of the arrow (ter Braak, 1987).

Table 1. Environmental conditions at the River Yarqon stations in August 2003, March 2004, June 2005, and February 2006.
Note: ± Standard Deviation; * data from Israeli Ministry of Environment; - no data.

Parameter	Year	1	2	3	4	5	6	7	10	Shela	11	Qane	12	13	14	15
pH	2003	7.9 ±0.4	-	7.8 ±0.0	-	7.9 ±0.1	8.3 ±0.1	7.8 ±0.0	7.9 ±0.0	-	-	7.8 ±0.0	-	7.5 ±0.0	8.6 ±0.0	-
	2004	7.4 ±0.0	-	-	7.4 ±0.0	-	7.8 ±0.0	7.8 ±0.1	7.8 ±0.0	7.6 ±0.0	7.9 ±0.0	7.7 ±0.0	7.7 ±0.3	-	7.2 ±0.0	7.3 ±0.0
	2005	-	-	7.7 ±0.0	7.9 ±0.2	-	-	7.8 ±0.0	-	-	7.7 ±0.0	7.9 ±0.0	-	7.5 ±0.0	7.8 ±0.0	7.4 ±0.0
	2006	-	7.4 ±0.0	-	7.7 ±0.0	-	7.9 ±0.0	-	-	7.7 ±0.0	7.7 ±0.3	7.6 ±0.0	8 ±0.0	-	-	7 ±0.4
Temperature, °C	2004	22 ±0.0	-	22 ±0.0	16 ±0.0	-	20 ±4.2	19.1 ±3.4	19 ±1.4	17.3 ±3.2	20.3 ±0.4	20 ±0.0	17.5 ±2.1	-	15 ±0.0	20.5 ±0.7
	2005	-	28 ±0.0	31 ±0.0	29.5 ±1.7	-	-	27 ±1.0	27 ±0.0	-	25.5 ±0.5	-	-	25 ±0.0	26 ±0.0	26 ±0.0
	2006	-	19 ±0.0	-	20.5 ±0.0	-	18 ±0.0	-	-	16 ±0.0	21.5 ±0.7	19 ±0.0	14 ±0.0	-	-	22.5 ±3.5
E ms/cm	2003	10.3 ±0.1	-	9.2 ±0.0	-	1.6 ±0.0	1.5 ±0.0	1.5 ±0.0	1.5 ±0.0	-	-	1.9 ±0.0	-	1.2 ±0.0	1.4 ±0.0	-
	2004	10.4 ±0.0	-	-	1.4 ±0.0	-	1.4 ±0.0	1.2 ±0.2	1.6 ±0.0	4.2 ±0.0	1.6 ±0.0	1.7 ±0.0	0.8 ±0.0	-	1.1 ±0.0	1.2 ±0.0
	2005	-	-	8.7 ±0.0	1.7 ±0.2	-	-	1.6 ±0.0	-	-	1.6 ±0.0	1.6 ±0.0	-	1.3 ±0.0	1.1 ±0.0	1.1 ±0.0
	2006	-	1.4 ±0.0	-	1.2 ±0.0	-	1.5 ±0.0	-	-	4.1 ±0.0	1.4 ±0.3	1.7 ±0.0	0.9 ±0.0	-	-	1.1 ±0.2
TDS mg/L	2003	-	-	-	-	1176.3 ±2.9	1119.5 ±35.2	1113 ±0.0	1122 ±0.0	-	-	1434 ±0.0	-	842 ±0.0	1007 ±0.0	-
	2004	-	-	-	1010 ±0.0	-	995 ±0.0	921.3 ±127.0	1163 ±0.0	-	1200 ±0.0	1265 ±0.0	599 ±16.4	-	768 ±0.0	850 ±0.0
	2005	-	-	-	1228 ±168.6	-	-	1202 ±0.0	-	-	1204 ±0.0	1137 ±0.0	-	910 ±0.0	783 ±0.0	774 ±0.0
	2006	-	1010 ±0.0	-	902 ±0.0	-	1068 ±0.0	-	-	-	1002.5 ±279.3	1260 ±0.0	614 ±0.0	-	-	766.5 ±118.1
Nitrates, mg N/L	2003	-	1.5 ±0.05	15.3 ±5.1	0.2 ±0.16	0.8 ±0.54	2.3 ±0.15	12.7 ±0.64	2.6 ±0.0	-	2.9 ±0.2	-	1.3 ±0.4	15.3 ±0.82	-	1 ±0.0.0
	2004	-	1.7 ±0.17	12.4 ±0.6	1.6 ±0.05	2 ±0.11	6.5 ±0.9	6.3 ±0.42	4.2 ±0.5	1.3 ±0.0	0.2 ±0.16	-	1.85 ±0.09	-	0.4 ±0.24	1.8 ±0.2
	2006	-	1.6 ±0.05	-	-	-	1.3 ±0.19	-	-	-	0.8 ±0.26	-	15.3 ±0.82	-	-	2.4 ±0.15

Table 1. (Continued).

Note: ± Standard Deviation; * data from Israeli Ministry of Environment; - no data.

Parameter	Year	1	2	3	4	5	6	7	10	Shela	11	Qane	12	13	14	15
*Dissolved Oxygen, mg/L	2003	-	-	4	-	-	6	2	2	-	5.3	-	2	-	-	4
	2004	-	-	1.5	-	-	5	37	2.3	10.5	6	-	4.8	-	-	5.3
	2005	-	61	-	59	-	-	17	9.5	-	20	-	-	17	184	84
*E. coli, no/mL	2003	-	-	-	-	-	160	1400	21000	-	790000	-	90	-	-	220
	2004	-	-	1000	-	-	4400	6800	90000	10	110000	-	10	-	-	180
	2005	-	140	-	9	-	-	21	1.4	-	1800	-	-	0.8	8.2	0.6
*BOD, mg/L	2003	-	-	5.4	-	-	15	12.6	4.9	-	18.9	-	0.9	-	-	6.9
	2004	-	-	18	-	-	14.7	9.8	10	1.4	15.3	-	5.4	-	-	11.7
	2005	-	14.4	-	22.2	-	-	25.8	11.4	-	11.4	-	-	2.2	3.2	1.6
*NH4 , mg/l	2003	-	-	1.4	-	-	2.2	5.3	20	-	20.1	-	0.05	-	-	0.05
	2004	-	-	21.2	-	-	19.1	23	22.3	44.7	33	-	0.05	-	-	0.05
	2005	-	3.9	-	10.7	-	-	17.8	24.3	-	28	-	-	0.005	0.005	0.005
*Tot N, mg/L	2003	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	2004	-	-	33.1	-	-	33.1	29.4	47.5	1.3	38.3	-	1.7	-	-	1.3
	2005	-	-	-	18	-	-	24.1	35	-	31.8	-	-	0.005	0.01	0.01
*Tot P, mg/L	2003	-	-	3.2	-	-	4.1	5.6	7.3	-	9.5	-	0.2	-	-	0.2
	2004	-	-	5.1	-	-	5.6	5.5	7.93	0.2	7.2	-	0.2	-	-	0.2
	2005	-	2.3	-	4.3	-	-	5.6	6.6	-	7.4	-	-	0.01	0.001	0.001
*Turbidity, NTU	2003	-	-	15.3	-	-	26.4	23.5	7.7	-	13.7	-	20	-	-	30.9
	2005	-	15	-	30.5	-	-	31.5	34.5	-	11	-	-	8	17	9.8
*TSS 105, mg/L	2003	-	-	46	-	-	41	57	10	-	29	-	35	-	-	38
	2004	-	-	104	-	-	74	55	19	5	28	-	21	-	-	41
	2005	-	11	-	68	-	-	77	22	-	8	-	-	17	127	15

Table 2. Species frequencies according to the 6-scores scale (Korde, 1956).

Score	Visual estimate	Cell numbers per slide
1	Occasional	1-5
2	Rare	10-15
3	Common	25-30
4	Frequent	1 cell over a slide transect
5	Very frequent	Several cells over a slide transect
6	Abundant	One or more cells in each field of view

Results and discussion

Physical-chemical variables

The values of temperature, pH, conductivity, mineralization, and concentration of nitrates ($N\text{-}NO_3$), which we measured in the site, as well as additional chemical data of the Ministry of Environment (marked with asterisk) from the sites along the River Yarqon are presented in Table 1.

The conductivity values at the central section were higher than in the upper section, which could be related to the municipal effluents entering via the Qane tributary. In addition, the conductivity values at the lower section were much higher than those along the whole river; this could be related to the tidal influence. However, the conductivity value at Station 3 (head of the lower section) was much higher (9.17 mS/cm) during the dry season in comparison to the rainy season (3.33 mS/cm).

The pH values did not vary significantly between the 2 periods and along the entire river. There also was no significant temperature variance along the entire river.

Algal species abundance

As was preliminarily studied (Tavassi et al., 2004), in the River Yarqon communities till 2004, we revealed 247 taxa of algae and cyanobacteria. We prolonged this investigation and therefore during the period of 2003-2006 we identified 313 taxa of algae and cyanobacteria belonging to 8 taxonomical divisions. Eighty-one samples of plankton and periphyton were collected at 16 stations along the River Yarqon (Table 3). Out of this diversity, 268 taxa (85.6% of taxa) were indicators of environmental conditions such as habitats, temperature, streaming and oxygenation, saprobity, halobity, and acidification (Tavassi et al., 2004). More than two-thirds of the entire diversity (196) was seasonally dependent.

Table 3. Diversity and abundance of algal species (6-scores scale by Korde, 1956) in the River Yarqon in 2003-2006. The abbreviation name given for each species in column Code.

No.	Code	Taxa	2003	2004	2005	2006
		Cyanoprokaryota				
1	ANO01Y	*Anabaena pseudoscillatoria* Bory de Saint-Vincent	0	0	1	0
2	AN001Y	*Anabaena* sp.	2–3	1	0	0
3	APF01Y	*Aphanizomenon flos-aquae* (L.) Ralfs ex Born et Flah.	4	0	0	0
4	ACD01Y	*Aphanocapsa delicatissima* W. et G.S. West	0	0	2	0
5	ACG01T	*Aphanocapsa grevillei* (Hassal) Rabenh.	2	0	3	1
6	ACPH1Y	*Aphanocapsa holsatica* (Lemm.) Cronb. et Kom.	0	0	0	3
7	ACP01Y	*Aphanocapsa* sp.	0	0	1–6	0
8	ATCA1Y	*Aphanothece caldariorum* Richter	1	0	0	0
9	ATC01Y	*Aphanothece clathrata* W. et G.S. West	5	3–4	0	0
10	ATS01Y	*Aphanothece stagnina* (Spreng.) A. Br.	2	0	0	0
11	CAT01Y	*Arthrospira fusiformis* (Voronichin) Kom. et Lund.	0	0	1–2	0
12	CHRD1Y	*Calothrix* sp.	0	0	5	0
13	CHRT1Y	*Chroococcus dispersus* (Keissler) Lemm.	1	0	1	0
14	CTG01Y	*Chroococcus turgidus* (Kütz.) Näg.	0	1	0	0
15	MIA01Y	*Coleofasciculus chthonoplastes* (Thur. ex Gom.) Siegesmund, J.R. Hohans. & Friedl	3	0	2	0
16	GCR01Y	*Cyanothrix gardneri* f. *anabaeniformis* Kisselev	0	3	0	0
17	GCC01Y	*Geitlerinema amphibium* (Ag.) Anagn.	0	2–4	0	5
18	LTS01Y	*Gloeocapsa rupicola* Kütz.	0	0	4–5	0
19	LIA01Y	*Gloeocapsopsis crepidinum* (Thur.) Geitl. ex Kom.	1–6	1–6	1	2
20	LYA01Y	*Heteroleibleinia kuetzingii* (Schmidle) Compère	0	6	6	0
21	ANC01Y	*Komvophoron constrictum* (Szafer) Anagn. & Kom.	0	1	0	0
22	LYE01Y	*Leptochaete stagnalis* Hansg.	3	0	0	6
23	LYK01Y	*Limnothrix guttulata* (Van Goor) Umezaki et M. Watanabe	0	0	1–6	0
24	LYL01Y	*Limnothrix meffertae* Anagn.	0	1-6	1	0
25	LY001Y	*Lyngbya aestuarii* (Mert.) Liebm. ex Gom.	0	0	2–6	0

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
26	MRG01Y	*Lyngbya* sp.	0	0	1	0
27	MRM01Y	*Merismopedia glauca* (Ehrb.) Näg.	0	0	1–6	0
28	MRT01Y	*Merismopedia minima* Beck	1–2	2	5	0
29	MCC01Y	*Merismopedia tenuissima* Lemm.	3	0	0	0
30	MII01Y	*Microcystis aeruginosa* (Kütz.) Kütz.	2	0	0	0
31	MIW01Y	*Microcystis ichthyoblable* Kütz.	2–4	3	0	0
32	OSA01Y	*Microcystis wesenbergii* (Kom.) Kom.	5	1–6	0	0
33	OSGU1Y	*Oscillatoria amoena* (Kütz.) Gom.	1–2	0	1–3	0
34	OSAI1Y	*Oscillatoria limosa* Ag. ex Gom.	0	1–2	0	0
35	OSAM1Y	*Oscillatoria princeps* Vauch. ex Gom.	0	0	1–2	0
36	OSAN1Y	*Oscillatoria tenuis* Ag.	0	0	6	0
37	OSA02Y	*Oscillatoria* sp.	3–5	0	0	0
38	OSB01Y	*Phormidium aerugineo-coeruleum* (Gom.) Anag. et Kom.	2	1–6	1–6	1
39	OSG01Y	*Phormidium ambiguum* Gom.	0	1	0	0
40	OSL01Y	*Phormidium animale* (Ag. ex Gom.) Anag. et Kom.	0	0	6	0
41	OSP01Y	*Phormidium autumnale* (Ag.) Trevisan ex Gom.	0	4-6	1-3	0
42	OS001Y	*Phormidium breve* (Kütz. ex Gom.) Anag. et Kom.	2–3	1–6	1–2	0
43	OST01Y	*Phormidium granulatum* (Gardner) Anag.	5	4	0	0
44	PRAU1Y	*Phormidium uncinatum* Gom. ex Gom.	1–2	4–6	1–3	1
45	PRA01Y	*Phormidium* sp.	0	6	0	0
46	PR001Y	*Planktolyngbya limnetica* (Lemm.) Kom.-Legn. et Cronb.	3	1	2	0
47	PRU01Y	*Planktolyngbya regularis* Kom.-Legn. et Tavera	2–4	1–6	0	0
48	PLR01Y	*Planktothrix agardhii* (Gom.) Anag. et Kom.	3–5	1	0	0
49	PCC01Y	*Planktothrix isothrix* (Skuja) Kom. et Komarkova	0	3–6	0	3
50	PSS01Y	*Pleurocapsa crepidinum* Collins	0	1	0	0
51	RDL01Y	*Pseudocapsa sphaerica* (Proshkina-Lavrenko) Kováčik	3	0	0	0
52	RIH01Y	*Rhabdoderma lineare* Schmidle et Lauterborn	6	0	0	0
53	SZP01Y	*Rivularia haematites* (De Candolle) Born. et Flah.	2	0	0	0
54	SWA01Y	*Schizothrix pulvinata* Kütz. ex Gom.	0	0	1	0
55	SWL01Y	*Snowella atomus* Kom. et Hindak	1	0	0	0
56	SPM01Y	*Snowella lacustris* (Chod.) Kom. et Hindak	1	1–6	1–2	0
57	SPP01Y	*Spirulina major* Kütz. ex Gom.	0	0	1	0
58	SYS01Y	*Synechocystis salina* Wislouch	6	2	6	0
		Bacillariophyta				
59	ABI01Y	*Achnanthes brevipes* var. *intermedia* (Kütz.) Cl.	2	0	0	0
60	AC001Y	*Achnanthes coarctata* (Bréb.) Grun.	0	1–6	0	0
61	AC008A	*Achnanthidium exiguum* var. *heterovalvum* (Krasske) Czarn.	1–4	1–3	0	0
62	AC9961	*Achnanthidium minutissimum* (Kütz.) Czarn.	1	1–4	1–2	0
63	AC160A	*Achnanthidium thermale* Rabenh.	1–4	0	0	0
64	AMC01Y	*Amphora coffeaeformis* (Ag.) Kütz.	1–4	1–2	1–5	3
65	AMD01Y	*Amphora delicatissima* Krasske	0	0	1	0
66	AMO01Y	*Amphora ovalis* (Kütz.) Kütz.	2	1–3	0	0
67	AMP01Y	*Amphora pediculus* (Kütz.) Grun. ex Schmidt	1	1–4	0	2
68	AM004A	*Amphora veneta* Kütz.	0	1–3	0	0
69	AN009A	*Anomoeoneis sphaerophora* (Kütz.) Pfitz.	0	0	1	0
70	AUL01Y	*Aulacoseira granulata* (Ehrb.) Sim.	2–3	1	0	0
71	XXG989	*Aulacoseira italica* (Ehrb.) Sim.	2	1	0	0
72	BAP01Y	*Bacillaria paxillifera* (O.F. Müll.) Hendey	2	2–6	1–3	0
73	AVI01Y	*Brachysira vitrea* (Grun.) Ross	0	1	0	0
74	CLA01Y	*Caloneis amphisbaena* (Bory) Cl.	1	2	0	1
75	CLB01Y	*Caloneis bacillum* (Grun.) Cl.	0	1	0	0

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
76	SWCHYA	*Caloneis hyalina* Hust.	0	1	0	0
77	CLP01Y	*Caloneis permagna* (Bailey) Cl.	0	0	1	0
78	CCP01Y	*Cocconeis placentula* Ehrb.	1	1	1	4
79	CRA01Y	*Craticula accomoda* (Hust.) D.G. Mann	1–6	1	0	0
80	CRC01Y	*Craticula cuspidata* (Kütz.) D.G. Mann	0	1–6	0	0
81	NAH01Y	*Craticula halophila* (Grun. in V. H.) D.G. Mann	0	1	0	0
82	FRPUIY	*Ctenophora pulchella* (Ralfs ex Kütz.) D.M. Williams & Round	0	1	0	0
83	CYM01Y	*Cyclotella meneghiniana* Kütz.	1	1–4	1–4	0
84	MCTS1Y	*Cymatopleura librile* (Ehrb.) Pant.	0	1–2	1	2
85	CM006A	*Cymbella cistula* (Ehrb. in Hemprich & Ehrb.) Kirchn. var. *cistula*	0	1	1	0
86	CM00GR	*Cymbella gracilis* (Ehrb.) Kütz.	1	0	0	0
87	CM009A	*Cymbella naviculiformis* (Auersw.) Cl.	0	1	0	0
88	CMTU1Y	*Cymbella tumida* (Bréb.) Grun. in V. H.	1	2–4	1	0
89	CM109A	*Cymbella tumidula* Grun.	0	0	1–2	0
90	DP009A	*Diploneis elliptica* (Kütz.) Cl.	3	1	0	0
91	DPS01Y	*Diploneis subovalis* Cl.	0	0	3	4
92	CM031A	*Encyonema minutum* (Hilse in Rabenh.) Mann in Round et al.	3	1	0	0
93	ENO01Y	*Entomoneis alata* (Ehrb.) Ehrb.	0	1	0	0
94	ENP01Y	*Entomoneis paludosa* (W. Sm.) Reim. var. *paludosa*	0	1	0	0
95	ENPS1Y	*Entomoneis paludosa* var. *subsalina* (Cl.) Kram.	0	4	0	0
96	EP001Y	*Eunotia pectinalis* (Kütz.) Rabenh.	0	1	0	0
97	FP001Y	*Fallacia pygmaea* (Kütz.) Stikle et D.G. Mann	0	1–4	1–3	2
98	FS001Y	*Fallacia subhamulata* (Grun. in V.H.) D.G. Mann	0	2	1	0
99	SDV01Y	*Fragilaria vaucheriae* var. *capitellata* (Grun.) R. Ross	0	1	0	0
100	FU001A	*Frustulia vulgaris* (Thw.) De Toni	0	1	0	0
101	NAI01Y	*Geissleria ignota* (Krasske) Lange-Bertalot et Metzeltin	0	1	0	0
102	GO020A	*Gomphonema affine* Kütz.	2	1–3	0	0
103	GOA01Y	*Gomphonema angustatum* (Kütz.) Rabenh.	3–4	3–4	0	0
104	GOU01Y	*Gomphonema augur* Ehrb.	0	1	0	0
105	GO029A	*Gomphonema clavatum* Ehrb.	0	3	0	0
106	GO004A	*Gomphonema gracile* Ehrb.	1	1–3	1–2	0
107	GO013A	*Gomphonema parvulum* (Kütz.) Kütz.	1–5	1–6	1–6	1
108	GO023A	*Gomphonema truncatum* Ehrb.	1	1–3	2	0
109	GO073A	*Gomphonema vibrio* var. *intricatum* (Kütz.) Playfair	0	2	0	0
110	GOE01Y	*Gomphonemopsis exigua* (Kütz.) Medlin	0	1	0	0
111	GY005A	*Gyrosigma acuminatum* (Kütz.) Rabenh.	0	1–2	1–3	0
112	HAD01Y	*Hantzschia amphilepta* (Grun.) Lange-Bertalot	0	1	0	0
113	HA001A	*Hantzschia amphioxys* (Ehrb.) Grun.	0	1	1	1
114	HAV01Y	*Hantzschia virgata* (Roper) Grun.	3	1	0	0
115	LUC01Y	*Luticola cohnii* (Hilse) D.G. Mann	0	1–3	0	0
116	NA747A	*Luticola goeppertiana* (Bleisch) D.G. Mann	0	1	0	0
117	NAGP1Y	*Luticola monita* (Hust.) D.G. Mann	0	1	0	0
118	LUM01Y	*Luticola mutica* (Kütz.) D.G. Mann	0	1	0	0
119	LUS01Y	*Luticola muticopsis* (V.H.) D. G. Mann	0	2	0	0
120	NAMV1Y	*Luticola ventricosa* (Kütz.) D.G. Mann	0	1	0	0
121	MSS01Y	*Mastogloia smithii* Thw. ex W. Sm.	0	1	0	0
122	ME015A	*Melosira varians* Ag.	1	2–6	2–3	3
123	NA037A	*Navicula angusta* Grun.	0	1	0	0
124	NAE01Y	*Navicula erifuga* Lange-Bertalot	3	1–6	0	0
125	NA011A	*Navicula exigua* Greg.	0	0	2–6	1

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
126	NAG01Y	*Navicula gregaria* Donk.	0	1–6	0	0
127	NA009A	*Navicula lanceolata* (Ag.) Ehrb.	0	1	0	0
128	NAM01Y	*Navicula menisculus* Schum.	1–4	2–3	0	0
129	NAP01Y	*Navicula pseudonivalis* Bock	0	1	0	0
130	NAR01Y	*Navicula recens* (Lange-Bertalot) Lange-Bertalot	0	0	1–3	0
131	NA650A	*Navicula schroeteri* Meister	0	6	0	0
132	NA001Y	*Navicula* sp.	0	1–3	0	0
133	NA054A	*Navicula veneta* Kütz.	0	1–5	1–3	0
134	NAV01Y	*Navicula viridula* (Kütz.) Ehrb.	0	2–3	2	0
135	NI042A	*Nitzschia acicularis* (Kütz.) W. Sm.	1–2	2–6	1–5	1
136	NIA01Y	*Nitzschia amphibia* Grun.	2–6	1–4	0	0
137	NI028A	*Nitzschia capitellata* Hust.	1–6	1–5	0	0
138	NICL1Y	*Nitzschia clausii* Hantzsch	1–6	0	0	0
139	NI083A	*Nitzschia constricta* (Kütz.) Ralfs	0	1-6	0	1-5
140	NID01Y	*Nitzschia dippelii* Grun.	0	1	0	0
141	NI018A	*Nitzschia dubia* W. Sm.	0	1–2	0	0
142	NIFI1Y	*Nitzschia filiformis* (W. Sm.) Hust. var. *filiformis*	1	1–4	1	0
143	NIFI2Y	*Nitzschia filiformis* var. *conferta* (Richt.) Lange-Bertalot	0	1	0	0
144	NI002A	*Nitzschia fonticola* (Grun.) Grun.	4	1–3	3	0
145	NI008A	*Nitzschia frustulum* (Kütz.) Grun.	6	1–3	0	6
146	NI017A	*Nitzschia gracilis* Hantzsch	0	0	3	0
147	TYL01Y	*Nitzschia levidensis* (W. Smith) Grun.	0	1	0	0
148	NI031A	*Nitzschia linearis* (Ag.) W. Sm.	0	1–6	0	0
149	NIR01Y	*Nitzschia lorenziana* var. *incerta* Grun.	0	1	1	0
150	NIM01Y	*Nitzschia macilenta* Greg.	1	0	0	0
151	NIMC1Y	*Nitzschia microcephala* Grun.	1	1–5	0	0
152	NI036A	*Nitzschia obtusa* W. Sm.	0	1–3	0	0
153	NI009A	*Nitzschia palea* (Kütz.) W. Sm.	2–3	1–6	1–5	0
154	NIC01Y	*Nitzschia punctata* (W. Smith) Grun.	0	1-3	2	1
155	NISC1Y	*Nitzschia scalpelliformis* (Grun.) Grun.	0	1–3	0	0
156	NIS01Y	*Nitzschia sigma* (Kütz.) W. Sm.	1	1–5	3	0
157	NISL1Y	*Nitzschia solita* Hust.	0	1–4	0	0
158	NI9999	*Nitzschia* sp.	1–2	0	3	1
159	TYG01Y	*Nitzschia tryblionella* Hantzsch	1	1–5	1	0
160	NI184A	*Nitzschia umbonata* (Ehrb.) Lange-Bertalot	0	1–3	2–4	0
161	NI049A	*Nitzschia vermicularis* (Kütz.) Hantzsch	0	1–3	0	2-6
162	NIV01Y	*Nitzschia vitrea* G. Norm.	0	1	0	0
163	PI047A	*Pinnularia intermedia* (Lagerst.) Cl.	1	0	0	0
164	PI9999	*Pinnularia* sp.	0	1	0	0
165	XXG975	*Planothidium delicatulum* (Kütz.) Round et Bukhtiyarova	3–6	0	0	0
166	AH001Y	*Planothidium haynaldii* (Schaar. emend. Cl.) Haw et Kelly	0	1	0	0
167	AL001Y	*Planothidium lanceolatum* (Bréb. ex Kütz.) Lange-Bertalot	1	1	0	0
168	PL050A	*Pleurosigma salinarum* (Grun.) Grun.	5	1–2	0	0
169	RC002A	*Rhoicosphenia abbreviata* (Ag.) Lange-Bertalot	2	0	1	0
170	RHPG1Y	*Rhopalodia gibba* (Ehrb.) O. Müll.	0	0	2	0
171	SELP1Y	*Sellaphora pupula* (Kütz.) Mereschkowsky	1–5	1–5	1–3	0
172	NA650A	*Sellaphora stroemii* (Hust.) H. Kobayasi	0	2	0	0
173	SAA01Y	*Stauroneis anceps* Ehrb.	0	1	0	0
174	SA003A	*Stauroneis smithii* Grun.	0	1	0	0
175	FRP01Y	*Staurosirella pinnata* (Ehrb.) Williams et Round	0	1	0	2

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
176	STH01Y	*Stephanodiscus hantzschii* Grun. in Cl. et Grun.	0	1	0	0
177	SU001A	*Surirella angusta* Kütz.	0	1–4	0	0
178	SUV01Y	*Surirella ovalis* Bréb.	1	1–6	0	0
179	SUT01Y	*Surirella tenera* var. *nervosa* A. Schmidt	0	0	1–3	0
180	TBF01Y	*Tabularia fasciculata* (C. Ag.) Williams & Round	1	5	2-3	0
181	NI020A	*Tryblionella acuminata* W. Sm.	0	1–3	0	0
182	TYH01Y	*Tryblionella hungarica* (Grun.) Frenquelli	0	1	1–3	0
183	NIL01Y	*Tryblionella littoralis* (Grun.) D.G. Mann	1	0	0	0
184	FRU01Y	*Ulnaria ulna* (Nitzsch) P. Compère	1–3	1–6	2–6	0
		Chrysophyta				
185	CHSI1Y	*Chrysocrinus irregularis* Pasch.	0	0	6	0
186	SYA01Y	*Epipyxis aurea* (Chodat) Hilliard	2	0	0	0
187	LGT01Y	*Lagynion triangulare* (Stokes) Pasch.	3	0	0	0
		Euglenophyta				
188	EUE01Y	*Amblyophis viridis* Ehrb.	0	0	1–6	0
189	ASS01Y	*Astasia sagittifera* Skuja	0	1	0	0
190	COLC1Y	*Colacium cyclopicola* (Gicklhorn) Bourr.	2–5	2–3	1–6	0
191	COLP1Y	*Colacium parasiticum* (Sokolov) Hub.-Pest.	1	0	0	0
192	PHA01Y	*Cryptoglena skujae* Marin & Melkonian	0	0	1–2	0
193	EUA01Y	*Euglena acus* Ehrb. var. *acus*	1	1–4	1–2	0
194	EUAA1Y	*Euglena acus* var. *angularis* Johnson	0	1	0	0
195	EUD01Y	*Euglena deses* Ehrb.	4	1–5	1–5	1
196	EUF01Y	*Euglena fundoversata* Johnson	0	0	1–4	0
197	EUL01Y	*Euglena limnophila* Lemm.	0	0	0	0
198	EUM01Y	*Euglena minima* Fr.	0	0	1–4	2
199	EUO01Y	*Euglena oxyuris* Schmarda f. *oxyuris*	2–3	1–4	1–6	0
200	EUOS1Y	*Euglena oxyuris* f. *skvortzovii* (Popowa) Popowa	0	1	0	0
201	EUP01Y	*Euglena proxima* Dang.	0	0	1–5	0
202	EU001Y	*Euglena* sp.	0	1–2	1	0
203	EUSP1Y	*Euglena spathirhyncha* Skuja	0	0	2	0
204	EUS02Y	*Euglena srinagari* (Bathia) Hub.-Pest.	0	1	0	0
205	EUT01Y	*Euglena texta* (Duj.) Hubn.	1	1–2	1	1
206	EUTR1Y	*Euglena tripteris* (Duj.) Klebs	0	0	1	0
207	EUV01Y	*Euglena viridis* Ehrb.	0	1–6	0	0
208	LEF01Y	*Lepocinclis fusiformis* (Carter) Lemm. emend. Conr.	0	4–5	0	0
209	LEM01Y	*Lepocinclis marssonii* Lemm. emend. Conr.	0	4	0	0
210	LEO01Y	*Lepocinclis ovum* (Ehrb.) Lemm.	1–3	1–6	0	1
211	PHAL1Y	*Phacus alatus* Klebs	3	0	1–3	0
212	PHB01Y	*Phacus brevicaudatus* (Klebs) Lemm.	3	1–2	3–4	0
213	PHO01Y	*Phacus circulatus* Pochmann	0	0	1–2	0
214	PHC01Y	*Phacus curvicauda* Swir.	3–4	5	0	0
215	PHG01Y	*Phacus granum* Drez.	0	0	3	0
216	PHH01Y	*Phacus hispidulus* (Eichwald) Lemm.	1	0	0	0
217	PHL01Y	*Phacus longicauda* var. *insecta* Koczw.	3–5	0	0	0
218	PHL02Y	*Phacus longicauda* (Ehrb.) Duj. var. *longicauda*	1–4	0	0	0
219	PHS01Y	*Phacus oscillans* Klebs	0	0	0	1
220	PHP01Y	*Phacus pleuronectens* (Ehrb.) Duj.	2	1	1–4	0
221	PHPY1Y	*Phacus pyrum* (Ehrb.) Stein	0	1	1	0
222	PHL03Y	*Phacus tortus* (Lemmermann) Skvortsov	1–3	1	1	0
223	PHT01Y	*Phacus turgidulus* Pochmann	0	1	0	0

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
224	SRP01Y	*Strombomonas planctonica* (Wolosz.) Popova	1	1	0	0
225	SRS01Y	*Strombomonas subcurvata* (Proshkina-Lavrenko) Defl.	0	3	0	0
226	TRA01Y	*Trachelomonas aspera* Da Cuncha	0	1	0	0
227	TRH01Y	*Trachelomonas hispida* (Perty) F. Stein ex Defl.	0	1	1	0
228	TRS01Y	*Trachelomonas spiralis* Playf.	0	1	0	0
		Xanthophyta				
229	VA001Y	*Vaucheria* sp.	0	0	3	0
		Dinophyta				
230	PE001Y	*Peridinium* sp.	0	0	1–2	0
		Chlorophyta				
231	ACH01Y	*Actinastrum hantzschii* Lagerh. var. *hantzschii*	0	0	2–4	0
232	ACHS1Y	*Actinastrum hantzschii* var. *subtile* Wolosz.	0	0	2	0
233	BOB01Y	*Botryococcus braunii* Kütz.	1	4	0	0
234	CRT01Y	*Carteria* sp.	0	0	1	0
235	COR01Y	*Characium ornithocephalum* A. Br.	1	0	0	0
236	CHM01Y	*Chlamydomonas* sp.	0	1–4	1	1
237	CHMP1Y	*Chlamydopodium pluricoccum* (Korsch.) Ettl et Kom.	0	0	3–6	3
238	CHLM1Y	*Chlorangium minus* (Korsch.) Ettl	1	3	0	0
239	CHC01Y	*Chlorococcum* sp.	0	1–3	2	6
240	CLAG1Y	*Cladophora glomerata* (L.) Kütz.	0	2–6	2–6	6
241	CLAD1Y	*Cladophora* sp.	1–5	1	0	0
242	CLSA1Y	*Closterium acerosum* (Schrank) Ehrb. ex Ralfs	1	0	0	0
243	CLSE1Y	*Closterium ehrenbergii* Menegh. ex Ralfs	0	0	1–3	0
244	CLSR1Y	*Closterium rectimarginatum* Scott et Prescott	2	0	0	0
245	CLS01Y	*Closterium* sp.	1	0	1	0
246	COEA1Y	*Coelastrum astroideum* De-Not.	1	0	0	0
247	COEM1Y	*Coelastrum microporum* Näg.	1	0	2–6	0
248	COES1Y	*Coelastrum sphaericum* Näg.	0	0	1–6	0
249	CONP1Y	*Coenococcus planctonicus* Korsch.	1–2	0	0	0
250	COHP1Y	*Coleochaete pulvinata* A. Braun	0	0	0	2
251	COH01Y	*Coleochaete* sp.	0	1	0	0
252	CSP01Y	*Cosmarium punctulatum* Bréb.	1	0	0	0
253	CS001Y	*Cosmarium* sp.	1	1	0	0
254	CSAB1Y	*Cosmoastrum brebissonii* (Arch.) Pal.-Mordv.	0	1	0	0
255	CT001Y	*Crucigenia tetrapedia* (Kirchn.) W. et G.S. West	0	0	1	0
256	CA001Y	*Crucigeniella apiculata* (Lemm.) Schmidle	0	0	1	0
257	CI001Y	*Crucigeniella irregularis* (Wille) Tsarenko et D.M. John	1	0	0	0
258	CRE01Y	*Crucigeniella rectangularis* (Näg.) Kom.	0	0	1–4	0
259	DEA01Y	*Desmodesmus armatus* (R. Chod.) Hegew. var. *armatus*	1	1–2	1–3	0
260	DEA02Y	*Desmodesmus armatus* var. *bicaudatus* (Roll) Hegew.	1–2	0	1–6	0
261	DEB01Y	*Desmodesmus brasiliensis* (Bohlin) Hegew.	1	0	0	0
262	DEC01Y	*Desmodesmus communis* (Hegew.) Hegew.	1–2	1–2	1	0
263	DECG1Y	*Desmodesmus costato-granulatus* (Skuja) Hegew.	2	0	0	0
264	DEI01Y	*Desmodesmus insignis* (W. et G. S. West) Hegew.	0	0	1	0
265	DEIT1Y	*Desmodesmus intermedius* (R. Chod.) Hegew.	1	0	0	0
266	DEL01Y	*Desmodesmus lefevrii* (Defl.) An, Friedl. et Hegew.	2	0	0	0
267	DEM01Y	*Desmodesmus maximus* (W. et G.S. West) Hegew.	1	1	1	0

Table 3. (Continued).

No.	Code	Taxa	2003	2004	2005	2006
268	DEO01Y	*Desmodesmus opoliensis* (P. Richt.) Hegew.	2–4	0	1–4	0
269	DEP01Y	*Desmodesmus protuberans* (Fritsch et Rich) Hegew.	1	0	1–2	0
270	DE001Y	*Desmodesmus* sp.	0	1	0	0
271	DES01Y	*Desmodesmus spinosus* (K. Biswas) Hegew.	1	0	2	0
272	DICP1Y	*Dictyosphaerium pulchellum* Wood	1	1–4	1–4	1
273	DIML1Y	*Dimorphococcus lunatus* A. Br.	0	1	0	0
274	ENT01Y	*Enteromorpha torta* (Mert.) Reinb.	0	0	0	1
275	EUDE1Y	*Eudorina elegans* Ehrb.	1–6	1–3	1	0
276	FT001Y	*Franceia tenuispina* Korsch.	1	0	0	0
277	GR001Y	*Golenkinia radiata* Chod.	0	1	0	0
278	HYC01Y	*Hyaloraphidium contortum* var. *tenuissimum* Korsch.	3	0	0	0
279	CHHS1Y	*Klebsormidium subtile* (Kütz.) Tracanna	0	2	0	0
280	LA001Y	*Lagerheimia* sp.	0	1	0	0
281	MP001Y	*Micractinium pusillum* Fres.	2–6	1–3	3	0
282	MSA01Y	*Microspora amoena* var. *gracilis* (Wille) De Toni	0	0	1–2	0
283	MOA01Y	*Monoraphidium arcuatum* (Korsch.)Hind.	0	0	1–2	0
284	MOG01Y	*Monoraphidium griffithii* (Berk.) Kom.-Legn.	1–4	6	1–3	1
285	MOI01Y	*Monoraphidium irregulare* (G.M. Smith) Kom.-Legn.	0	4	1–3	0
286	MOK01Y	*Monoraphidium komarkovae* Nygaard	0	0	1–2	0
287	MOM01Y	*Monoraphidium minutum* (Näg.) Kom.-Legn.	1	0	1	0
288	MU001Y	*Mougeotia* sp.	0	1	1–3	1
289	NW001Y	*Nephrochlamys willeana* (Printz) Korsch.	0	1	0	0
290	OE001Y	*Oedogonium* sp.	2	1–6	2–6	1
291	OOC01Y	*Oocystis submarina* Lagerh.	1	1	2–4	1
292	PAM01Y	*Pandorina morum* (O.F. Müll.) Bory	0	1–2	2–3	0
293	PDB01Y	*Pediastrum boryanum* (Turp.) Menegh.	1–2	0	0	0
294	PDD01Y	*Pediastrum duplex* Meyen	1–6	0	2–4	0
295	PDS01Y	*Pediastrum simplex* Meyen	2	2	0	0
296	RCC01Y	*Raphidocelis contorta* (Schmidle) Marvan et al.	1	0	0	0
297	RCS01Y	*Raphidocelis sigmoidea* Hind.	2	1	0	0
298	RCSU1Y	*Raphidocelis subcapitata* (Korsch.) Nygaard et al.	1	1	0	0
299	RHZ01Y	*Rhizoclonium hieroglyphicum* (Ag.) Kütz.	4–6	4	1–6	0
300	SA001Y	*Scenedesmus acuminatus* (Lagerh.) Chod.	1–3	0	1–2	0
301	SAC01Y	*Scenedesmus acutus* Meyen ex Ralfs	4	0	1–3	0
302	SF001Y	*Scenedesmus falcatus* Chodat	1–2	0	1	0
303	SO001Y	*Scenedesmus obtusus* Meyen	1–2	1	1	0
304	SP001Y	*Scenedesmus parvus* (G.M. Smith) Bourr.	0	0	1	0
305	SDS01Y	*Schroederia setigera* (Schroed.) Lemm.	0	1	0	0
306	SPG01Y	*Spirogyra* sp.	0	1–6	4–6	0
307	SCT01Y	*Stigeoclonium tenue* (Ag.) Kütz.	0	1–5	1–6	6
308	STYE1Y	*Stylosphaeridium epiphyticum* (Korsch.) Korsch.	3	0	0	0
309	TTE01Y	*Tetrastrum elegans* Playf.	0	1	0	0
310	TTT01Y	*Tetrastrum triacanthum* Korsch.	1	0	0	0
311	UXT01Y	*Ulothrix tenuissima* Kütz.	2	0	0	0
312	URC01Y	*Uronema confervicola* Lagerh.	1	1–3	1–4	1
		Rhodophyta				
313	AU001Y	*Audouinella pygmaea* (Kütz.) Weber-van Bosse	0	1	0	0

In Figure 3 we can see the taxonomical distribution of all algal species diversity as opposed to the diversity of the seasonal indicators. The 2 distributions are very similar with a dominant diatom group.

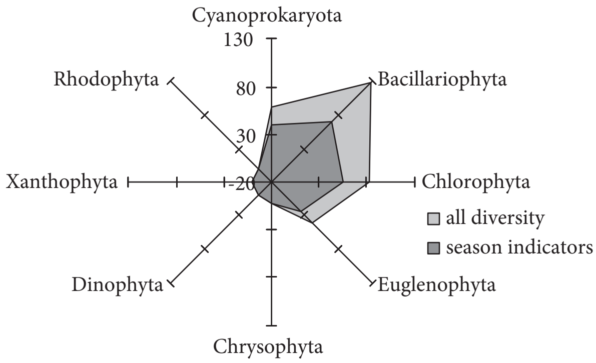

Figure 3. Taxonomical diversity from the River Yarqon and season indicators diversity.

In Figure 4 we can see the divisional distribution of 110 taxa, which was presented during all seasons. These algae belong to 4 taxonomical divisions with significant dominance of the diatoms division.

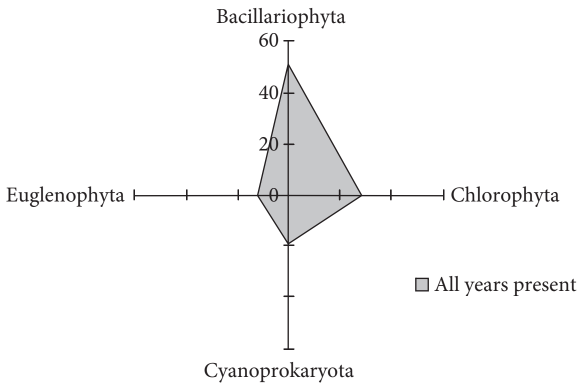

Figure 4. Taxonomical diversity of algae and cyanobacteria present in the River Yarqon during the entire period of study.

Out of the 85 seasonal indicating taxa, the cyanobacteria and diatoms were the most abundant (Figure 5); the next were green algae and euglenoids. Remarkably, this group included Chrysophyta species, even though they were only slightly evident in the entire diversity.

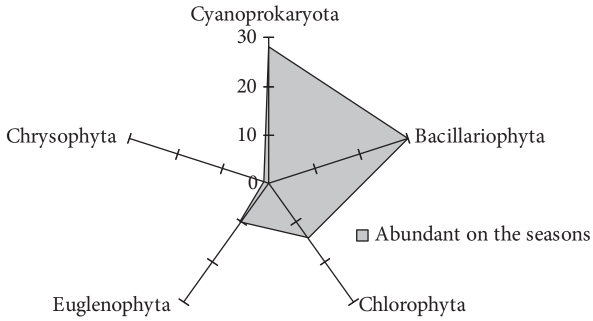

Figure 5. Taxonomical diversity of most abundant algae and cyanobacteria present in the River Yarqon as seasonal indicators.

We revealed the diversity of dominant species that were abundant in both dry and rainy seasons (Figure 6), and it can be seen that the species composition is not similar. Among the most abundant 54 taxa in the dry season, the cyanobacteria prevailed and the green algae followed. The winter communities were dominated by 49 taxa, mostly the diatoms; cyanobacteria and green algae followed. The Chrysophyta dominant species appeared only in the summer community.

The environmental factors, such as current and light, mostly impact on the community structure and colonization patterns of diatoms in streams (McIntire, 1968; Stevenson, 1983). In the lotic habitats of Turkey and Egypt, salinity is strongly increased and algal species diversity decreased during the dry season (Aktan & Aykulu, 2005; El-Awamri et al., 2007). On one hand, in the Turkish rivers species diversity is

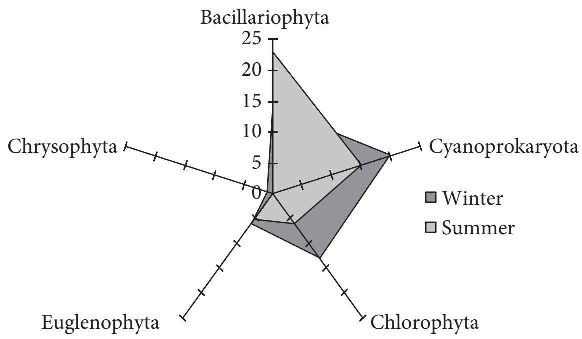

Figure 6. Taxonomical diversity of dominant species abundant in all dry or wet seasons.

considered higher in communities in stable environments than in disturbed ones. On the other hand, in some seasons, the effect of nutrients carried by wastewater has caused certain species to increase substantially, thus reducing the species diversity (Aktan & Aykulu, 2005).

The effect of early spring was more significant in determining diatom community structure than the habitat differences between the upper Damour and el-Hamam rivers or the upper and lower Damour sites in Lebanon (Squires & Saoud, 1986). Summer environmental conditions in the River Damour in Lebanon resulted in floras as distinctive characteristics. Habitat differences between the upper and lower River Damour became significant when the salinity began to increase in the estuary (Squires & Saoud, 1986).

In the River Yarqon communities the dominant algal species that survived both dry and rainy seasons are presented in Table 4. We can see that their ecological preferences are opposite. Therefore, these species can be used as indicators for the collective seasonal influences. During the dry season, the dominant species were the green chlorococcoid algae; they survive in planktonic-benthic habitats and prefer fresh, low streaming, and middle polluted water with medium contents of organic matter and neutral amplitude of pH.

Diatoms are the dominant species in the rainy season only. They are typical periphytonic algae surviving by attaching themselves to hard substrates in more alkali and saline water. Their presence usually indicates increases in organic matter pollution. This quality helps us to conclude that the water in the River Yarqon flows slower during the dry season. As a result, the algal community experiences stress. Another conclusion that can be made is that, although the drift of organically polluted saline water in the River Yarqon is much stronger in the rainy season in comparison to the dry season, the self-purification processes are more intensive as well. Therefore, algae are more likely to survive in the periphyton during the winter season as their photosynthetic activity is sufficient for the self-purification of the River Yarqon.

CCA Analysis

The algal species diversity in the River Yarqon is larger during the dry season (222 taxa) than during the wet season (207 taxa), as can be seen in the species diversity analysis results. The dominance tendency shows overall resemblance between the present communities and does not reveal any major influencing factors or typical species. For this reason, in order to reveal major influencing factors and typical species, we decided to use a statistical method, implementing a factorial analysis.

Table 4. Ecological parameters (Barinova et al., 2006) and abundance of algal species (6-scores scale, Korde, 1956) that may serve as seasonal indicators in the River Yarqon.

Taxon	2003	2005	2004	2006	Season	Hab	Reo	Sal	pH	D	Sap	IS
Coelastrum microporum	1	2-6			Summer	P-B	st-str	i	ind		b	2.1
Pediastrum duplex	1-6	2-4			Summer	P	st-str	i	ind		o-a	1.8
Desmodesmus armatus var. *bicaudatus*	1-2	1-6			Summer	P-B	st-str				b	2.0
Nitzschia constricta			1-6	1-5	Winter	B		mh	alf	es	b	2.2
Nitzschia vermicularis			1-3	2-6	Winter	B		i	alf		o	1.3

Note: Hab – habitat (B – benthic; P – planktonic; P-B – planktonic-benthic); Reo – streaming and oxygenation (st-str – low streaming water); Sal – halobity (salinity) degree (i – oligohalobes-indifferent, mh – mesohalobes); pH – pH degree (alf – alkaliphiles, ind – indifferents); D – degree of saprobity on the Watanabe's (Watanabe et al., 1986) (es - eurysaprobes); Sap – degree of saprobity on the Pantle-Buck's (Pantle & Buck, 1955; Sládeček, 1986) (o – oligosaprobes, o-a – oligo-alfamesosaprobes, b – betamesosaprobes); IS – species-specific Index of saprobity on the Sládeček (Sládeček, 1986; Barinova et al., 2006).

The main advantages of this analysis are (1) a reduction in the number of variables and (2) determination of the structure of relations between the different variables. The CCA ordination method was chosen for its ability to reveal influences of a collection of variables on many species' communities.

CCA analysis was performed on the basis of chemical data (Table 1) and revealed diversity (Table 3). To the available parameters, we added the number of species in each community.

The connection between the algal community and the environmental variables for the rainy season in the River Yarqon according to 2004 data is presented in Figure 7. From this biplot, we can conclude that all the salinity and nutrient variables have similar influence on the biotic community. Algal species, such as *Aphanothece clathrata* (cyanobacteria) and *Phacus brevicaudatus* (euglenoids) (bottom circle in Figure 7), prefer highly mineralized water with high pH. Indicators of anthropogenic pollution and eutrophication (marked by the right circle) are *Phormidium autumnale*, *Limnothrix meffertae* (cyanobacteria), *Navicula schroeteri*, *Luticola cohnii*, *Tabularia fasciculata* (diatoms), and *Phacus curvicauda* (euglenoids). As biosensors for the beginning of anthropogenic stress we revealed species that prefer low concentrations of the influencing factors. Biosensor species in respect to anthropogenic pollution and eutrophication are *Mougeotia* sp., *Chlorococcum* sp. (greens), and *Amphora pediculus* (diatom) (the lower left circle). Biosensor species in respect to high mineralization, high pH, and high biodestruction processes are *Cymbella tumida*, *Bacillaria paxillifera*, *Amphora veneta*, *Navicula viridula* (diatoms), and *Spirulina major* (cyanobacteria) (the upper left circle).

The connection between the algal community and environmental variables for the dry season in the River Yarqon, according to 2005 data, is presented in Figure 8. From this biplot we can conclude that all analysing variables also have a similar influence on the biotic community. Algal species that prefer highly mineralised water are *Phacus brevicaudatus* (euglenoids), *Phormidium animale*, and *Spirulina major* (cyanobacteria) (lower left circle). These species are also indicators of water rich in organic matter (Barinova et al., 2006). The indicator species

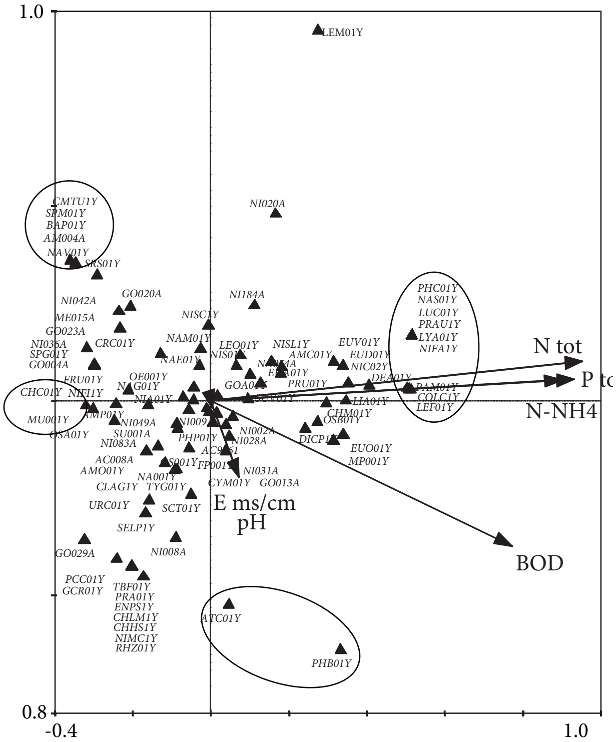

Figure 7. Biplot of environmental variables and species scores in a CCA of the River Yarqon as constructed for rainy season data. Full names of species are presented in Table 3. Correlations presented in Appendix.

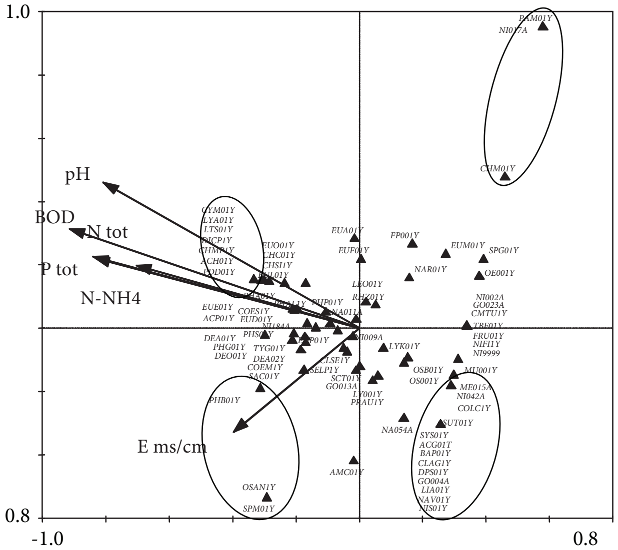

Figure 8. Biplot of environmental variables and species scores under CCA of the River Yarqon as constructed for the dry season data. Full names of species are presented in Table 3. Correlations presented in Appendix.

show the connection between anthropogenic pollution and high mineralisation. In the upper left circle, we marked a few species that can indicate anthropogenic pollution and eutrophication during the dry season. However, the relationship between species ecological properties and anthropogenic variables is not clear.

As biosensor species in respect to anthropogenic pollution, eutrophication, and high biodestruction processes in the dry season communities, we revealed *Cladophora glomerata* (green), *Nitzschia sigma, Navicula viridula, Diploneis subovalis, Bacillaria paxillifera* (diatoms)*, Limnothrix meffertae,* and *Synechocystis salina* (cyanobacteria) (lower right circle). As biosensor species, with respect to high mineralisation, *Pandorina morum*, *Chlamydomonas* sp. (greens), and *Nitzschia gracilis* (diatom) (upper right circle) were revealed.

The results of CCA analysis for all algal communities during the rainy and dry seasons are shown in Figure 9. As can be seen, all the environmental variables were grouped into one quadrant of the biplot. Increases in these variables show anthropogenic influence. We found specific reactions of algal diversity to environmental parameters in winter and summer. We intended to investigate which species will react to specific parameters influenced by both summer and winter. The biplot specifies cyanobacteria *Planktolyngbya limnetica* and *Phormidium animale*, euglenoids *Euglena oxyuris*, *Phacus brevicaudatus*, and *Lepocinclis fusiformis,* and greens *Desmodesmus armatus* (top circle) to be indicators of highly mineralised water with high pH, anthropogenic pollution, and eutrophication. Most of these species are marked in our database as indicators of high-salinity and high-organic matter concentration (Barinova et al., 2006).

As seen on the River Darmur in Lebanon (Squires & Saoud, 1986), a diatom community may be most sensitive to environmental change or perturbation, and differential distribution and density patterns of rare taxa are usually good, reliable indicators of environmental changes. On the other hand, the wide tolerance limits of many of the diatoms that grow in lotic habitats such as the River Damour help them resist extinction in stressed conditions. For these taxa, relative numbers become an important indicator, and they may be more sensitive to environmental change than more abundant species.

In the River Yarqon communities the biosensor species with respect to high mineralization, high pH, high biodestruction processes, anthropogenic pollution, and eutrophication are mostly diatoms and not abundant, e.g. *Aphanocapsa grevillei*, *Synechocystis salina* (cyanobacteria), *Stephanodiscus hantzschii*, *Diploneis subovalis*, and *Nitzschia gracilis* (diatoms) (Figure 9, lower circle).

CCA analysis enabled us therefore to reveal a few green algae, diatoms, and cyanobacteria species that can be used as indicators for higher salinity and anthropogenic pollution of the River Yarqon. This correlates with the autecology of these species (Table 5). CCA analysis enabled us to reveal biosensor species with respect to the beginning of anthropogenic pollution of the River Yarqon. We are looking at biosensor species as sensitive to small concentrations of substances in contrast to the species-indicators that depend on a high concentration of substances in the water. It is possible to reveal biosensor species with the CCA analysis, as we can see in the River Yarqon communities.

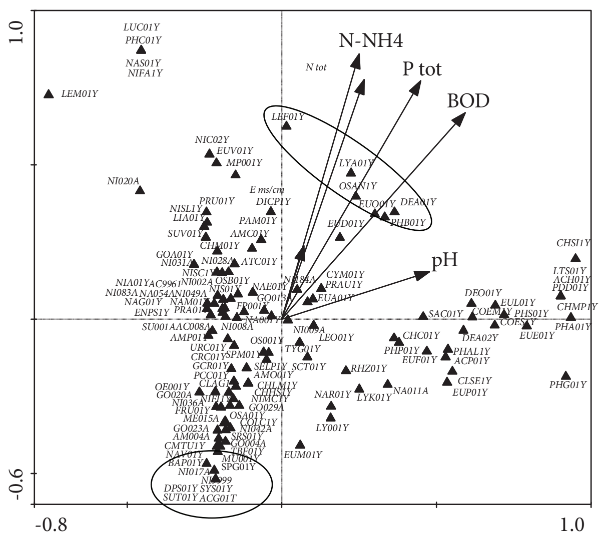

Figure 9. Biplot of environmental variables and species scores under CCA of the River Yarqon as constructed according to data collected in all seasons. Full names of species are presented in Table 3. Correlations presented in Appendix.

Table 5. Ecological parameters and abundance of algae (6-scores scale, Korde, 1956) that may serve as biosensor and bioindicator species for the River Yarqon.

Species	2004	2005	Bio-sensor	Bio-indi-cator	Hab	Reo	T	Hal	pH	Sap	IS
Amphora pediculus	1-4		+		B	st	temp	i	alf	a-b	
Amphora veneta	1-3		+		B			i	alf	a-p	
Aphanocapsa grevillei		3	+		B		temp	hb	acf	o-b	1.4
Aphanothece clathrata	3-4			+	P			hl		b	1.7
Bacillaria paxillifera	2-6	1-3	+		P-B			mh	ind	a-b	2.8
Cymbella tumida	2-4	1	+		B		temp	i	alf	o	
Desmodesmus armatus	1-2	1-3		+	P-B	st-str				o-a	1.9
Euglena oxyuris	1-4	1-6		+	P-B	st-str		mh	ind	b-a	2.5
Lepocinclis fusiformis	4-5			+	P	st-str	eterm	i	ind	b	2.0
Limnothrix meffertae	1-6	1		+	B	st		mh			
Luticola cohnii	1-3			+	B			i	ind	o	
Planktolyngbya limnetica	2			+	P-B	st-str		hl		o-b	1.5
Mougeotia sp.	1	1-3	+		B						1.0
Navicula schroeteri	6			+	B			i	alf		
Navicula viridula	2-3	2	+		B			hl	alf	a	2.8
Tabularia fasciculata	5	2-3		+	P-B			mh			
Nitzschia gracilis		3	+		P-B		temp	i	ind	o-x	0.6
Phormidium animale		6		+	P-B	str				o	1.1
Pandorina morum	1-2	2-3	+		P	st		i		b	2.0
Phacus brevicaudatus	1-2	3-4		+	P	st-str	eterm	hl		b	2.0
Phacus curvicauda	5			+	P-B	st		i	ind		
Phormidium autumnale	4-6	1-3		+	B	st-str				b	1.95

Note: Hab – habitat (B – benthic; P – planktonic; P-B – planktonic-benthic); Reo – streaming and oxygenation (st - standing water, st-str – low streaming water); T – temperature (temp – temperate, eterm - eurythermic); Sal – halobity (salinity) degree (hb – halophobes, i – oligohalobes-indifferent, hl – halophiles, mh – mesohalobes); pH – pH degree (acf – acidophles, alf – alkaliphiles, ind – indifferents); Sap – degree of saprobity on the Pantle-Buck's (Pantle & Buck, 1955; Sládeček, 1986) (o – oligosaprobes, o-a – oligo-alfamesosaprobes, o-b – oligo-betamesosaprobes, o-x – oligo-xenosaprobes, b – betamesosaprobes, b-a – beta-alfamesosaprobes, a – alfamesosaprobes, a-b – alfa-betamesosaprobes, a-p – alfa-polysaprobes); IS – species-specific Index of saprobity on the Sládeček (Sládeček, 1986; Barinova et al., 2006).

Conclusion

In our research of the River Yarqon during 2003-2006, we recognised 313 taxa of algae and cyanobacteria belonging to 8 taxonomical divisions. Out of this diversity, 268 taxa (85.6% of taxa) were indicators of environmental conditions that can characterise the river water as alkaline with medium mineralisation.

The algal taxonomic compositions in the rainy and dry seasons are quite different, with the diatoms' group diversity being much richer in winter, whilst the greens and cyanobacteria are more diverse in summer. Although the diversity of the algae that survived in all seasons was low, the diatoms still prevailed.

Among seasonal indicators, the dominant groups were diatoms in the winter and greens and cyanobacteria in the summer. The taxonomical distribution of indicators in the seasonal communities yielded similar reactions. This distribution reflects the taxonomic preferences for the self-purification processes for each season.

During the rainy season, the self-purification processes are more intensive and photosynthetic activity of the algae is sufficient for the self-purification of the River Yarqon. In contrast, the low level of river water in the dry season stresses the algal community such as in similar conditions in the rivers in Turkey, Lebanon, and Egypt.

According to CCA analysis, we revealed algal species that can serve as indicators in respect to higher salinity and organic pollution. There are characteristic indicators of species diversity for each of the seasons. They belonged mostly to cyanobacteria and euglenoids. For the typical river in the Eastern Mediterranean, CCA analysis revealed biosensor species with respect to anthropogenic pollution of the River Yarqon, which belonged mostly to diatoms. We can therefore conclude that the combination of bioindicational methods with statistics is an effective means in the determination of the main factors influencing algal diversity. This approach is also helpful in specifying indicators (for the high levels of environmental parameter) and biosensors (for the low levels of environmental parameter) for the most important environmental parameters.

These results can be used for water-quality assessment and monitoring systems in Israeli and other Mediterranean coastal rivers.

Acknowledgements

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Appendix. Correlations for CCA analysis of the River Yarqon communities and environmental variables.

CCA for wet season.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.493	0.439	0.409	0.386	3.594
Species-environment correlations	0.993	0.999	0.991	0.988	
Cumulative percentage variance					
of species data	13.7	25.9	37.3	48.0	
of species-environment relation	20.7	39.1	56.3	72.5	
Sum of all eigenvalues	3.594				
Sum of all canonical eigenvalues	2.383				

Test of significance of first canonical axis	
Eigenvalue	0.493
F-ratio	0.477
P-value	0.5440
Test of significance of all canonical axes	
Trace	2.383
F-ratio	0.984
P-value	0.5020

CCA for dry season.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.839	0.660	0.578	0.544	3.746
Species-environment correlations	1.000	0.995	1.000	0.997	
Cumulative percentage variance					
of species data	22.4	40.0	55.5	70.0	
of species-environment relation	26.7	47.7	66.1	83.4	
Sum of all eigenvalues	3.746				
Sum of all canonical eigenvalues	3.143				

Test of significance of first canonical axis	
Eigenvalue	0.839
F-ratio	0.289
P-value	0.0220
Test of significance of all canonical axes	
Trace	3.143
F-ratio	1.042
P-value	0.1180

CCA for dry and wet seasons.

Axes	1	2	3	4	Total inertia
Eigenvalues	0.677	0.507	0.420	0.402	6.771
Species-environment correlations	0.988	0.974	0.991	0.984	
Cumulative percentage variance					
of species data	10.0	17.5	23.7	29.6	
of species-environment relation	25.4	44.4	60.2	75.2	
Sum of all eigenvalues	6.771				
Sum of all canonical eigenvalues	2.667				

Test of significance of first canonical axis	
Eigenvalue	0.677
F-ratio	1.111
P-value	0.0020
Test of significance of all canonical axes	
Trace	2.667
F-ratio	1.083
P-value	0.0640