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# Diversity and ecology of algae from the Alexander River (Central Israel)

**Abstract**

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In 26 samples of plankton and periphyton taken from nine stations on the Alexander River and one station on the tributary we found 145 species of algae and cyanoprokaryotes from seven divisions. Green algae strongly prevailed. Fifteen algal species are recorded for the first time in Israel. Among them *Salpingorhiza pascheriana, Salpingoeca ringens,* and *Chrysocrinus irregularis* (*Chrysophyta*) as well as *Lepocinclis lefeèvrei* (*Euglenophyta*) were widespread, but rare all over their ranges. As a whole, 129 species are indicators of environmental conditions. *Onkonema compactum* (*Cyanoprokaryota*) is an indicator of warm water habitats. A green filamentous alga Enteromorpha torta is an indicator of a strongly saline habitat. The group of pH indicators is dominated by oligohalobes-indifferents and alkaliphiles. Indicators of saprobity, according to Watanabe's and Sládeèek's methods, show a moderate level of organic pollution. Species richness in the algal communities over the stations of the Alexander River is changing from rich communities with 6 divisions in the upper reaches to poor communities of cyanoprokaryote-diatom-green algae in the more polluted station below the crossing with the Highway 4, and to the chrysophytic epiphytes at the mouth.
Thus, our study of algal communities in the Alexander River reveals the natural trend of algal diversity and the influence of pollution over the river. On the basis of bioindication methods the Alexander River is characterized as moderately transformed, with changes of algal communities revealing hot spots of anthropogenic impactmineralized, low streaming, and alkaline with a moderate level of organic pollution.
We conclude that the EU Framework indication system is applicable for the assessment and monitoring of aquatic ecosystems in Israel related to rehabilitation program for the river.

## Introduction

The study of algal biodiversity in the eastern Mediterranean gains importance in relation to the rapidly increasing industrial impact on aquatic ecosystems in this region. Monitoring studies of aquatic systems in Israel are admittedly less advanced than on the European coast (Dell'Uomo 1999; Prygiel & Coste 1999). Although during 130 years of algological studies in Israel 1459 species and varieties were reported (Nevo & Wasser 2000; Vinogradova & al. 2000a, b, c, d, 2001; Massjuk & al. 2001a,b; Michailuk & al.

2001a, b; Tsarenko & al. 2001; Kovalenko & al. 2002a, b, 2003; Barinova & al. 2003, 2004; Krakhmalny & al. 2004; Tavassi & al. 2004), our knowledge of the regional algal diversity is far from exhaustive. The purpose of this study was to reveal the algal diversity and relate it to environmental variables in a protected river of central Israel. The bioindication methods are regularly utilized in the EU for evaluation of ecosystem responses to changes of major environmental variables, i.e. salinity, pH, and organic pollution. Here we apply these methods for assessment of the current state and potentials of aquatic ecosystems in the Alexander River, a larger coastal river of eastern Israel recently (since 1995) selected for ecosystem recovery program.

## River description

The Alexander River is one of the larger coastal rivers in Israel (Figures 1, 2). It runs for about 44 km from the western side of the Mountain Belt across cultivated areas and past towns of the Coastal Plain to the Mediterranean Sea (Fig. 1). Industrial and domestic effluents were discharged to the Alexander River and introduced considerable pollutants

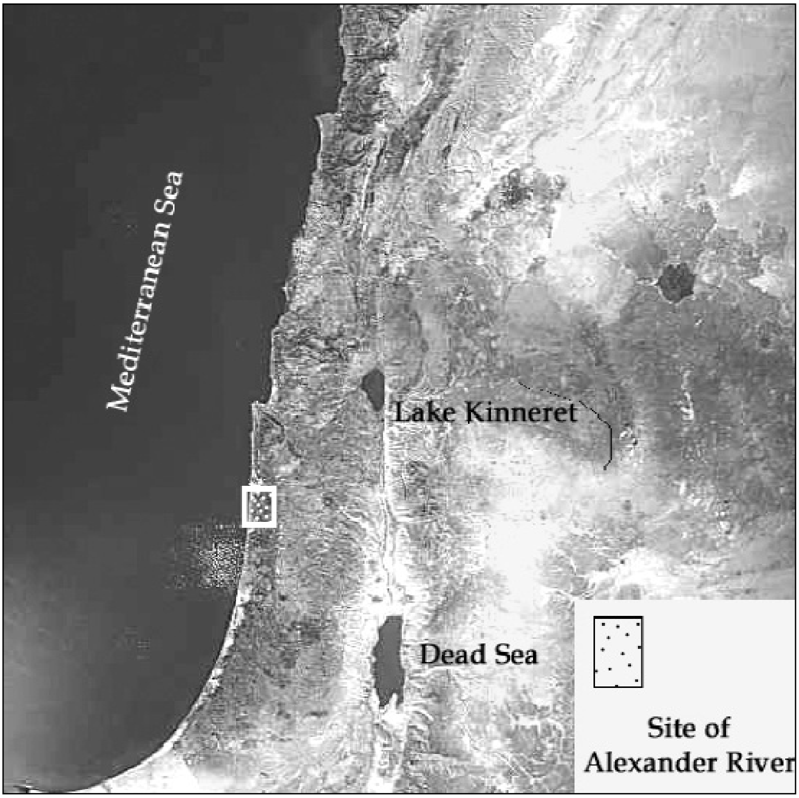



Fig. 1. Study area (rectangle) on the satellite map of the region.

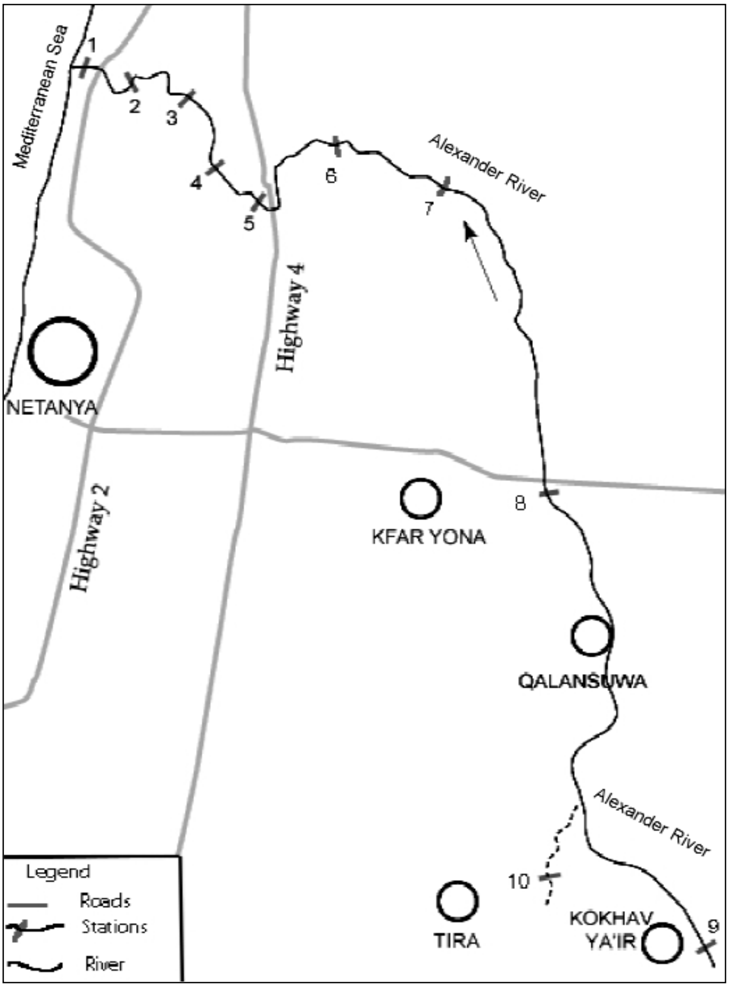



Fig. 2. Region of investigations: Stations on the Alexander River.

over the past 40 years (Israel Nature and National Parks Protection Authority, http://www.parks.org.il). These have degraded the water quality and the ecosystem. However, improvements are underway with preservation of breeding sites along the river for the rare Nile soft-shell turtle. The Alexander River flows through agricultural land in the northern part of the Tel Aviv metropolitan area, the country's most densely populated region. Its watershed spans 550 square kilometers.

Two central problems have plagued the river for years: pollution from a variety of domestic, agricultural, and industrial sources and development pressures in the open space surrounding the river, which threaten its potential for leisure and recreation uses. It is no wonder, then, that this river was one of the first in Israel to be selected for restoration. In

1995, the Alexander River Restoration Administration of the Ministry of Environment, the Jewish National Fund, and the Emek Hefer Regional Council, was established. Its mandate was to remove pollutants, restore landscapes and ecosystems, and develop the river for recreational purposes.

## Previous publication

Up to now, as a result of sporadic investigation, only 21 species of algae and cyanoprokaryotes were identified in the Alexander River (Rayss 1944, 1951; Hisoriev & al. 1996, 1999; Tsarenko & al. 1996a,b; 1997; Vinogradova & al. 1996c; Kondratyuk in Nevo & Wasser 2000). Among them, there were six diatoms, six cyanoprokaryotes, four green algae, and five euglenoids. Only five of this species were found during our investigation (marked with an asterisk in the additional taxonomic table).

## Material and Methods

Material for this study came from 26 samples of phytoplankton and periphyton from 10 sampling stations over the Alexander River (Fig. 2). The sampling was conducted during three collecting trips encompassing rainy and dry seasons from September 2003 to October 2005. We sampled the temporary water flow of the upper reaches (1 station in the river channel), tributary (1 station), and permanent water flow of the lower reaches (8 stations). The samples were obtained by scooping up for phytoplankton and by scratching for periphyton and all samples were preserved in 3% formaldehyde (Whitton & al. 1991). Algae were studied with a dissecting Swift microscope under magnifications of 740–1850 and were photographed with the digital camera Inspector 1. The diatoms were prepared with the peroxide technique (Swift 1967) modified for glass slides (Barinova 1997).

The taxonomy of this study mainly follows the systems adopted in "Süswasserflora von Mitteleuropa" (Ettl 1978; Starmach 1985; Krammer 1985; Ettl & Gärtner 1988; Krammer & Lange-Bertalot 1991a,b, 1997a,b; Krause 1997; Komárek & Anagnostidis 1998) and Mattox & Stewart (1984) with additions for individual taxa (Gollerbach & al. 1953; Popova 1966; Moshkova & Gollerbach 1986; Lange-Bertalot & Krammer 1987; Meffert 1987; Komárek & Anagnostidis 1989; Barber & Carter 1996; Hegewald 2000; Krammer 2000).

In parallel with sampling for algae we measured temperature, conductivity, mineralization, and pH with HANNA HI 9813, and concentration of N-$NO_3$ with HANNA HI 93728 (Table 1).

Ecological and geographic characteristics of algal species come from the above listed publications and are obtained from the database compiled by the first author for freshwater algae of Israel as a basis for a multipurpose analysis of algal biodiversity (Barinova & al. 2000). The histograms of species distribution against the ascending trend of ecological variable appear as normal distribution, in which the mean square deviation (sigma) line separates dominant groups in respect to a particular environmental variable (Hill 1973):

$$(1) \quad \sigma = +\sqrt{\frac{\Sigma (x - M)^2}{(n - 1)}}$$

where σ is mean square deviation (unitless), x is number of species in a group, M is mean number of species per group, and n is total number of indicator species for an respect environmental variable. Species groups that fall in the interval between the maximum and single sigma value are considered as finding optimal conditions for their development and achieve the numerical dominance. This approach is used (Cumming & al. 1995, Batterbee & al. 1999) for assessing the tolerance ranges of algae for specific environmental variables.

Our ecological analysis revealed a grouping of freshwater algae in respect to environmental variables: pH, salinity, organic pollution, temperature as well as reophility and oxygenation (Table 2). Each group was separately assessed in respect to its significance for bioindications. Species that respond predictably to these variables can be used as bioindicators reflecting the reactions of aquatic ecosystems to eutrophication, pH levels (acidifications), salinity, and organic pollutants.

The indicators of halobity, primarily the diatom algae, were analyzed in respect to the classification system proposed by Kolbe (1927) and further developed by Hustedt (1957). The system is presently widely used in bioindication studies (Stoermer & Smol 1999). The system divides the indicator species into four groups: (1) Polyhalobes, living in hypersaline waters from 40‰ to 300‰, (2) Euhalobes inhabiting marine waters of 20‰–40‰, (3) Mesohalobes of brackish shelf seas and estuaries, as well as of continental basins with salinity ranging from 5‰ to 20‰, and (4) Oligohalobes of fresh and slightly saline water, 0 to 5‰, further divided into four groups: a) Halophiles, essentially freshwater, but enhanced by a slightly elevated concentration of NaCl, b) Indifferents, typically freshwater, occurring but never abundant in slightly brackish waters, and c) Halophobes, strictly

Table 1. Environmental variables over the stations of Alexander River.

| **Station** | **pH** | **E ms/cm** | **TDS mg/l** | **N-$NO_3$ mg/l** |
|---|---|---|---|---|
| 1 | 8.2-8.5 | 8.58-9.78 | - | 1.7-15.3 |
| 2 | 8.3-8.6 | 8.41-9.63 | - | 0.4-2.0 |
| 3 | 8.1 | 7.35-9.08 | 1041 | 3.5-3.6 |
| 4 | 7.9 | 4.78 | 1806 | 1.2 |
| 5 | 8.0-8.1 | 1.97-1.98 | 1461-1471 | 1.3-4.9 |
| 6 | 8.0-8.8 | 1.6-1.85 | 1177-1373 | 0.4-1.2 |
| 7 | 8.2-9.3 | 1.77-2.47 | 1303-1859 | 1.3 |
| 8 | 7.7 | 1.24 | 906 | 1.3 |
| 9 | 8.1 | 1.86 | 1387 | 0.5 |

freshwater, perishing at a slight increase of NaCl. Our database contains information on 2,319 species indicative of chloride concentrations.

Distribution of species sensitive to pH and prospective bioindicators for this variable is analyzed according to the classification developed by Hustedt (1938, 1939). His classification system includes 11 pH-related groups ranging from alkalibiontes (surviving at pH = 8 and higher) to acidobiontes (surviving in acid waters, with pH = 5 and less).

Of several currently used estimates of saprobity, that of Pantle & Buck (1955) modified by Sládeèek's estimates (1973, 1986) proved the most suitable for the present analysis. The indicators of saprobity are assigned to four groups according to their saprobity index values (S) ranging from polysaprobes (S = 3.5-4.0) to xenosaprobes (S = 0-0.5).

The density score were calculated on 5-score scale (Whitton & al. 1991) and 6-score scale (Korde, 1956).

As alternative methods, we used the system introduced by Watanabe (1986), with three groups of indicators: the saproxenes, eurysaprobes, and polysaprobes.

Diagrams of species distribution were constructed for each group of ecological indicators. The algal groups were ordinated according to their increasing tolerances for a given environmental variable, e.g., from alkaliphiles to acidophiles along the axis of increasing acidity.

For the geographic analysis, the species ranges were plotted and attributed to phytogeographic divisions of global (Takhtajan 1978), Mediterranean (Zohary & Feinbrun-Dothan 1966-1986), and regional Israeli (Zohary 1966; Galun 1970) scales. A polynomial trend line was defined (as a statistic function in the Microsoft EXCEL software) for showing geographical trends of taxonomic diversity.

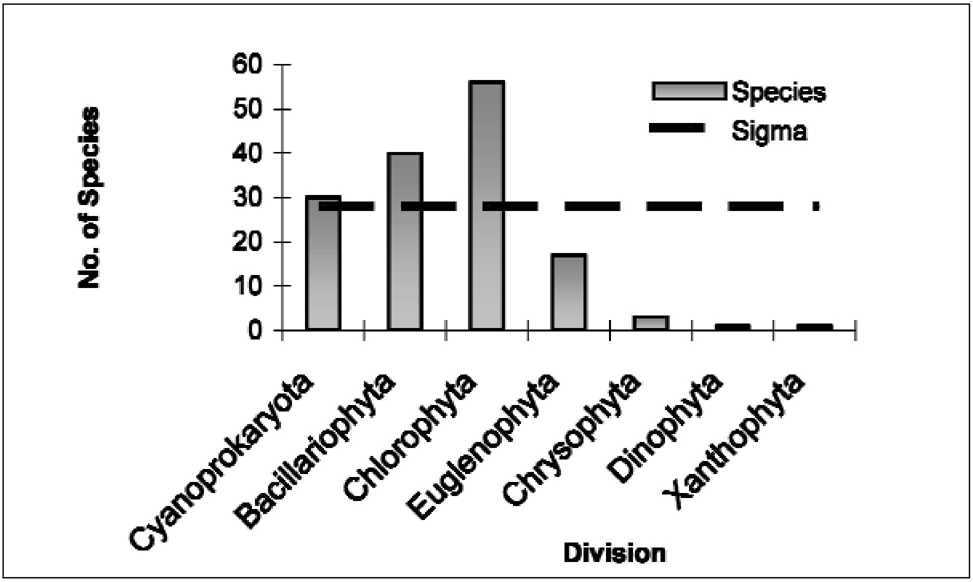



Fig. 3. Number of species per algal divisions in the Alexander River. Symbols are the same as in Table 2.

Table 2. Algal indicators of environments in the Alexander River with their autecology and abundance scores in communities: Scor – abundance score on the Wisloukh's scale (Korde, 1956); Hab – habitat (P – planktonic, B – benthic, P-B – plankto-benthic, Ep – epibiont); T – temperature (eterm – eurytermic; temp – temperate; warm – warm water); Reo – streaming and oxygenation (st – standing water; st-str – low streaming water; str – streaming water); D – degree of saprobity on the Watanabe's (Watanabe & al., 1986) (sx – saproxenes; es - eurysaprobes; sp – saprophilous); S – degree of saprobity on the Pantle-Buck's (Pantle & Buck, 1955) (o – oligosaprobes, o-β – oligo-beta-mesosaprobes, β – betamesosaprobes, β-α – beta-alphamesosaprobes, α-β – alpha-betamesosaprobes, α – alphamesosaprobes, ρ – polysaprobes; x - xenosaprobes); Hal – halobity degree (oh – undifferentiated oligohalobes, i – oligohalobes-indifferent, mh - mesohalobes, hl - halophiles, ph - polyhalobes); pH – pH degree (alf – alkaliphiles, ind – indifferents; acf – acidophiles; alb - alkalibiontes); Geo – group of phytogeographic distribution (Ha – Holarctic; Pt – Paleotropc; Nt – Neotropic; Au – Australian; b – Boreal; cb – Circum-Boreal; it – Irano-Turanian; mt – Mediterranean; r - rare); * - taxon found formerly on the Alexander River basin; ** - taxon new for Israel.

| No | Taxon | Scor | Hab | T | Reo | D | S | Hal | pH | Geo |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cyanoprokaryota | | | | | | | | | |
| 1 | ***Anabaena oscillarioides* Bory | 3 | P-B | - | - | - | - | - | - | k |
| 2 | *Anabaena variabilis* (Kütz.) Born & Flah. | 5 | P-B | - | st | - | - | mh | - | k |
| 3 | *Aphanocapsa delicatissima* W. & G.S. West | 5 | P | - | - | - | - | - | - | Ha,Pt |
| 4 | ***Chroococcus dispersus* (Keissler) Lemm. | 3-6 | P | - | st | - | o | - | - | Ha,Pt |
| 5 | *Gloeocapsopsis crepidinum* (Thur.) Geitl. ex Kom. | 1 | B | - | - | - | - | hl | - | k |
| 6 | *Leptochaete stagnalis* Hansg. | 5 | B,Ep | - | - | - | - | - | - | Ha |
| 7 | *Limnothrix amphigranulata* (Van Goore) Meffert | 1-6 | B | - | st | - | - | mh | - | b,mt |
| 8 | *Lyngbya aestuarii* (Mert.) Leibm. | 2-6 | P-B,S | - | - | - | - | ph | - | k |
| 9 | *Lyngbya limnetica* Lemm. | 1 | P-B,S | - | st-str | - | - | hl | - | k |
| 10 | *Lyngbya sp.* | 1 | - | - | - | - | - | - | - | - |
| 11 | ***Merismopedia hyalina* (Ehrb.) Kütz. | 1 | P | - | st-str | - | - | hl | - | k |
| 12 | *Merismopedia minima* Beck | 1-6 | B,S | - | - | - | - | - | - | Ha |
| 13 | *Merismopedia punctata* Meyen | 1 | P-B | - | - | - | β | i | ind | k |
| 14 | *Merismopedia tenuissima* Lemm. | 1-5 | P-B | - | - | - | β | hl | - | k |
| 15 | *Microcystis aeruginosa* (Kütz.) Kütz. | 1-6 | P | - | - | - | β | hl | - | k |
| 16 | *Microcystis flos-aquae* (Wittr.) Kirchn. | 6 | P | - | - | - | β | - | - | k |
| 17 | *Microcystis pulverea* (Wood) Forti | 1 | P-B,S | - | - | - | β | i | - | k |
| 18 | *Microcystis viridis* (A. Br. In Rabenh.) Lemm. | 2 | P | - | - | - | - | - | - | k |
| 19 | *Microcystis* sp. | 3 | - | - | - | - | - | - | - | - |
| 20 | *Nostoc* sp. | 4 | - | - | - | - | - | - | - | - |
| 21 | ***Onkonema compactum* Geitl. | 3 | Ep | warm | - | - | - | - | - | Pt,mt |
| 22 | *Oscillatoria brevis* Kütz. ex Gom. | 1-4 | P-B,S | - | st | - | α | - | - | k |
| 23 | **Oscillatoria chalybea* Mert. ex Gom. | 3 | P-B,S | - | st | - | α | - | - | Ha,Nt |
| 24 | *Oscillatoria formosa* Bory ex Gom. | 6 | P-B,S | - | st | - | - | - | - | k |
| 25 | *Oscillatoria sp.* | 1-4 | - | - | - | - | - | - | - | - |
| 26 | *Phormidium ambiguum* Gom. | 1-3 | B,S | eterm | st-str | - | - | i | ind | k |
| 27 | *Phormidium ambiguum var. maior* Lemm. | 1 | B | eterm | st-str | - | - | i | ind | k |
| 28 | *Phormidium autumnale* (Ag.) Gom. | 1-2 | B,S | - | st-str | - | β | - | - | k |
| 29 | *Phormidium uncinatum* (Ag.) Gom. | 1 | P-B | eterm | - | - | α | i | - | k |
| 30 | *Spirulina major* Kütz. ex Gom. | 1-4 | P,S | - | st | - | - | ph | - | k |

Table. 2. (continued.)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Chrysophyta | | | | | | | | | |
| 31 | ***Chrysocrinus irregularis* Pasch. | 2-4 | Ep | - | - | - | - | - | ind | b,mt |
| 32 | ***Salpingoeca ringens* Kent | 1-3 | Ep | - | st | - | - | - | - | Ha |
| 33 | *Salpingorhiza pascheriana* Klug | 1-3 | Ep | - | st | - | - | ph | - | b,mt |
| | Dinophyta | | | | | | | | | |
| 34 | *Peridiniopsis elpatiewskyi* (Ostf.) Bourr. | 1 | P | - | st | - | - | - | - | Ha |
| | Euglenophyta | | | | | | | | | |
| 35 | *Colacium cyclopicola* (Gicklhorn) Bourr. | 2 | P | - | st | - | - | - | - | cb,it,mt |
| 36 | *Euglena acus* Ehrb. | 1 | P | eterm | st | - | β | i | ind | k |
| 37 | **Euglena deses* Ehrb. | 2 | P-B,S | - | st-str | - | p | mh | ind | k |
| 38 | *Euglena minima* Fr. | 1-2 | P-B | eterm | st | - | o | mh | alb | Ha |
| 39 | *Euglena proxima* Dang. | 1-4 | P-B | eterm | st-str | - | α | mh | ind | k |
| 40 | *Euglena* sp. | 1 | - | - | - | - | - | - | - | - |
| 41 | ***Lepocinclis autumnalis* Chu | 2 | P | - | st-str | - | - | - | - | r |
| 42 | *Lepocinclis globosa* France | 3 | P-B | - | st | - | - | - | | Ha |
| 43 | ***Lepocinclis lefevrei* Conr. | 1 | P | - | st | - | - | - | ind | b,mt |
| 44 | *Lepocinclis marssonii* Lemm. emend. Conr. | 2 | P | - | st | - | β | - | - | k |
| 45 | *Lepocinclis ovum* (Ehrb.) Lemm. | 1-4 | P | eterm | st | - | α | i | ind | k |
| 46 | *Phacus oscillans* Klebs | 1 | P-B | - | st-str | - | - | i | ind | Ha,Pt,Nt |
| 47 | *Phacus pleuronectens* (Ehrb.) Duj. | 1 | P-B | - | st-str | - | β | i | ind | k |
| 48 | *Phacus pusillus* Lemm. | 1 | P-B | - | st-str | - | | - | acf | Ha,Pt,Nt |
| 49 | *Phacus pyrum* (Ehrb.) Stein | 1 | P | eterm | st-str | - | β | i | ind | k |
| 50 | *Trachelomonas hispida* Delf. | 1 | P-B | eterm | st-str | - | β | i | - | k |
| 51 | *Trachelomonas volvocina* Ehrb. | 1 | B | eterm | st-str | - | β | i | ind | k |
| | Xanthophyta | | | | | | | | | |
| 52 | ***Pseudochlorothecium spinifer* (Printz) Korsch. | 3 | Ep | - | st-str | - | - | - | ind | Ha |
| | Bacillariophyta | | | | | | | | | |
| 53 | *Achnanthes coarctata* (Bréb.) Grun. | 4 | B | - | ae | - | x | - | - | k |
| 54 | *Achnanthes exigua* Grun. in Cl. & Grun. | 1 | B | eterm | st-str | sp | β | i | alf | k |
| 55 | *Amphora coffeaeformis* (Ag.) Kütz. | 2-6 | B | - | st-str | - | - | mh | - | k |
| 56 | *Amphora ovalis* (Kütz.) Kütz. | 1 | B | temp | st-str | sx | β | i | alf | k |
| 57 | *Amphora* sp. | 2 | - | - | - | - | - | - | - | - |
| 58 | *Craticula ambigua* (Ehrb.) D.G. Mann | 1 | B | temp | st | es | - | i | alf | k |
| 59 | *Craticula cuspidata* (Kütz.) D.G. Mann | 1-3 | B | temp | st | es | - | i | alf | k |
| 60 | *Cyclotella meneghiniana* Kütz. | 1-3 | P-B | temp | st | sp | α | hl | alf | k |
| 61 | *Entomoneis alata* (Ehrb.) Ehrb. | 1 | P-B | - | st | - | - | mh | alf | k |
| 62 | *Entomoneis paludosa* (W. Sm.) Reim. | 2 | B | - | - | - | - | - | - | k |
| 63 | *Entomoneis paludosa* var. *subsalina* (Cl.) Krammer | 1-6 | - | - | - | - | - | hl | - | - |
| 64 | *Eucocconeis* sp. | 1 | - | - | - | - | - | - | - | - |
| 65 | *Fallacia pygmaea* (Kütz.) Stikle & Mann | 2-5 | B | - | - | es | α | mh | alf | k |
| 66 | *Gomphonema affine* Kütz. | 1-2 | P-B | - | st | es | - | - | - | k |
| 67 | *Gomphonema parvulum* (Kütz.) Kütz. | 2-6 | B | temp | str | es | β | i | ind | k |
| 68 | *Gyrosigma spencerii* (Quek.) Griff. & Henfr. | 1 | B | - | - | es | o | mh | alf | k |
| 69 | *Gyrosigma* sp. | 1 | - | - | - | - | - | - | - | - |
| 70 | *Meridion circulare* (Grev.) C. Ag. | 1 | B | - | str | es | o | i | alf | k |
| 71 | *Navicula cryptocephala* Kütz. | 1 | P-B | temp | - | es | α | i | alf | k |
| 72 | *Navicula recens* (Lange-Bert.) Lange-Bert. | 3-4 | P-B | - | - | es | o-β | i | - | Ha,Pt,Nt |

Table. 2. (continued.)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 73 *Navicula tuscula* Ehr. | 1 | P-B | - | - | - | o-β | i | alf | k |
| 74 *Navicula viridula* (Kütz.) Ehrb. | 1-3 | B | - | - | es | α | hl | alf | k |
| 75 *Navicula* sp. | 1-6 | - | - | - | - | - | - | - | - |
| 76 *Nitzschia acicularis* (Kütz.) W. Sm. | 1-2 | P-B | temp | - | es | α | i | alf | k |
| 77 *Nitzschia commutata* Grun. | 1 | B | - | - | - | - | mh | - | k |
| 78 *Nitzschia filiformis* (W. Sm.) Van Heurck | 1 | B | - | - | es | α-β | hl | - | k |
| 79 *Nitzschia fonticola* Grun. | 1 | B | - | - | - | o-β | oh | alf | k |
| 80 *Nitzschia gracilis* Hantzsch | 2 | P-B | temp | - | sp | o-β | i | ind | k |
| 81 *Nitzschia palea* (Kütz.) W. Sm. | 1-4 | P-B | temp | - | sp | β-α | i | ind | k |
| 82 *Nitzschia reversa* W. Sm. | 1 | P | - | - | - | - | hl | - | k |
| 83 *Nitzschia solita* Hust. | 2 | B | - | st | es | α-β | mh | alf | k |
| 84 *Nitzschia umbonata* (Ehrb.) Lange-Bert. | 2 | P | - | st-str | es | α-β | - | - | k |
| 85 **Nitzschia vermicularis* (Kütz.) Hantzsch | 1 | B | - | - | - | β | i | alf | k |
| 86 *Nitzschia* sp. | 1-6 | - | - | - | - | - | - | - | - |
| 87 *Sellaphora pupula* (Kütz.) Mereschkowsky | 2 | B | eterm | st | sp | α | hl | ind | k |
| 88 *Stauroneis anceps* Ehrb. | 1 | P-B | - | - | sx | β | i | ind | k |
| 89 *Surirella ovalis* Bréb. | 1-3 | P-B | - | st-str | es | o | mh | alf | k |
| 90 *Tabularia fasciculata* (Ag.) Williams & Round | 1 | B | - | - | es | | mh | ind | k |
| 91 *Tryblionella acuminata* W. Sm. | 1 | P | - | st | sx | α | mh | alf | k |
| 92 *Tryblionella gracilis* W. Sm. | 1 | B | - | - | - | - | - | - | k |
| Chlorophyta | | | | | | | | | |
| 93 *Actinastrum hantzschii* var. *hantzschii* Lagerh. | 1 | P-B | - | st-str | - | β | i | - | k |
| 94 *Actinastrum hantzschii* var. *subtile* Wołosz. | 2 | P-B | - | - | - | β | i | - | k |
| 95 *Apiocystis caput-medusae* (Bohl.) Korsch. | 2 | Ep | - | - | - | - | - | - | Ha |
| 96 *Chlamydomonas* sp. | 1-6 | - | - | - | - | - | - | - | - |
| 97 ***Chlamydopodium pluricoccum* (Korsch.) Ettl & Komárek | 1-6 | Ep | - | st-str | - | - | - | - | Ha |
| 98 *Chlorococcum* sp. | 1-3 | - | - | - | - | - | - | - | - |
| 99 *Cladophora glomerata* (L.) Kütz. | 6 | P-B | - | st-str | - | β | i | alf | k |
| 100 *Closteriopsis acicularis* (G.M. Smith) Belcher & Swale | 1 | P-B | - | st-str | - | - | i | - | k |
| 101 *Closterium acerosum* (Schrank) Ehrb. ex Ralfs | 1 | P-B | - | st-str | - | α | i | ind | k |
| 102 *Coelastrum astroideum* De-Not. | 1 | P | - | st-str | - | - | - | - | k |
| 103 *Coelastrum microporum* Näg. in A. Br. | 1 | P-B | - | st-str | - | β | i | ind | k |
| 104 *Coelastrum sphaericum* Näg. | 1 | P-B | - | st-str | - | | i | | k |
| 105 *Coleochaete pulvinata* A. Braun in Kütz. | 1-5 | B,Ep | - | st | - | - | - | - | k |
| 106 *Crucigenia tetrapedia* (Kirchn.) W. & G.S. West | 1 | P-B | - | st-str | - | β | i | ind | k |
| 107 *Desmodesmus armatus* var. *armatus* (R. Chod.) Hegew. | 1-4 | P-B | - | st-str | - | - | - | - | k |
| 108 **Desmodesmus armatus* var. *bicaudatus* (Roll) Hegew. | 1 | P-B | - | st-str | - | - | - | - | k |
| 109 **Desmodesmus brasiliensis* (Bohlin) Hegew. | 2 | P-B | - | st-str | - | β | - | - | k |
| 110 *Desmodesmus communis* (Hegew.) Hegew. | 1 | P-B | - | st-str | - | - | i | ind | k |
| 111 *Desmodesmus insignis* (W. & G. S. West) Hegew. | 1 | P-B | - | st | - | - | - | - | Ha |
| 112 *Desmodesmus intermedius var. intermedius* (R. Chodat) Hegew. | 1 | P-B | - | st-str | - | β | - | - | k |
| 113 ***Desmodesmus intermedius var. inflatus* (Svir.)Hegew. | 1 | P-B | - | st-str | - | β | - | - | b,mt |
| 114 *Desmodesmus lefevrii* (Defl.) An, Friedl & Hegew. | 1-2 | P-B | - | st-str | | - | - | - | k |
| 115 *Desmodesmus opoliensis* var. *carinatus* (Lemm.) | 1 | P-B | - | st-str | - | - | - | - | k |

Table. 2. (continued.)

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 116 *Desmodesmus perforatus* (Lemm.) Hegew. | 1 | P-B | - | st-str | - | - | - | - | Ha,Pt |
| 117 *Desmodesmus protuberans* (Fritsch & Rich) Hegew. | 1-2 | P-B | - | st-str | - | - | - | | Ha |
| 118 *Desmodesmus spinosus* (K. Biswas) Hegew. | 1 | P-B | - | st-str | - | o-β | - | - | Ha,Nt |
| 119 *Dictyosphaerium pulchellum* Wood | 1 | P | - | | - | - | i | ind | k |
| 120 *Dunaliella salina* (Dun.) Teod. | 6 | P | - | st | - | - | - | | Ha,Pt,Au |
| 121 *Enteromorpha torta* (Mert.) Reinb. | 4-6 | P-B | - | | - | - | ph | alf | b,it,mt |
| 122 *Franceia tenuispina Korsch.* | 1 | P | - | st | - | | - | - | k |
| 123 *Gongrosira debaryana* Rabenh. | 1 | B,Ep | - | str | - | - | - | - | Ha |
| 124 ***Hyaloraphidium contortum* var. *contortum* Pasch. & Korsch. | 1-6 | P-B | - | - | - | β | i | - | k |
| 125 ***Hyaloraphidium contortum* var. *tenuissimum* Korsch. | 2-3 | P-B | - | - | - | β | i | - | Ha |
| 126 *Monoraphidium arcuatum* (Korsch.) Hind. | 1-2 | P-B | - | st-str | - | - | - | - | k |
| 127 ***Monoraphidium contortum* (Thur.) Kom.-Legn. | 1-6 | P-B | - | st-str | - | - | - | - | k |
| 128 *Monoraphidium griffithii* (Berk.) Kom.-Legn. in Fott | 1 | P-B | - | st-str | - | - | - | - | k |
| 129 *Monoraphidium irregulare* (G.M. Smith) Kom.-Legn. | 1-3 | P-B | - | st-str | - | - | - | - | k |
| 130 *Monoraphidium minutum* (Näg.) Kom.-Legn. | 1-3 | P-B | - | st-str | - | - | - | - | k |
| 131 *Oedogonium* sp. ster. | 1 | B | - | - | - | - | - | - | - |
| 132 *Oocystis lacustris* Chod. | 1 | P-B | - | st-str | - | β | hl | - | k |
| 133 *Pandorina morum* (O.F. Müll.) Bory | 1 | P | - | st | - | β | i | - | k |
| 134 *Pediastrum boryanum* (Turp.) Menegh. | 3 | P-B | - | st-str | - | β | i | ind | k |
| 135 *Pediastrum duplex* Meyen | 1-3 | P | - | st-str | - | β | i | ind | k |
| 136 ***Pseudocharacium obtusum* (A. Br.) Pertý-Hesse | 1 | Ep | - | st | - | - | - | - | Ha,Pt |
| 137 *Rhizoclonium hieroglyphicum* (Ag.) Kütz. | 6 | B | - | st-str | - | - | hl | - | k |
| 138 *Scenedesmus acutus* Meyen | 1 | P-B | - | st-str | - | o-β | i | - | k |
| 139 *Scenedesmus ellipticus* Corda | 1 | P-B,S | - | st-str | - | o-β | - | - | k |
| 140 *Scenedesmus obtusus* Meyen | 1 | P-B | - | st-str | - | - | - | - | Ha |
| 141 *Schroederia setigera* (Schröd.) Lemm. | 1 | P | - | st-str | - | β | i | - | Ha,Nt |
| 142 *Stigeoclonium tenue* (Ag.) Kütz. emend. Cox & Bold | 2 | B | - | st-str | - | α | - | - | k |
| 143 *Tetraedron minimum* (A. Br.) Hansg. | 1 | P-B | - | st-str | - | β | i | - | k |
| 144 *Tetrastrum elegans* Playf. | 1 | P | - | st-str | - | | i | - | k |
| 145 *Tetrastrum staurogeniaeforme* (Schröd.) Lemm. | 1 | P-B | - | st-str | - | β | i | - | k |

## Results and discussion

In 26 samples of periphyton and plankton from 9 stations on the Alexander River and one station on the hot water tributary, we distinguished 145 species belonging to 7 algal divisions. The Chlorophyta strongly prevailed followed by diatoms, blue-greens, and euglenoids in nearly equal species numbers. The chrysophytes, xanthophytes, and dinophytes were relatively rare (Fig. 3). Only five species from the checklist were found previously in the Alexander River (marked by *). Sigma-line in Fig. 3 cut-off the first three major divisions. Distribution of species diversity shows that the most auspicious conditions in the Alexander River is for the development of algae from *Chlorophyta*, *Bacillariophyta*, and *Cyanoprokaryota*.

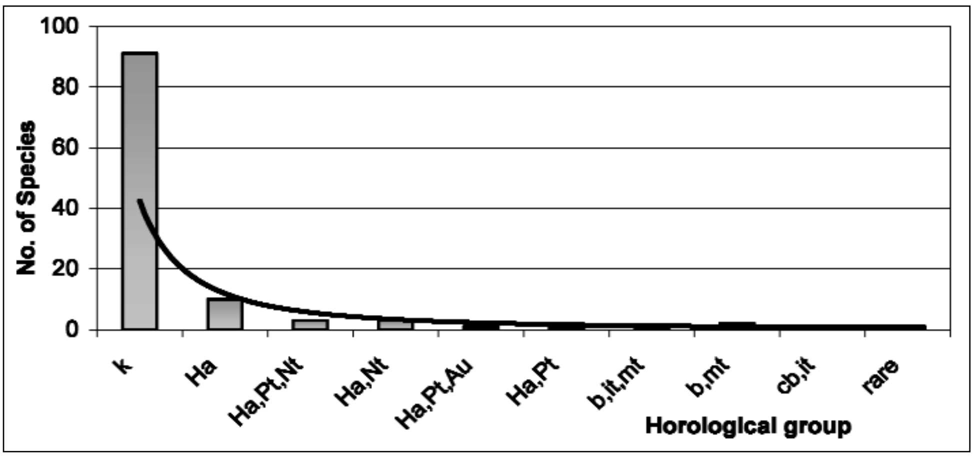
All algal species found were cosmopolitic or widespread and common in the Boreal, Mediterranean, and Irano-Turanean realms (Fig. 4). The trend line does not reveal deviation in this distribution. Among 145 algal species found, 15 species were recorded for the first time in freshwater habitats of Israel (marked with double asterisk in Table 2). *Lepocinclis autumnalis* (*Euglenophyta*) is a rare species from freshwater habitats. *Salpingorhiza pascheriana*, *Salpingoeca ringens* (Plate 2: 1), and *Chrysocrinus irregularis* (Plate 1: 11) from *Chrysophyta* as well as *Lepocinclis lefèvrei* (*Euglenophyta*) were widespread, but rare all over their ranges. *Onkonema compactum* (*Cyanoprokaryota*, Plate 3: 1) was previously found as epiphyte of submerged substrate in the Paleotropic realm indicating warm water habitats. We found the blue-green *Limnothrix amphigranulata* in a few coastal rivers of Israel. A green filamentous alga *Enteromorpha torta* (Plate 1: 6,7,8) is an indicator species of strongly saline habitat, which we found previously in the experimental salinity pools (Barinova & al. 2004) as well as in the coastal rivers of Israel (Barinova & al. 2003, 2004, 2005; Tavassi & al. 2004).

For this study we selected the indicators (129 taxa, 87.2% of species list) of habitats, temperature, streaming and oxygenation, saprobity, halobity, and acidification (Table 2). These indicators adequately reflected the distribution of algal communities over the river habitats. We found that the distribution of each indicator group was correlated with the measured physico-chemical variables (Table 1).

As a whole, the Alexander River is alkaline, fresh in the upper and middle reaches, brackish in the lower reaches, and moderately warm with the temperature increasing in summer. The alkalinity corresponds to the regional norm because the river flows over carbonate rocks (Meybeck & Helmer 1989).

The indicators of temperature conditions (22 species, 17% of indicators species) are assigned to three groups. The eurythermic and moderately thermophilic species prevail including *Gomphonema parvulum* and *Nitzschia palea* (*Bacillariophyta*).

Fig. 4. Number of algal species per groups of geographical distribution in the Alexander River. Symbols are the same as in Table 2.



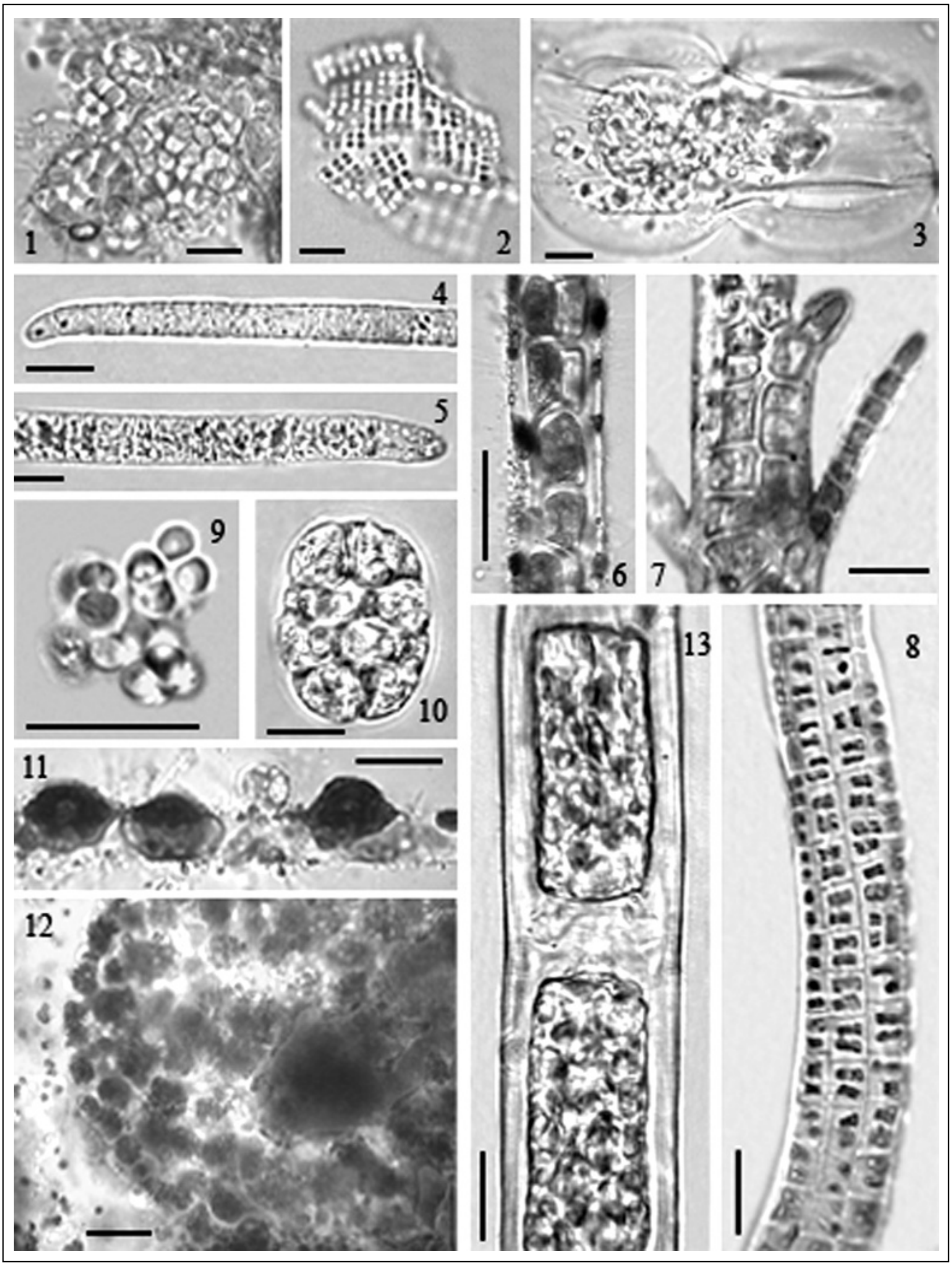



Plate 1. New for Israel, abundant and rare algal species in the Alexander River: **1.** *Gloeocapsopsis crepidinum*; **2.** *Merismopedia tenuissima*; **3.** *Entomoneis paludosa*; **4.** *Oscillatoria brevis*; **5.** *Oscillatoria chalybea* f. *chalybea*; **6-8.** *Enteromorpha torta*; **9.** *Merismopedia hyalina*; **10.** *Pandorina morum*; **11.** *Chrysocrinus irregularis*; **12.** *Microcystis viridis*; **13.** *Rhizoclonium hieroglyphicum*. Scale bar: 1-11; 13 – 10 µm; 12 – 50 µm.

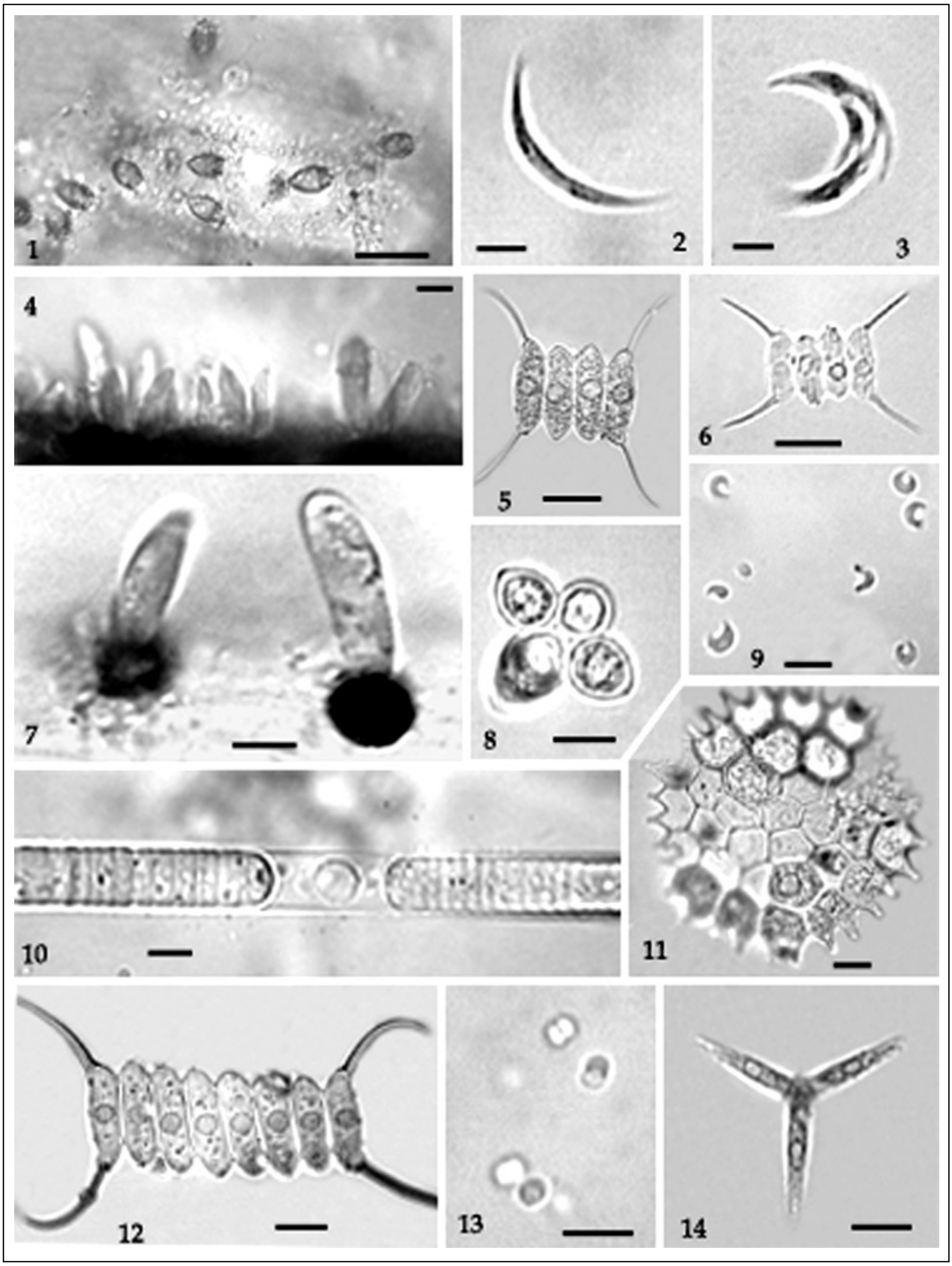



Plate 2. New for Israel, abundant and rare algal species in the Alexander River: **1.** *Salpingoeca ringens*; **2, 3.** *Monoraphidium arcuatum*; **4, 7.** *Chlamydopodium pluricoccum*; **5.** *Desmodesmus opoliensis*; **6.** *Desmodesmus armatus* var. *armatus*; **8.** *Coelastrum astroideum*; **9.** *Monoraphidium minutum*; **10.** *Lyngbya aestuarii*; **11.** *Pediastrum boryanum* var. *boryanum*; **12.** *Desmodesmus perforatus*; **13.** *Chroococcus dispersus*; **14.** *Actinastrum hantzschii* var. *hantzschii*. Scale bar: 1-8, 10-14 – 10 μm; 9 – 20 μm.

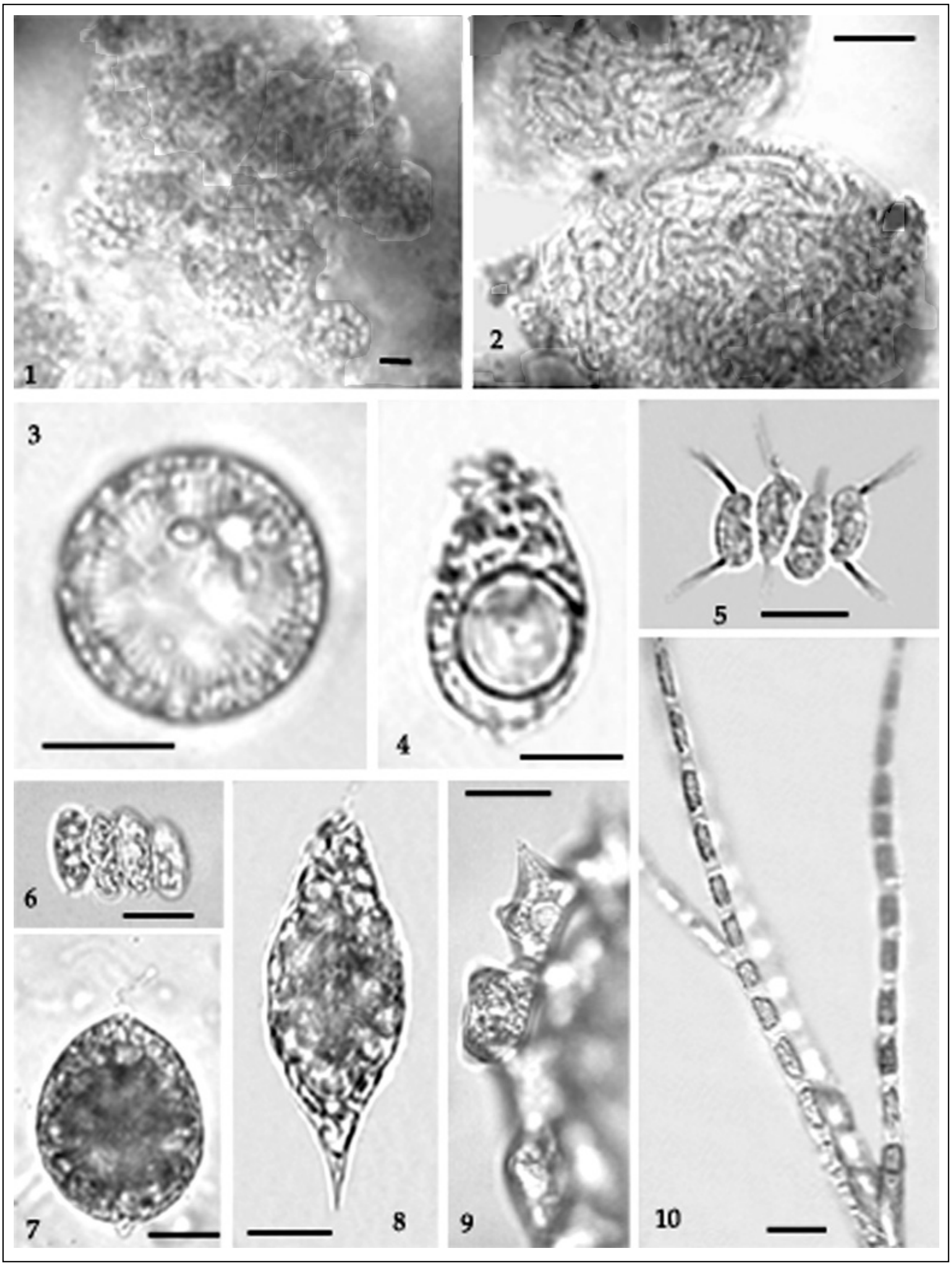



Plate 3. New for Israel, the abundant, and rare algal species in the Alexander River: **1.** *Onkonema compactum*; **2.** *Nostoc* sp.; **3.** *Cyclotella meneghiniana* var. *meneghiniana*; **4.** *Lepocinclis lefevrei*; **5.** *Desmodesmus intermedius*; **6.** *Scenedesmus ellipticus*; **7.** *Lepocinclis ovum* var. *ovum*; **8.** *Euglena proxima*; **9.** *Pediastrum duplex* var. *duplex*; **10.** *Stigeoclonium tenue*. Scale bar: 1, 3-9 – 10 µm; 2 – 200 µm; 10 – 20 µm.

In relation to chloride concentrations, the algae of the Alexander River are divided into four groups comprising 84 indicator species (56.7%). These groups are arranged in the histogram (Fig. 5a) according to their salinity tolerances. The extreme polyhalobes are the minority. The indifferents constitute the dominant group including *Gomphonema parvulum*, *Nitzschia palea* (*Bacillariophyta*), *Cladophora glomerata*, *Hyaloraphidium contortum* (*Chlorophyta*). The halophiles, such as *Microcystis aeruginosa*, *Merismopedia tenuissima* (*Cyanoprokaryota*, Plate 1: 2) and *Rhizoclonium hieroglyphicum* (*Chlorophyta*, Plate 1: 13), are abundant in the river. Of the mesohalobes, the dominant position is maintained by

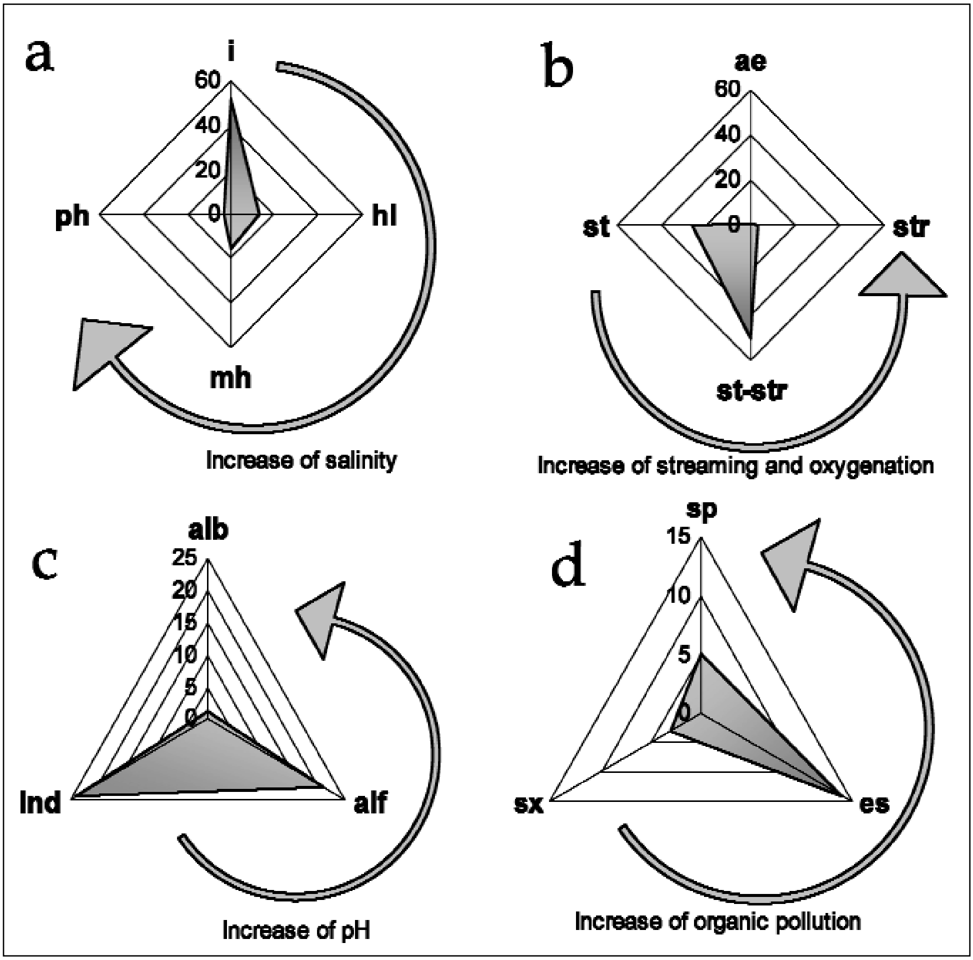



Fig. 5. Diversity of algal indicators of Alexander River in the ecological groups: a - Number of species in groups of salinity indicators; b - Number of species in the groups of streaming and oxygenation indicators; c - Number of species in groups of acidophility indicators; d - Number of species in groups of organic pollution indicators according to Watanabe (1986) system. Symbols are the same as in Table 2.

*Limnothrix amphigranulata* (*Cyanoprokaryota*), *Amphora coffeaeformis* and *Fallacia pygmaea* (*Bacillariophyta*). These species, as well as the presence of such polyhalobic species as *Pleurocapsopsis crepidinum* (*Cyanoprokaryota*, Plate 1: 1) and *Enteromorpha torta* (*Chlorophyta*, Plate 1: 6, 7, 8), is consistent with a considerable impact of marine waters. The frequency of polyhalobes correlates with fluctuations of conductivity (Table 1).

There are 80 indicator species of streaming and oxygenation (54%). They are divided into four groups. In the histogram (Fig. 5b), these groups are ordinated according to the rates of streaming and oxygen concentrations in their typical habitats. The low-streaming water group prevails including *Amphora coffeaeformis* (*Bacillariophyta*), *Cladophora glomerata*, *Monoraphidium contortum*, and *Rhizoclonium hieroglyphicum* (*Chlorophyta*, Plate 1: 13). Following these species in significance are the species of still water – *Limnothrix amphigranulata*, *Oscillatoria formosa* (*Cyanoprokaryota*), and *Coleochaete pulvinata* (*Chlorophyta*). True aerophiles are represented by *Achnanthes coarctata* (*Bacillariophyta*), as well as by the species inhabiting strongly streaming water, such as *Gomphonema parvulum* (*Bacillariophyta*). The summit of the trend is shifted towards the indicators of low-streaming waters.

The indicators of proton concentration (46 species, 31%) are assigned to three groups arranged according to the acidophility trend on the histogram (Fig. 5c). The indifferents prevail, including such species as *Gomphonema parvulum*, *Nitzschia palea* (*Bacillariophyta*), accompanied by the alkaliphiles *Fallacia pygmaea* (*Bacillariophyta*), *Cladophora glomerata*, *Enteromorpha torta* (*Chlorophyta*, Plate 1: 6, 7, 8), which corresponds to the regional norm of alkalinity and is also correlated with pH fluctuations (Table 1). Only one infrequent alkalibiont *Euglena minima* is present. Notably, acidophilic species are lacking among the pH-indicators, which reveals an insignificant, inflow of acidic waters.

The saprobity indicators of Watanabe's classification (22 species, 14.9%) constitute three groups (Fig. 5d) testifying to a medium concentration of organic substances available to the algae. The summit of the histogram corresponds to the maximum of eurysaprobes such as the dominant species *Fallacia pygmaea*, *Gomphonema parvulum* (*Bacillariophyta*), and others.

Similar results were obtained with the Pantle & Buck (1955) method modified by Sládeček (1973, 1986). The indicators of saprobity (67 taxa, 45.3%) were assigned to 8 ecological groups arranged according to their increased tolerance of organic pollution in the histogram (Fig. 6). The transitional groups are located below the trend line reflecting a situation in which such species are relatively rare. The betamesosaprobionts of moderate organic concentration prevail with *Merismopedia tenuissima* (Plate 1: 2), *Microcystis aeruginosa*, and *M. flos-aquae* (*Cyanoprokaryota*), *Gomphonema parvulum* (*Bacillariophyta*), *Cladophora glomerata*, *Hyaloraphidium contortum* (*Chlorophyta*). Less abundant are the oligosaprobionts of clear oligotrophic waters (*Chroococcus dispersus*, Plate 2: 13, *Cyanoprokaryota*; *Gyrosigma spencerii*, *Meridion circulare*, and *Surirella ovalis*, Bacillariophyta) as well as the alfamesosaprobionts of organic-rich waters (*Oscillatoria brevis, Oscillatoria chalybea Cyanoprokaryota*, Plate 1: 4 and 5; *Cyclotella meneghiniana,* Bacillariophyta, Plate 3: 3; *Lepocinclis ovum*, *Euglena proxima*, Plate 3: 7 and 8, Euglenophyta, and *Eudorina elegans, Chlorophyta*). The trend line summit is dis-

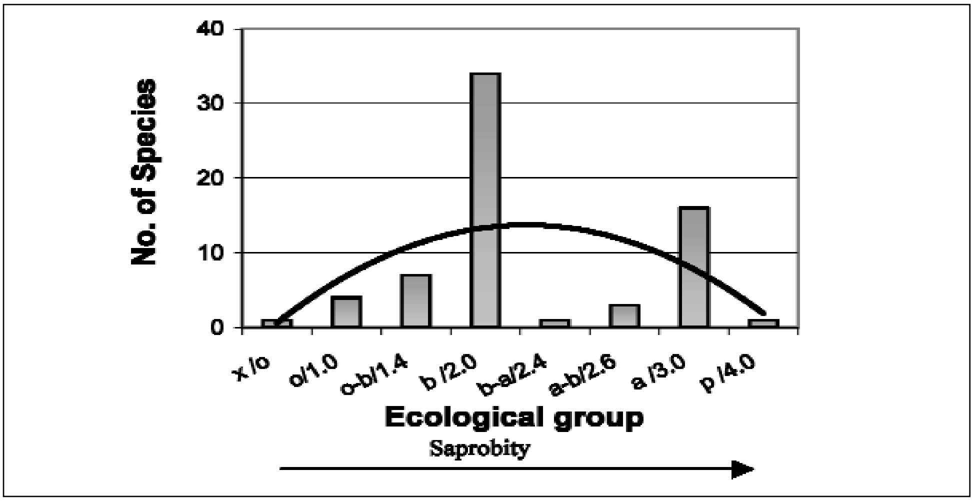



Fig. 6. Diversity of algal indicators of Alexander River in the organic pollution ecological groups according to Sládeček (1973) system. Symbols are the same as in Table 2.

placed towards the beta-alfamesosaprobiontes group. The most abundant among them is *Nitzschia palea* (*Bacillariophyta*) in the periphyton.

The bioindication analysis shows that all the major algal habitats are represented in the Alexander River including the planktonic, benthic, and periphytonic ones (Fig. 7). In the histogram the ecological groups are ranged according to their relation to the substrates.

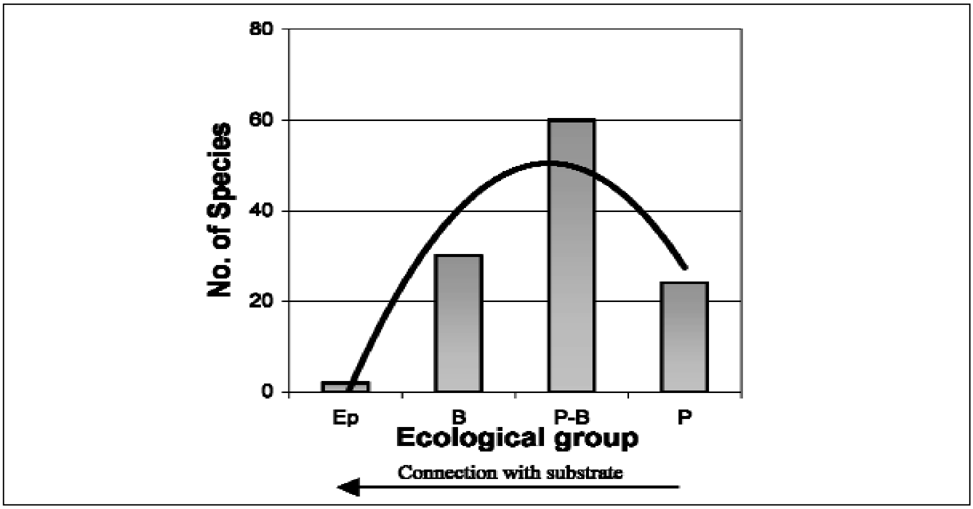



Fig. 7. Diversity of algal indicators of Alexander River in the habitat ecological groups. Symbols are the same as in Table 2.

The benthic and plankto-benthic groups prevail among 129 indicator species. The summit of the trend is slightly displaced toward the benthic group attesting to the relatively favorable conditions for the periphyton and benthos as a whole. The majority of abundant species come from the periphyton: *Limnothrix amphigranulata*, *Lyngbya aestuarii* (Plate 2: 10), *Oscillatoria formosa* (*Cyanoprokaryota*), *Amphora coffeaeformis*, *Fallacia pygmaea*, *Entomoneis paludosa* (Plate 1: 3), *Gomphonema parvulum*, (*Bacillariophyta*), *Cladophora glomerata, Enteromorpha torta* (Plate 1: 6, 7, 8), *Rhizoclonium hieroglyphicum* (Plate 1: 13) (*Chlorophyta*), as well as from epiphyton - *Coleochaete pulvinata*, *Chlamydopodium pluricoccum* (Plate 2: 4, 7). In the phytoplankton the most abundant species were *Merismopedia tenuissima* (Plate 1: 2), *Microcystis flos-aquae*, *Microcystis aeruginosa* (*Cyanoprokaryota*), *Hyaloraphidium contortum*, *Monoraphidium contortum*, *Dunaliella salina* (*Chlorophyta*).

Changes of algal communities are shown in the diagram (Fig. 8). The green and diatom algae constitute the basis of algal assemblages, which is relatively constant over the river. In contrast, the blue-greens disappear at station 7, reappear downstream, and decrease toward the mouth. Cryptomonades are recorded in the upper reaches only (station 9). The euglenoids burst at stations 5 – 9 in the upper-middle reaches with slow streaming water and dense aquatic vegetation. At station 4 the algal communities are changing to the blue-green-diatoms-chlorophyte complex and shows an impact of anthropogenic pollution to the Alexander River after it crosses with Highway 4 (see map – Fig. 2). The communities with chrysophyte epiphytes are recorded only in the lower reaches affected by marine tides. Among them there are the first records of *Salpingorhiza pascheriana*, *Salpingoeca ringens* (Plate 2: 1), and *Chrysocrinus irregularis* (Plate 1: 11) in Israel.

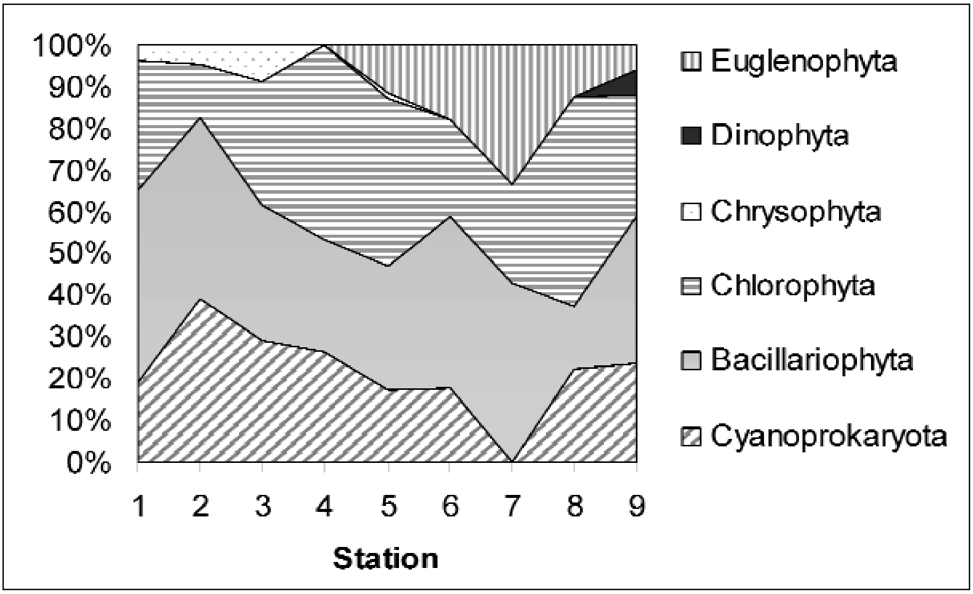



Fig. 8. Dynamic of algal divisions in the communities over the stations of Alexander River.

## Conclusion

In conclusion, in plankton and periphyton samples from the Alexander River we found 148 species of algae and cyanoprokaryotes from seven divisions. Green algae strongly prevailed.

Among 145 algal species found, 15 are recorded for the first time in freshwater habitats of Israel and are rare species of freshwater habitats in general. *Salpingorhiza pascheriana*, *Salpingoeca ringens* and *Chrysocrinus irregularis* (*Chrysophyta*) as well as *Lepocinclis lefèvrei* (*Euglenophyta*) are widespread, but rare over all their ranges. *Onkonema compactum* (*Cyanoprokaryota*) is an indicator of warm water habitats. Green filamentous alga *Enteromorpha torta* is an indicator of strongly saline habitats.

As a whole, 129 species are indicators of one or another environmental variable. Algae of the Alexander River prefer temperate, low-streaming water. The indifferents, halophiles, and mesohalobes prevail in the group of salinity indicators. The group of pH indicators is dominated by ologohalobes-indifferents and alkaliphiles, which correspond to the chemical composition of the aquatic environment and the low level of acidification. Indicators of saprobity, according to Watanabe's and Sládeèek's methods, show a moderate level of organic pollution. In conclusion, these indicators adequately reflect distribution of algal communities over the river habitats. We found that the distribution of each indicator group is correlated with the measured physico-chemical variables.

Species richness in the algal communities in stations of the Alexander River is changing from rich communities with six divisions in the upper reaches to the poor communities of cyanoprokaryote-diatom-green algae in the more polluted station 4 below the crossing with the highway 4, and to the chrysophytic epiphytes at the mouth.

Thus, our study of algal communities in the Alexander River reveals the natural trend of algal diversity and the influence of pollution over the river. On the basis of the bioindication methods we assess the level of anthropogenic transformation of the Alexander River as moderate owing to the rehabilitation efforts. At the same time, the changes of algal communities along the river reveal the hot spots of pollution, such as down the crossing with the highway no. 4.

We conclude that the EU Framework Monitoring indicator system is applicable for the assessment and monitoring of aquatic ecosystems in Israel and for implementation of rehabilitation program of the Alexander River.

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