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Main characteristics of the phytoplankton of the Southern Hungarian section of the River Danube

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Key words: river phytoplankton, water quality, discharge, chlorophyll *a*, suspended matter, species composition

Abstract

The Danube is a large eutrophic river and may be one of the best studied rivers in the world. This paper presents a short characterization of the biological water quality based on data from the 1986–1992 period, collected in the Southern Hungarian section at 1480.2 river km. Variations in the hydrological features (including discharge and turbulence) are the most important factors determining the total phytoplankton biomass in the River Danube. A good correlation has been found between chlorophyll *a* content and discharge, from early spring to autumn, whereas the suspended matter appeared weakly related to discharge. In addition, some taxonomic notes refer to the most common members of the phytoplankton, as well as to several rare taxa.

Introduction

The River Danube is probably among the most investigated rivers in the world. The first algological data from the Hungarian section of the Danube were published more than one hundred years ago (Borbás, 1879). Sporadic investigations at the end of the previous century and during the first half of the present one sought to describe the algal flora, both planktonic and periphytic, near Budapest. Since the 1960s, research projects on phytoplankton were numerous and involved both qualitative and quantitative studies. In particular, Szemes (1964, 1966, 1969, 1971) studied the seasonal changes along the Hungarian course of the river. Another important work was carried out by Uherkovich (1969), in his comparison of the planktonic algae of three Hungarian rivers (Danube, Tisza, and Dràva). According to his results, algal abundance and diversity were much higher in the River Danube. Thanks to these previous studies and to more recent ones, it is possible to trace back the increase of the algal numbers in the Danube, which were ten times lower during the sixties than during the following decade (Schmidt & Vörös, 1981; Kiss, 1985). These authors showed that blooms of centric diatoms were particularly responsible for these increases. Schmidt & Vörös (*op. cit.*) recorded for the first time in 1973, a seasonal biomass peak (26500 cells ml^{-1}) of the filamentous diatom *Skeletonema potamos* (Weber) Hasle. Since that time, late summer or early autumn blooms of this taxon have occurred every year, in such a way that they have become a characteristic feature of the phytoplankton of the Danube.

In the framework of water quality monitoring programs, three laboratories of the local environmental protection boards (Györ, Budapest, Baja) and the Danube Research Station of the Hungarian Academy of Science (Göd) have been regularly collected plankton samples from the 417 km long Hungarian Danube section. The results of these studies have been summarized in many papers covering various topics: taxonomic problems, eutrophication assessment, occurrence and nature of the water blooms, etc. (Uherkovich *et al.*, 1975; Kiss, 1984a, 1984b, 1985, 1986, 1988, 1991, in press; Kiss & Genkal, in press; Kiss *et al.*, 1990, 1991, this volume; Padisák *et al.*, 1991). New elements for the algal flora of the Hungarian Danube have been published mainly by Uherkovich *et al.* (*op. cit.*), among various algal classes and phyla (Euglenophyceae, Cryptophyceae, Bacillariophyceae, Chlorophyta) and, for the diatoms only, by Kiss (*op. cit.*), who has provided revised lists of centric diatoms based on EM examinations: *Cyclotella atomus* Hust., *C. cryptica* Reimann, Lewin & Guillard, *Stephanodiscus incogni-*

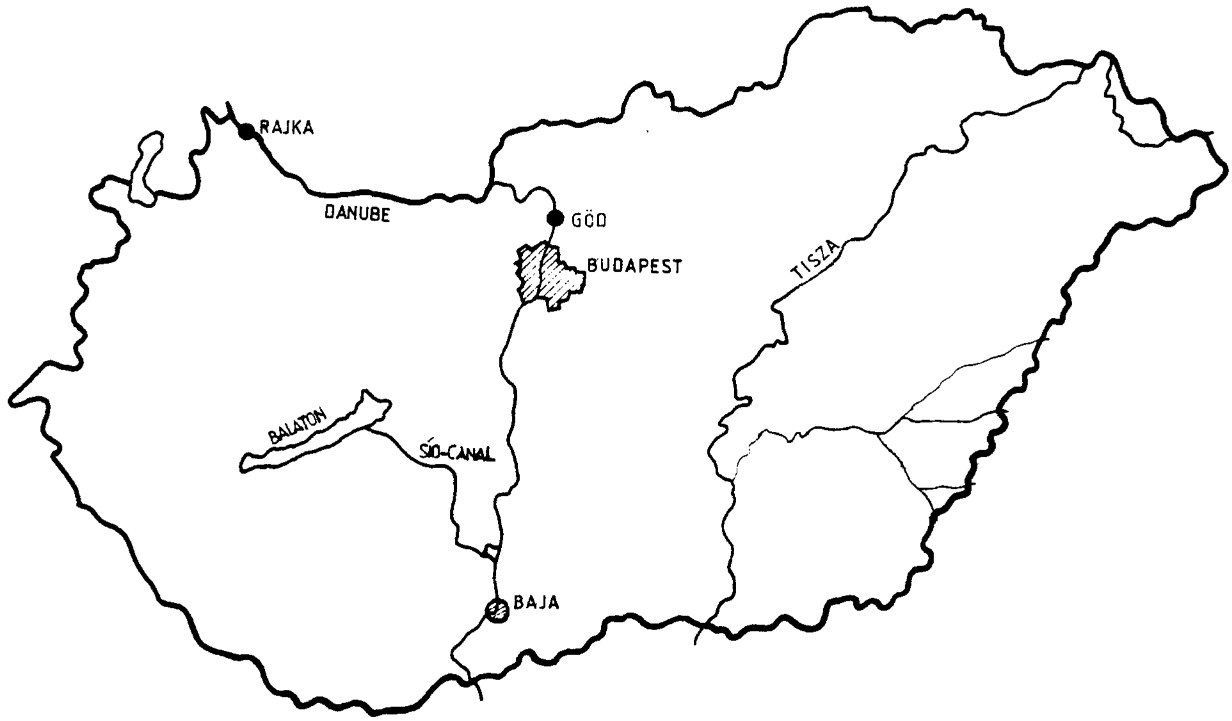

Fig. 1. Map of the Hungarian section of the Danube, with the location of the sampling sites (Rajka, Göd & Baja); the Sió-Canal, joining the Balaton and the river, is also indicated.

tus Kuzmin & Genkal, *S. invisitatus* Hohn & Hellerman, *S. makarovae* Genkal, *S. perforatus* Genkal & Kuzmin, *Thalassiosira guillardii* Hasle, *T. pseudonana* Hasle & Heimdal, *Actinocyclus normanii* (Greg.) Hust.

The aims of the present paper are: (i) to present a short summary about the purposes and methods of the environmental monitoring of the river; (ii) to discuss relationships among discharge, suspended matter and chlorophyll *a* content in the southern part of the Hungarian Danube and (iii) to contribute to the taxonomic knowledge of some rare or interesting algae recently found in the river.

Material and methods

Water samples have been collected weekly since 1986 for chemical and microscopic studies, from the River Danube at Baja (1480.2 river km). Physical and chemical variables (conductivity, pH, suspended matter, major ions, nutrients, chemical oxygen demand) have been measured according to COMECON chemical methods, and chlorophyll *a* according to Felföldy (1987), *i.e.* extraction of the algal material in hot methanol and calculation of total pigment content. Algal numbers were determined by the agarplate method (Németh & Vörös, 1986).

The water quality classification was based on the recommendations of Felföldy (1987), who divided the water quality parameters into four groups: halobity (the biologically important inorganic features), trophity (primary production and standing crop), saprobity (the capacity of dead organic matter degradation of the ecosystem) and toxicity (presence of various toxicants in the water).

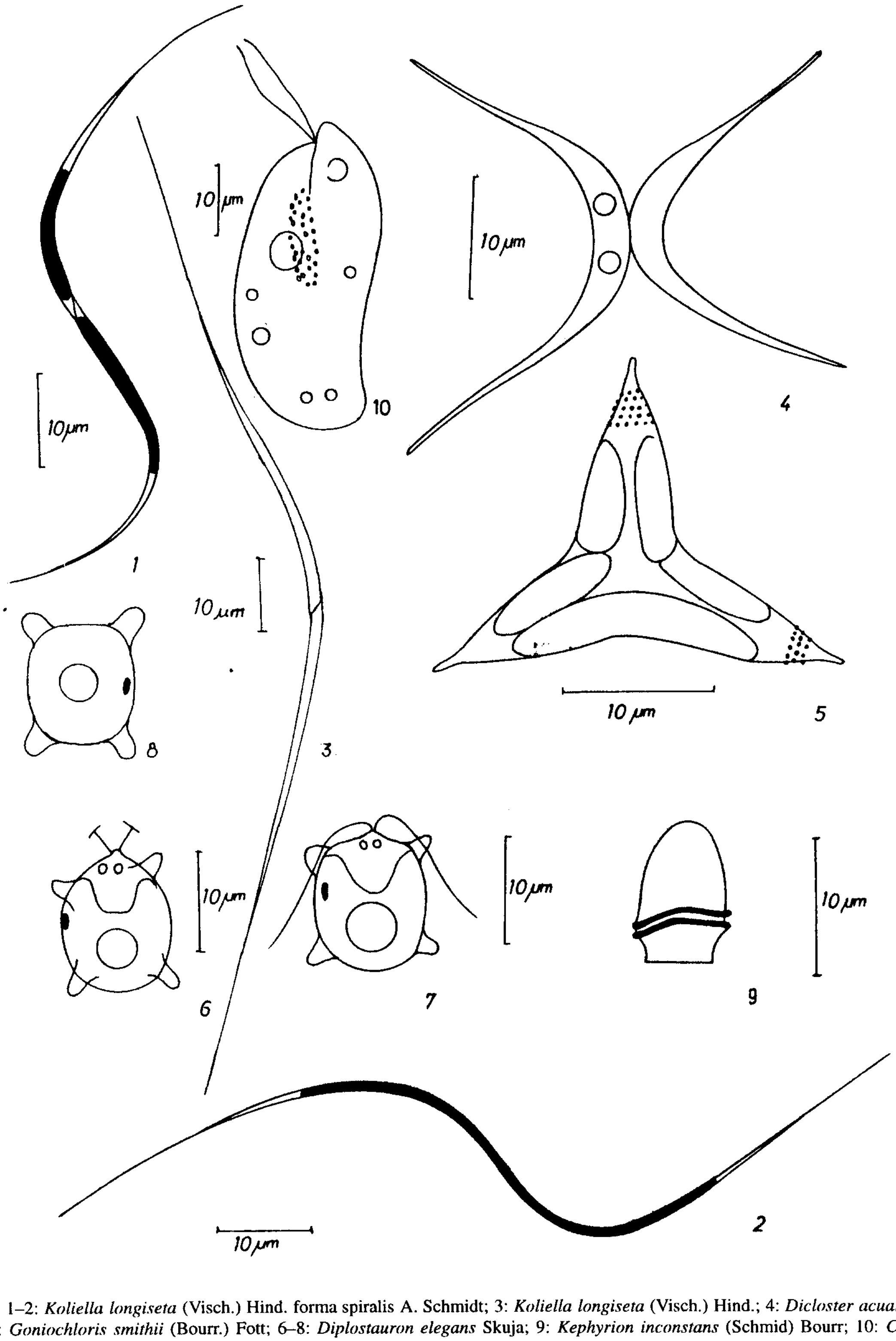

Plate 1. 1–2: *Koliella longiseta* (Visch.) Hind. forma spiralis A. Schmidt; 3: *Koliella longiseta* (Visch.) Hind.; 4: *Dicloster acuatus* Jao, Wei & Hu; 5: *Goniochloris smithii* (Bourr.) Fott; 6–8: *Diplostauron elegans* Skuja; 9: *Kephyrion inconstans* (Schmid) Bourr; 10: *Cryptomonas rostrata* Troitzkaja emend. Kiselev

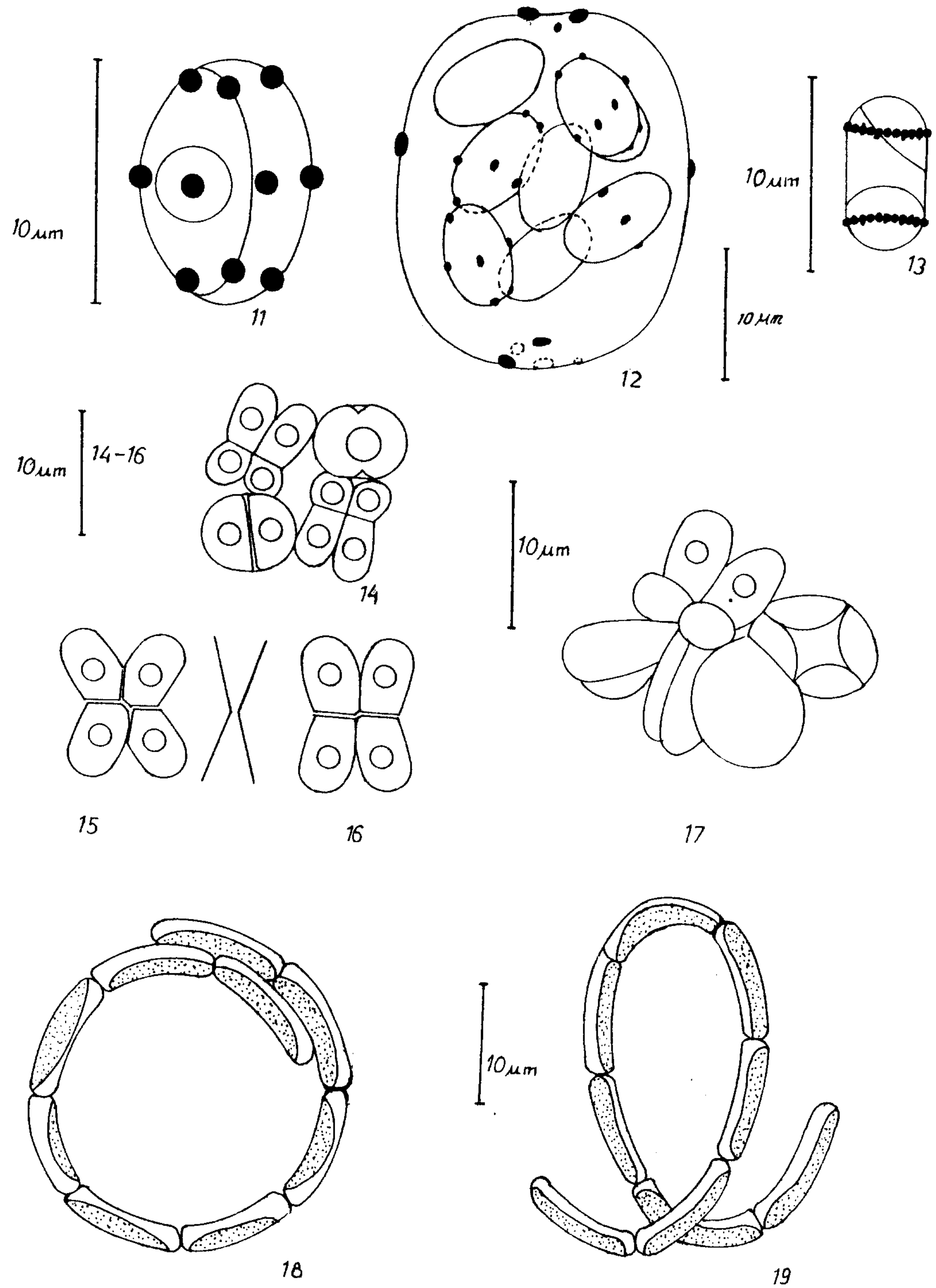

Plate 2. 11–12: *Granulocystopsis coronata* (Lemm.) Hind. var. elegans (Fott) Kom.; 13: *Amphikrikos minutissimus* Korš.; 14–17: *Crucigeniella divergens* (G.M. Smith) Fott; 18–19: *Gloeotila spiralis* Chod.

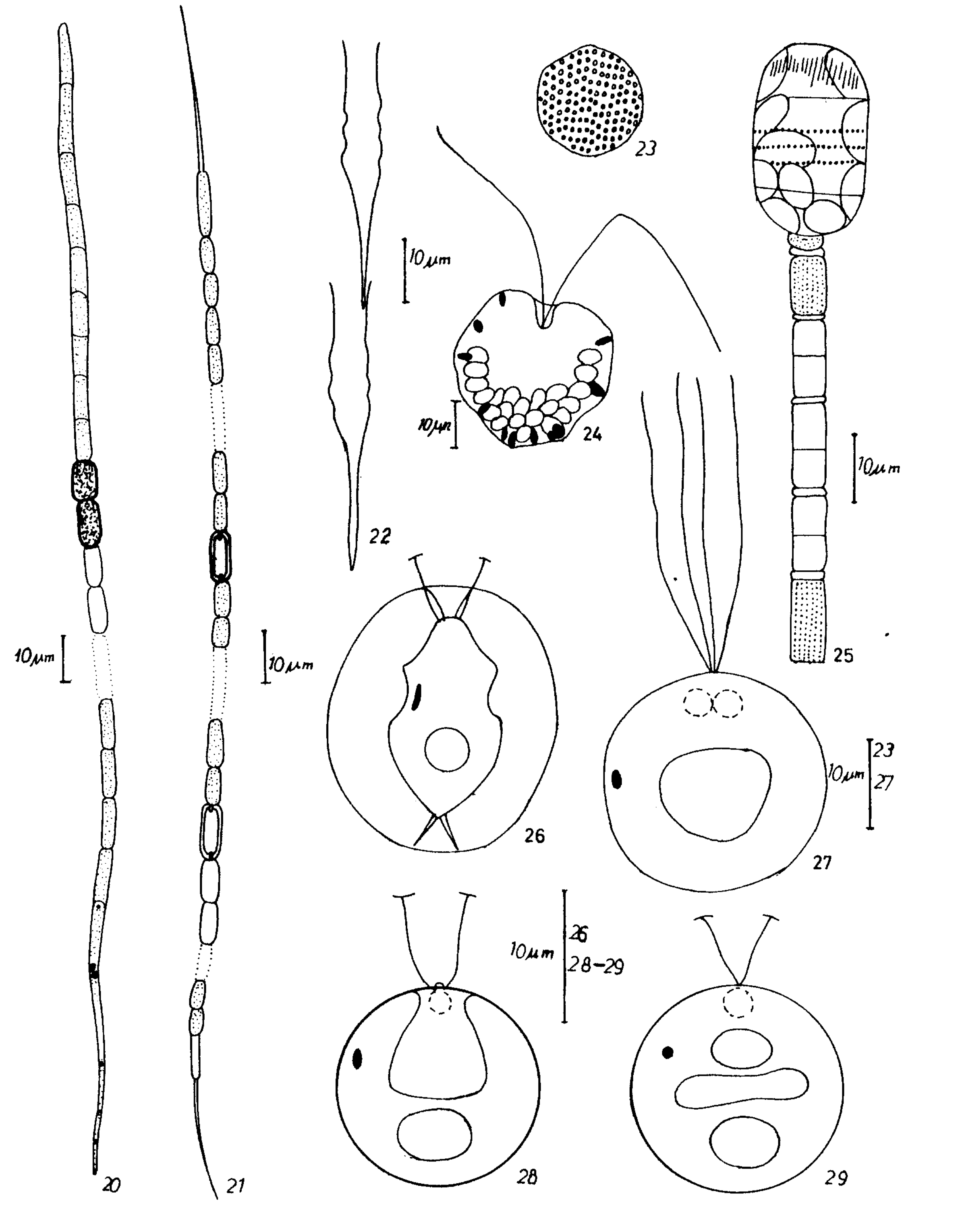

Plate 3. 20–21: *Aphanizomenon issatschenkoi* (Usacev) Proskina-LaVrenko; 22: *Dinobryon bavaricum* Imhof; 23: *Trachidiscus sexangulatus* Ettl; 24: *Gonyostomum latum* Ivanov; 25: *Aulacoseira islandica* (O. Müll.) Sim.; 26: *Pteromonas aequiciliata* (Glichlhorn) Bourr.; 27: *Carteria globosa* Korš. in Pasch.; 28: *Chlamydomonas simplex* Pasch.; 29: *Chlamydomonas skujae* Pasch.

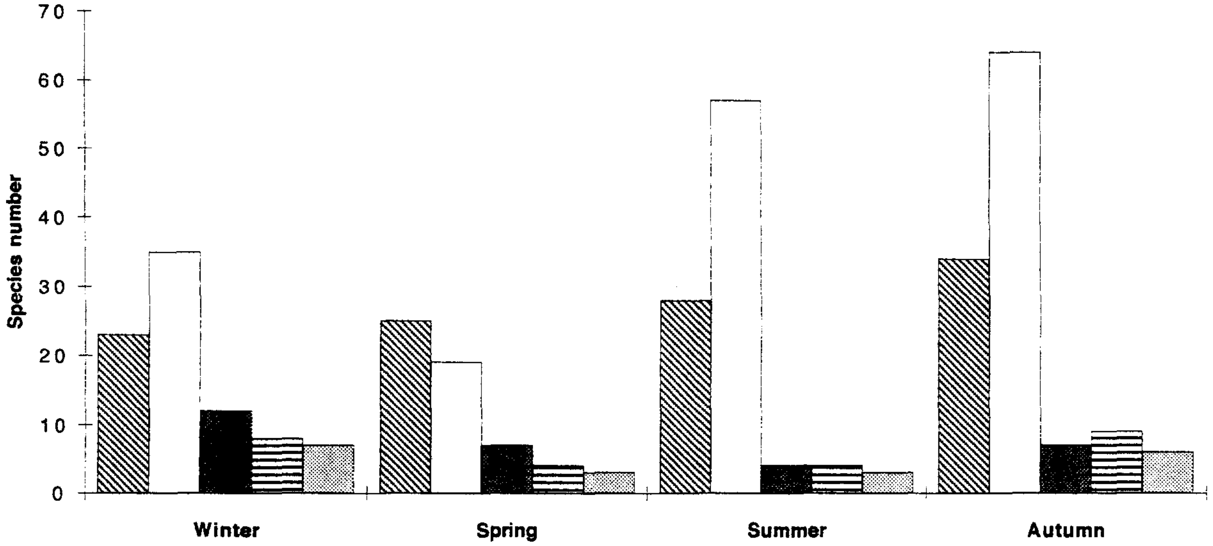

Fig. 2. Seasonal variation of the species number of phytoplankton in the River Danube (Göd, 1990) 1. Bacillariophyceae; 2. Chlorophyta; 3. Chrysophyceae – Xanthophyceae; 4. Cryptophyceae – Dinophyceae; 5. Others

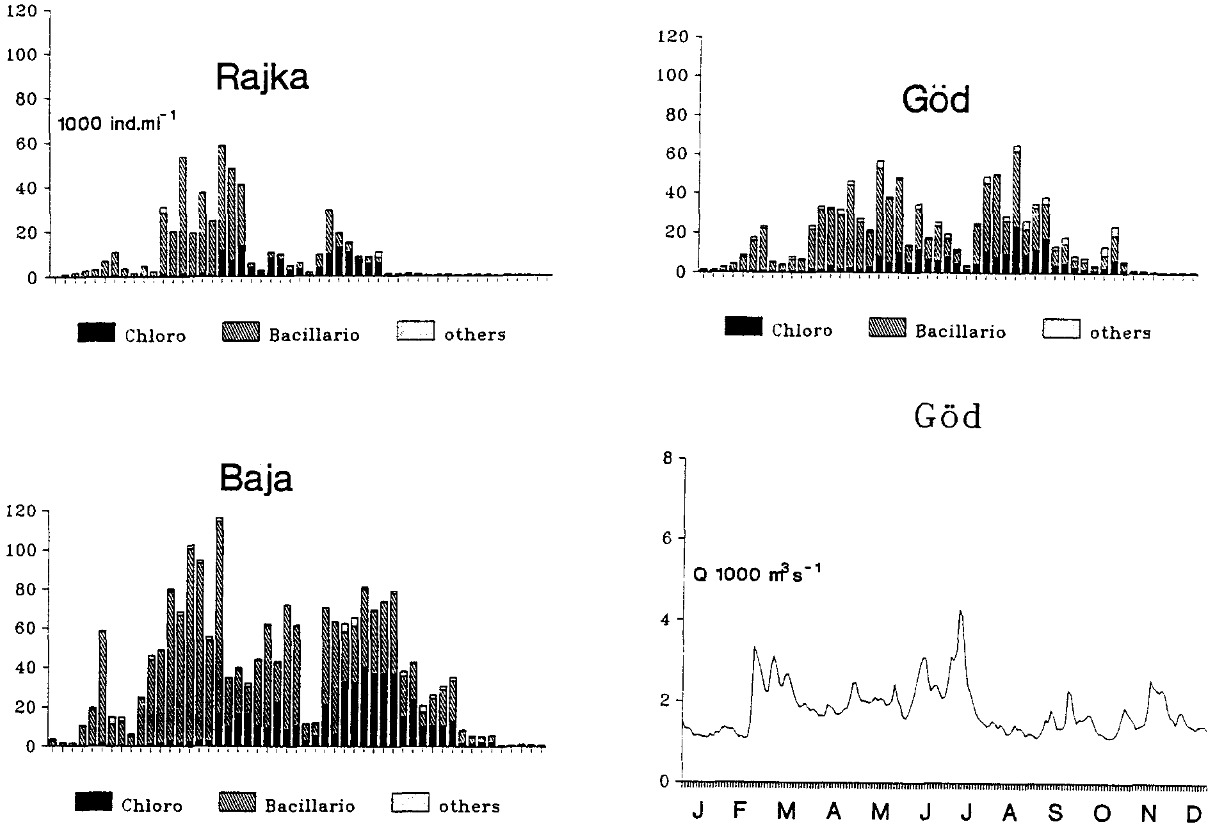

Fig. 3. Discharge and seasonal variations of the phytoplankton of the Hungarian section of the River Danube (year 1990).

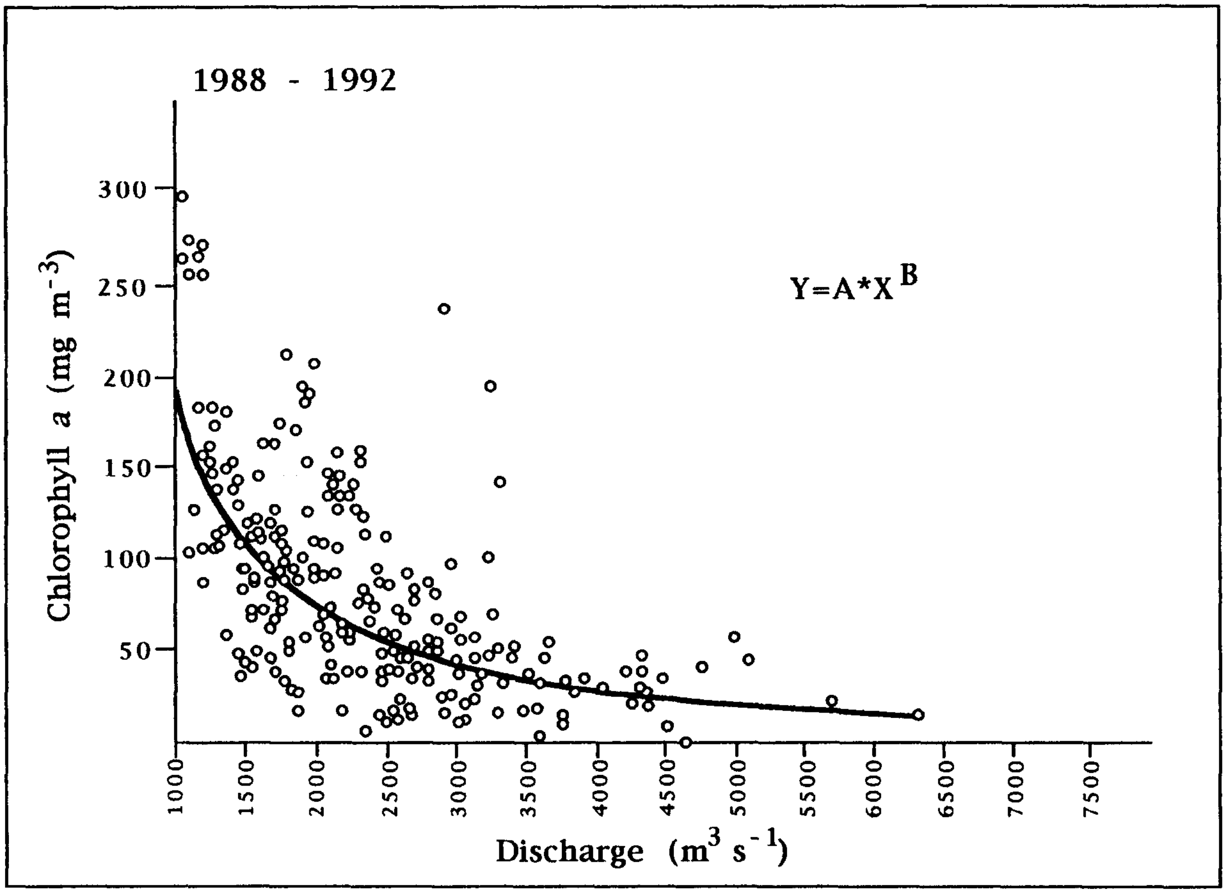

Fig. 4. Relation between chlorophyll *a* concentration and discharge in the Hungarian Danube (1988–1992).

Results and discussion

Water quality

According to Hungarian standards the River Danube is chemically a typical freshwater, with a mean conductivity of 389 μS cm^{-1}; the main ions are Ca^{2+}, Mg^{2+} and HCO_3^- which corresponds to a β–α oligohalobic water. With regard to the high nutrient loading, the potential trophic level is polytrophic or hypertrophic (Kiss, in press). The chlorophyll *a* values vary in a wide range (2–269 mg m^{-3} for the period 1988–1992); the maximal concentration (296 mg m^{-3}) was measured in October 1986 during a prolonged low-water episode. The average chlorophyll *a* of 67.2 mg m^{-3} indicates the eutrophic status of the river, according to the scale proposed by Felföldy (1987). However, if we consider that the maximum values of chlorophyll *a* reflects the carrying capacity of the river water, its trophic status is close to hypereutrophy according to the Felföldy's scale, and corresponds to eutrophy on a scale of world-wide use (Wetzel, 1983).

Sporadic investigations in the side arms of the Danube provided much higher maximal chlorophyll *a* records. For example, a peak of 1114 mg m^{-3} was observed on the 28th of July 1986 during a *Peridinium* cf. *penardii* (Lemm.) Lemm. bloom. This side arm called 'Rezéti Duna', near Baja, is continuously connected to the river by two mouths and does not receive extra nutrient input. The observed high value reflects a trophic level that can be reached under favourable trophic conditions in Danube water.

The Pantle-Buck index (1955) – that is used to characterize the saprobic state of the water – provides an average of 2.30 (turning point between β - and α –β mesosaprobic state, according to the scale of Gulyàs in Felföldy, 1987). This index is based on the frequency occurrence of saprobic bioindicators and indicates the

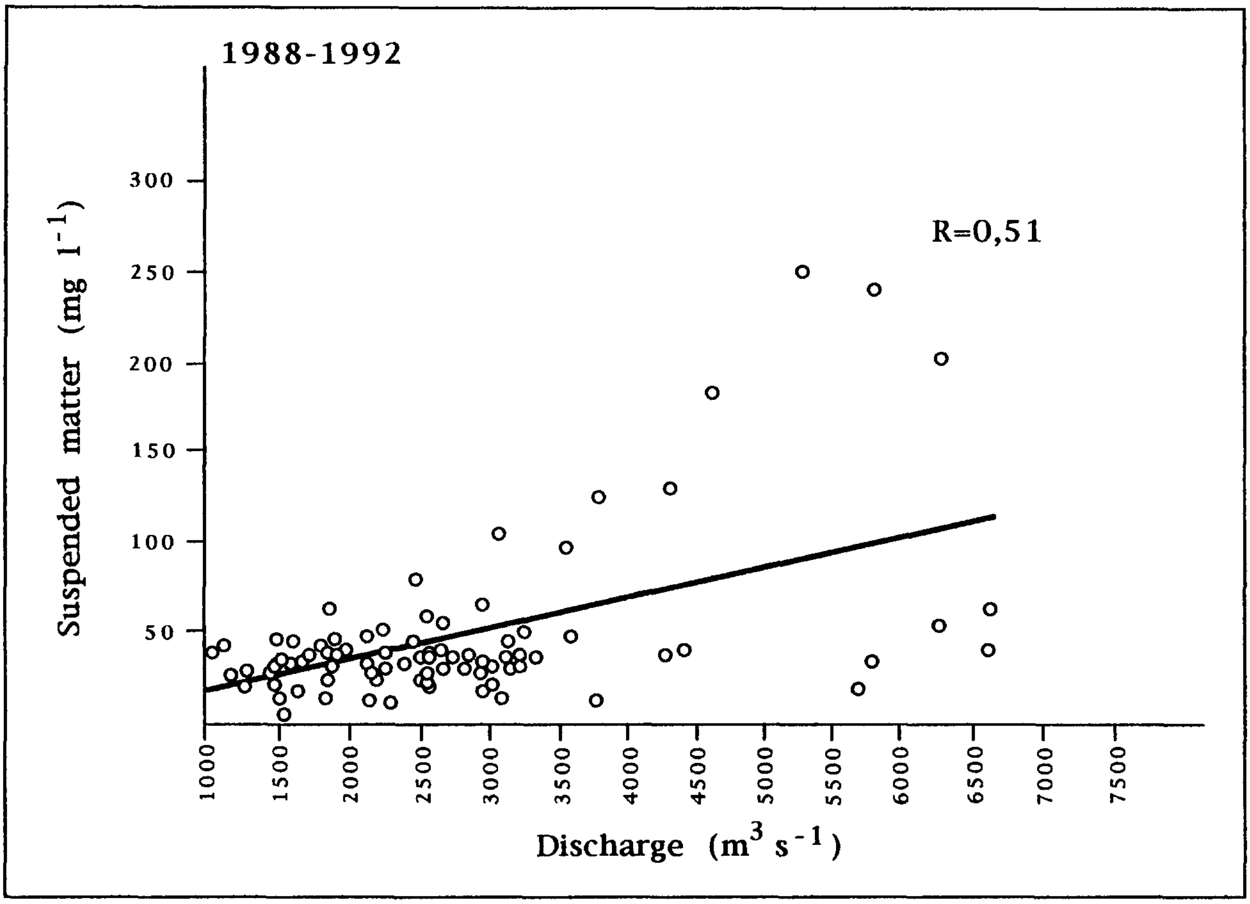

Fig. 5. Relation between suspended matter and discharge in the Hungarian Danube (1988–1992).

real saprobic level. The saprobic classification of the Danube agrees with that of the chemical: the average value of the COD (oxydability with $KMnO_4$) of 5.1 mg l^{-1} O_2 also indicates the turning point between β-mesosaprobic and α–β mesosaprobic state.

Species composition

A phytoplankton taxon number of 327 was recorded along the whole Hungarian section of the Danube in 1987, with the following percentages: 50% Chlorophyceae, 30% Bacillariophyceae taxa and 20% other algae. Diatoms dominated in spring. In other seasons green algae, especially coccal green algae, were the best represented group. According to Fig. 2, the species richness increased from spring (58) to autumn (119) when the diversity was maximal for all groups, including diatoms, but the species number (85) of the winter season was also remarkable. Therefore, the main difference between cold and warm seasons lay in the abundance of phytoplankton. The species richness in the vegetation period was connected with large algal numbers (up to 100 000 specimen ml^{-1}), while in winter the algal numbers were in general under 5000 specimen ml^{-1}. The increase in species number of the green algae in summer and autumn was related to the following ecological conditions: long-lasting low discharge (up to 2 months), higher water temperature (mainly 14–23 °C), good light conditions (146–335 sunny hours per month). However, a unispecific green algal bloom has been recorded only once during the last 20 years, namely a bloom of *Actinastrum hantzschii* Lag., in June 1977, but for a very short period. Chlorococcales was usually the most common green algal group in the Danube, the most diverse genus being *Scenedesmus*. Phytomonadina were also common in the Danube, but their species number was definitively lower than that of the Chlorococcales. Other green algae (Ulotrichales, Desmidiales) appeared sporadically in the phytoplankton.

The EM revision of the Thalassiosiraceae (by Kiss, 1986) resulted only a small change in the recognition of the late winter peak of very small centric diatoms and the summer or early autumn peak of *Skelelonema potamos* (Weber) Hasle.

Algae belonging to other taxonomic groups constantly enrich the flora of the river although they are sometimes erratic in their appearance. They may originate from side arms or dead-zones (Stoyneva, this volume; Kiss & Kristiansen, this volume), thus being autochtonous to the river. However, in several cases, an allochtonous origin is very likely. For example, the filamentous blue-green alga *Cylindrospermopsis raciborskii* Wolosz. was found in September 1982 far downstream from the outlet of the Sió-canal (river km 1496), that connects the River Danube with Lake Balaton, where the species regularly blooms late summers (G.-Tóth & Padisák, 1986; Padisák, in press). The highest numbers were recorded right downstream of the Sió-canal (1000 filaments ml^{-1}), but the density of this alga decreased rapidly along the river. Another example is the sporadic occurrence of *Chaetoceros muelleri* Lemm. or *Dicloster acuatus* Jao, Wei & Hu.

The most common algae in the phytoplankton of the River Danube are *Stephanodiscus hantzschii* Grun. f. *hantzschii*, *S. hantzschii* f. *tenuis* (Hust.) Håk. & Stoerm., *S. invisitatus* Hohn & Hellerm., *Cyclotella meneghiniana* Kütz., *Aulacoseira granulata* var. *angustissima* (O. Müll.) Sim., *A. islandica* (O. Müll.) Sim., *Skeletonema potamos* (Weber) Hasle, *Nitzschia fruticosa* Hust., *Actinastrum hantzschii* Lag., *Scenedesmus acuminatus* (Lag.) Chod., *S. armatus* Chod., *S. quadricauda* (Turp.) Bréb. sensu Chod., *Crucigeniella apiculata* (Lemm.) Kom., *Crucigenia tetrapedia* (Kirchn.) W. & G. S. West., *Coelastrum astroideum* De.-Not.. The diatom flora, especially the centrics, have been discussed in detail by Kiss (1984a, b; 1988) and by Kiss *et al.* (1990).

Most of the Danube sporadic algae are common in other freshwaters, but some are rare; taxonomically and/or ecologically insufficiently known species also occur. A list of recent additions (except Bacillariophyceae) to the algal microflora of the Hungarian Danube section is presented below.

List of new and interesting taxa in Danube

Cyanophyceae

Aphanizomenon issatschenkoi (Usacev) Proskina Lavrenko (Pl. 3, 20–21) Trichomes (295–733 μm long), cells: 2–4 × 5–13 μm, heterocysts: 4 × 8—10 μm, akinetes: 5 × 9–10 μm.

Rare and solitary filaments were collected from the whole Hungarian Danube section and also from backwaters.

Xanthophyceae

Dichotomococcus curvatus Korš.
Cell dimensions: 2 × 5.5 μm
A taxonomically insufficiently known, rare species of the Danube and side arms.

Goniochloris smithii (Bourr.) Fott (Pl. 1, 5.)
Dimension: 30 μm
Always in low quantities. The taxonomical position of this species has recently changed. The new combination, *Pseudogoniochloris tripus* (Pascher) Krienitz, Hegewald, Reymond & Peschke, includes the following taxa as synonyms: *Goniochloris contorta* (Bourr.) Ettl, *G. fallax* Fott and *G. smithii* (Bourr.) Fott.

Trachidiscus sexangulatus Ettl (Pl. 3, 23)
Diameter: 12 μm
Solitary and very rare.

Chrysophyceae

Chrysococcus biporus Skuja
Diameter: 5.5–7.5 μm
In the winter plankton, not so rare. Its density is much higher in the side arms and backwaters than in the river.

Dinobryon bavaricum Imhof (Pl. 3, 22)
Dimensions: 50–57.5 × 5–7.5 μm
Rare in the Hungarian section.

Diploeca flava (Korš.) Bourr.
Dimensions: 5–6.5 × 6.5–7.5 μm, neck 4 μm long.
It was found on a *Stephanodiscus*-valva. Rare in the Danube and in the side arms. An ecologically insufficiently known species.

Kephyrion inconstans (Schmid) Bourr. (Pl. 1, 9)
Dimensions: 5 × 7.5 μm
In the winter plankton, not so rare.

Kephyrion moniliferum (Schmid) Bourr.
Dimensions: 6–7 × 7–8μm
Rare in the Danube.

Kephyrion rubri-claustri Conrad
Dimensions: 5.5 × 7.5 μm

Kephyrion tubiforme Fott
Dimensions: 6.5–7.5 × 7.5–8 μm
Mainly in the side arms.

Mallomonas akrokomos Ruttner
Dimensions: 5–6 × 30–35 μm
Typical for the cold water period. Always solitary.

Crytophyceae
Cryptomonas marssonii Skuja
Dimensions: 9–15 × 19–27 μm
It has become a characteristic member of the Danube phytoplankton in the cold water period, after the first appearance in the mid 1970s.

Cryptomonas rostrata Troitzkaja emend. Kiselev (Pl. 1, 10)
Dimensions: 17.5 × 42,5 μm
Rare in the river, but high density in the side arms and backwaters.

Dinophyceae
Peridinium cf. *penardii* (Lemm.) Lemm.
Rare in the river but very high density in side arms around Baja (Rezéti Duna, Sugovica, Vén Duna).
The first bloom in this area was recorded on the 28th of July, 1986.

Rhaphidophyceae
Gonyostomum latum Ivanov (Pl. 3, 24)
Dimensions: 31 × 32 μm
Very rare in the river. It was previously known only in the backwaters.
This species is difficult to notice because of the quick disorganization of the cell structure.

Chlorophyta
Amphikrikos minutissimus Korš. (Pl. 2, 13)
Dimensions: 3–3.5 × 6–7.5 μm

Carteria globosa Korš. in Pasch. (Pl. 3, 27)
Diameter: 25 μm

Chlamydomonas simplex Pasch. (Pl. 3, 28)
Diameter: 13–17 μm

Chlamydomonas skujae Pasch. (Pl. 3, 29)
Diameter: 16 μm
Rare and this is may be the first publication from river phytoplankton.

Crucigeniella divergens (G. M. Smith) Fott (Pl. 2, 14–17)
Dimensions: 3–5 × 30–40 μm
This alga has rarely been found in Europe.

Dicloster acuatus Jao, Wei & Hu (Pl. 1, 4)
Dimensions: 3–5 × 30–40 μm
Very rare in the river, but also collected from the side arm called 'Szeremlei Duna-ág' near Baja.

Diplostauron elegans Skuja (Pl. 1, 6–8)
Dimensions: 8–11 × 10–14 μm
This variable species was found in Southern Hungary, only in winter.

Gloeotila spiralis Chod. (Pl. 2, 18–19)
Cell dimensions: 2 × 8–10 μm
Diameter of one spiral: 15 μm
The filaments of *Gloetila* species, for example *G. pelagica* (Nyg.) Skuja are rare and solitary in the plankton of the Danube.

Granulocystopsis coronata (Lemm.) Hind. var. *elegans* (Fott) Kom. (Pl. 2, 11–12)
Cell dimensions: 5–7.5 × 8–10 μm
It is a rare species for the river and also for the backwaters.

Koliella longiseta (Visch.) Hind. (Pl. 1, 3)
Dimension: 2 × 140 μm
Probably an intermediate form between the typical, rectilinear form and the spiral forma *spiralis* A. Schmidt.

Koliella longiseta (Visch.) Hind. forma *spiralis* A. Schmidt (Pl. 1, 1–2)
Dimension: 1.5–2 × 77.5–100 μm
Always in low quantities, first of all in the winterplankton and always together with the typical form.

Neodesmus danubialis Hind.
Cell dimension: 2–2.5 × 5–7.5 μm
It has been a sporadic, but characteristic member of the

vegetation period since its first record in the mid 1970s.

Paradoxia multiseta Svir.
Dimensions: 6.3 × 25.2 μm
Rare in the Hungarian section, but also found in Austria (Dokulil, pers. com.) and Bulgaria (Stoyneva, pers. com.).

Pteromonas aequiciliata (Gicklhorn) Bourr. (Pl. 3, 26)
Cell dimensions (without mucilage): 10–12.3 × 17–18 μm
Very rare in the phytoplankton of the Danube.

Seasonal development of phytoplankton

The phytoplankton of the Hungarian Danube usually starts to increase in late February under good meteorological conditions (water temperature 3–5 °C, 100 sunny hours per month at least). The highest algal numbers (up to 100 000 units ml^{-1} or more) regularly occur in March/April, when centric diatoms usually contribute 95–99% to total numbers.

Figure 3 presents a steady increase of algal numbers along the Hungarian section of the Danube. The multiplication factor varies from 2 to 3 times during the spring peak and up to about 20 times in late summer or early autumn. A 10–15 times increase of the algal numbers is commonly encountered.

This figure also shows the inverse relationship between discharge and phytoplankton density. Based on the weekly chlorophyll *a* data (1986–1992) from the vegetation period (15th of March–15th of October) the correlation coefficient (−0.67) shows a significant negative relationship between chlorophyll *a* and discharge (Fig. 4). During the period of study, phytoplankton blooms developed at relatively low discharge values (<1700 m^3 s^{-1}) but the highest peaks (chlorophyll *a* >250 mg m^{-3}) were observed at very low discharge (<1250 m^3 s^{-1}). At a discharge >3500 m^3 s^{-1} chlorophyll *a* remained below 50 mg m^{-3}.

Discharge and suspended matter were positively correlated (correlation coefficient: +0.51). Large suspended matter records were characteristic at discharges >3000 m^3 s^{-1} (Fig. 5). Hence, suspended matter and chlorophyll *a* content are negatively related in the Danube, as in upper sections of the river (Kiss *et al.*, this volume) and other large rivers (see e.g. Carvayal-Chitty, 1993).

Based on the above data, discharges lower than 2250 m^3 s^{-1} provide the best hydrological and water transparency conditions (suspended matter <50 mg l^{-1}) for the phytoplankton growth in the Baja section of the River Danube. Moreover, short-term observations (Kiss, 1991) on phytoplankton changes showed that after the establishment of a low discharge, an 8–10 day period free of flood waves is necessary for the establishment of high phytoplankton development. These observations are in agreement with the time scale described by Reynolds *et al.* (1993) discussing the diversity-disturbance relationship in phytoplankton.

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