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Phytoplankton of the Danube River: Composition and Long-Term Dynamics

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Abstract: Investigations on river phytoplankton in the Danube River are summarised and placed into a historic perspective. Phytoplankton species composition always has been dominated by diatoms, particularly centric taxa. Longitudinal, seasonal and long term dynamics are described and their implications are discussed. Factors responsible for the wax and wane of phytoplankton growth in the middle section of the Danube River are analysed and discussed. Survival, growth and production of phytoplankton in the Danube River and in large rivers in general are then incorporated and integrated into the existing fundamental concepts of riverine ecosystems.

Keywords: Large rivers, Danube River, plankton, seasonality, interaction

Introduction

Investigations on river phytoplankton in the Danube River have a long history. First qualitative studies in the years 1898 and 1899 indicated a similar species composition as nowadays (Brunnthaler 1900, Steuer 1900). Diatom species (Bacillariophycae), particularly *Aulacoseira granulata,* dominated the assemblage. Even such delicate species as *Atheya zachariasii* appeared in the river (Brunnthaler 1903). Quantitatively the authors observed considerable variation in space and time depending on environmental conditions. Both authors discussed already the applicability of the term '*Potamoplankton* introduced by Zacharias (1898) for river plankton. Because of the variable and very low quantities of the plankton in the Danube River, investigations in the following years concentrated more on the Danube back-waters.

Halász (1936) in Hungary and Schallgruber (1943) in Austria resumed the investigations in the Danube River. The latter author's annual quantitative data clearly indicated the dominance of centric diatoms. Therefore, the author concluded that the Danube's plankton should consequently be called '*Cyclotella* plankton'. Based on his finding that algal species in the river were healthy and alive he insisted to preserve the term 'potamoplankton' for such biocoenoses similar to the suggestions of Wawrik (1962). Wherever flow was reduced or where eutrophication became significant cyanobacteria and green algae became more important than diatoms, sometimes even forming surface blooms (Stundl 1951). The monograph '*Limnologie der Donau'* compiled by Liepolt (1967) provided the first synopsis of results obtained until then on the Danube River. In this monograph, Szemes (1967) made a systematic list of the Danubian flora.

Investigations expanded through the activities of the International Association for Danube Research (IAD, Wachs 1996). Comprehensive overviews were published among others by Weber (1993) and Kinzelbach (1994). Major steps forward in the protection of the water quality in the Danube River were the 'Bucharest Declaration' in 1985 and the International Commission for the Protection of the Danube River (ICPDR) established in 1998, which soon expanded its activities into the whole Danube River Basin initiating major projects and surveys.

The aim here is to summarise the widely dispersed information on the species composition, quality and quantity of the potamoplankton in the Danube River.

Material and Methods

Data analysed originate from a multitude of reports, journals, publications and electronic material. Besides regional investigations (*e.g*. Nausch 1987, Kiss, Nausch 1987, Schmid 1994, Siegel 1999) and results pertinent to specific stretches of the river (*e.g*. Hofmann *et al*. 1981, Kiss, Genkal 1996), longitudinal surveys of the Danube River provided important information. These surveys have been summarised by Wachs (1996, Table 3), described by Kusel-Fetzmann *et al.* (1998, p. 48ff) and were updated by Dokulil, Kaiblinger (2009). Additional information on water quality for most of the Danube River was provided by Weber (1993), who summarised data collected in 1988-1993, in fulfilment of the Bucharest Danube Declaration, adding the determinant chlorophyll-a (chl-a) as a surrogate parameter for phytoplankton in 1992. To convert phytoplankton cell numbers to chl-a or biomass equivalents, JDS2 data were systematically correlated and a graphical regression nonogram was developed (Dokulil 2014b).

Results

Numerous algal taxa lists have been published. A synopsis on plankton organisms was provided by Kusel-Fetzmann *et al.* (1998). Details for the section Bratislava to Budapest including tributaries can be found in Makovinská (2003). More recent lists have been compiled by Nemeth *et al.* (2001) and Dokulil, Kaiblinger (2008); see also Literáthy *et al*. (2002) and Liska *et al.* (2008).

The species composition of the phytoplankton has always been dominated by diatoms (Bacillariophyceae) and co-dominated by green algae (mainly Chlorococcales) during summer or in particular river stretches (Wawrik 1962, Szemes 1967, Saiz 1982, Gucunski 1990, Stoyneva, Draganov 1991, Nemeth *at al*. 2002, Dokulil, Kaiblinger 2008). The majority of the dominant diatoms were centric taxa, such as *Aulacoseira, Stephanodiscus* or *Cyclotella* among several others (*e.g*. Nausch 1988). These small centric diatoms often bloom even during winter (Kiss, Genkal 1993). Canalization, construction of hydropower dams, impoundments and eutrophication increased the phytoplankton biomass and changed the species composition in the past (Saiz 1985, 1990, Müller, Kirchesch 1990, Pujin 1990, Kiss, Genkal 1996). Prior to 1994, the chlorophyll concentrations often exceeded 100 $\mu g\ l^{-1}$ in the German river stretch due to the impounded character of this river section. The enhanced phytoplankton production resulted in oxygen over-saturation of up to 186% (Schmid 1994).

A large number of published investigations report a widely varying number of algal taxa depending on season, river stretch and discharge among other factors.

During JDS2 (Dokulil, Kaiblinger 2008) the number of phytoplankton taxa varied from 46 in the Sulina arm to 101 in the tributary Iskar. The average number was 75 taxa for all 96 samples from the Danube River and major tributaries. Bacillariophyceae (diatoms) clearly dominated the biomass at all stations in the Danube (average 59%, range 35–76). Higher contributions of green algae (Chlorophyta) were observed in the German stretch (37–63%). For the major part of the river, green algal contribution averaged 25% (range 0–64%). The small flagellated species of the Cryptophycean group appeared at all stations in the river (mean 16%, range 0–47%) with higher importance in the upper reaches (Austria, Slovakia, northern part of Hungary and in the Iron Gate section). Cyanoprokaryota (Cyanobacteria) were unimportant in the river. In contrast, some of the tributaries carried large amounts, especially the Arges River which contained 80% cyanobacteria exclusively species from one genus, the colonial, potential toxic *Microcystis*. Green algae dominated in the Timok River (87%) and were an important component in most of the tributaries, particularly the rivers Sio, Hron and Ipoly. Cryptophyta were of minor importance in these streams except in the Tisza River where the group contributed 36%.

The early investigations reported potamoplankton abundance primarily as individuals per liter.

Schallgruber (1944) stated maximum numbers of $2.7*10^6$ cells l^{-1} for the 1940s. This number increased to $5.5*10^6$ ind. l^{-1} by the end of the 1970s (Saiz 1982), and rose further to $26*10^6$ by 1988 (Nausch 1988), which is a 10-fold increase in about 45 years. These numbers correspond to fresh-weight biomass of 1.1, 1.8 and 7 mg l^{-1} or chlorophyll-a concentrations of 5, 8 and 31 µg l^{-1} respectively (Dokulil 2014b).

Longitudinal surveys since 1961 summarised in Table 1 have indicated consistently: low to moderate chlorophyll-a concentrations in the upper reaches, from about Ulm to the Gabcikovo impoundment east of Bratislava; increasing, peaking and declining values in the middle reaches; and low or only marginally increasing concentrations of chlorophyll-a in the lower reaches (Fig. 1).

The expedition in 1960 (Benda *et al.* 1961) reported cell numbers which peaked at 27 x 10^6 cells l^{-1} in Budapest at rkm 1647 (Wawrick 1962). This is equivalent to about 32 µg chl-a l^{-1} when converted using the relations in Dokulil (2014b). The concentrations persisted at about this level downstream until rkm 1488 but dropped to 4.2 x 10^6 cells l^{-1} (= 6.7 µg chl-a l^{-1}) near the confluence with the Drava River remaining low further downstream (Fig. 2, top panel, IAD 1961). The expedition in 1988 observed much higher concentrations of chl-a (Aponasenko *et al.* 1990). Values reached 85–136 µg chl-a l^{-1} between rkm 1731 and 1475, almost the same region as 17 years before (Fig. 1). Ten years later in 1998, maximum chl-a concentrations of 55-65 µg l^{-1} were attained between rkm 1659 upstream of Esztergom and rkm 1481 at the Drava confluence (Krauss-Kalweit 1999). The survey in 2001 detected chl-a values as high as in 1988 (>100 µg l^{-1}) and in about the same stretch. In contrast, the observations in 2007 (JDS2)

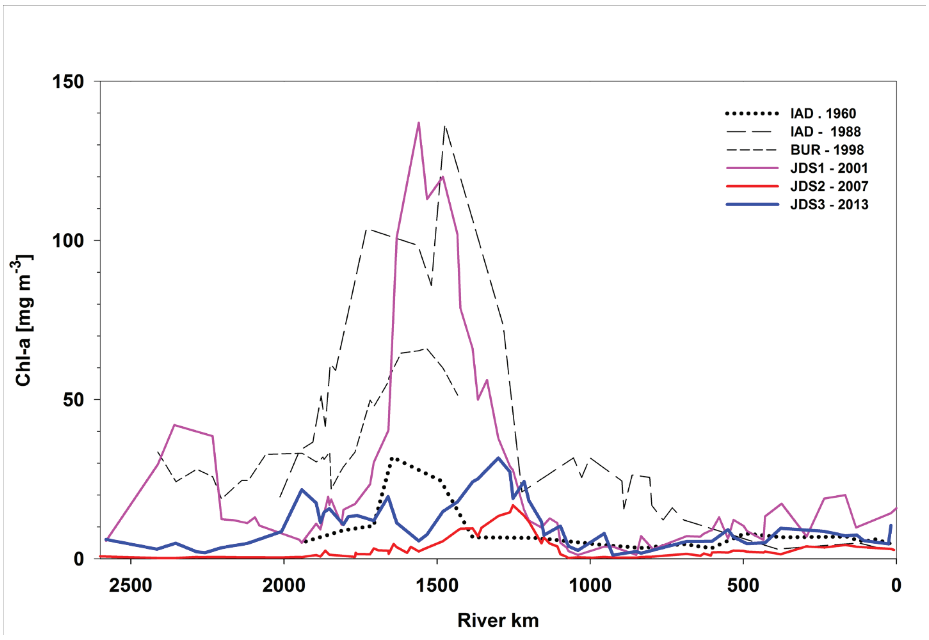

Fig. 1. Concentration of chlorophyll-a in the Danube River corridor for five surveys (data from references in Table 1)

Table 1. Danube surveys (expeditions)

Year, Month	From	To	Transport, Organisation	Reference
1960, 9-10	Vienna	Sulina	Amur, IAD	Benda *et al.* (1961), Wawrik (1962)
1961, 9	Vienna	Origin	Car, IAD	Liepolt (1967)
1978, 8-9			Ship, IAEO	Kiss (1991)
1988, 3	Sulina	Vienna	Amur, IAD	Weber (1990)
1990, 4	Ismail	Linz	Ship, UFD	Stoyneva, Draganov (1991)
1998, 5-6	Regensburg	Mohács	Burgund, Ministry	Krauss-Kalweit (1999)
2001, 8-9	Regensburg	Sulina	Argus, ICPDR	http://www.icpdr.org/
2007, 8-9	Regensburg	Sulina	Argus, ICPDR	http://www.icpdr.org/
2013, 8-9	Regensburg	Sulina	Argus, ICPDR	http://www.icpdr.org/

indicated a considerable reduction in the maximum concentration attained (25 µg l^{-1}) and a shift downstream to the section upstream of the Drava confluence (Fig. 1). Preliminary data from the 2013 survey (JDS3) show a similar picture and a minor increase in concentrations (Donabaum, Dokulil 2014).

Discussion

Although the existence of phytoplankton in rivers has been recognised soon after it was discovered in the sea and in lakes, it has never received the same level of attention (Reynolds, Descy 1996). This fact is even more surprising when considering the robust assemblages of potamoplankton assembled in Reynolds, Descy (1996, Table 1). In this list 59% of the taxa are diatoms of which 76% are centric. In fact, the potamoplankton of larger rivers is dominated by small or filamentous centric diatoms (see Table 3 in Dokulil 2014a). The reasons for the strong selectivity for these genera are attributed to the simultaneous selective bias of several morphological and physiological adaptations to survive in the rapidly fluctuating light field of a turbid, kinetic system (Reynolds 1994a,b,c, Reynolds, Descy 1996). Water residence time was identified as largely responsible for the selection of size structure and taxonomic composition in a comparative study of temperate rivers by Chételat *et al.* (2006).

The increase and maintenance of autotrophic plankton assemblages critically depend on photosynthetic activity, circulation depth versus euphotic zone and the daily balance of production and respiration (Holst, Dokulil 1987, Dokulil 2006a,b). Predictive models are now available to simulate potamoplankton composition and biomass from source to mouth using discharge, river morphology, water temperature, available light and nutrient inputs as forcing variables (*e.g.* Everbecq *et al*. 2001).

Conclusions

The conceptual framework of rivers being potentially autotrophic has fundamental implications for the Danube River. As pollution and turbidity from the catchment decline in the river, nutrient concentrations become gradually more significant. In combination with improved under-water light intensities, nutrients will enhance the algal primary production particularly in river sections where current speed is reduced or during periods of low discharge. Due to the complex hydrological situation and the large catchment of the Danube River, the timing and extent of seasonal maximum in the development of phytoplankton is difficult to predict and varies inter-annually. As a consequence, any monitoring schedule must react flexible to specific hydrological and meteorological situations. In particular it will be relevant for water quality evaluation within the EC-WFD.

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