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The consequences of river impoundments for the macrozoobenthos – demonstrated at the example of the River Danube in Germany

by
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Abstract: At the time before damming the river Danube in the area between Regensburg and Geisling, because of the pollution the prevailing macrozoobenthic community could not be characterized as a natural or near-natural potamal community. At that time generalists dominated and only a few stenoecious species of running water had a small share in the species spectrum. In the first year after the filling of the impoundment Geisling (1986) a massive appearance of chironomid populations occured. The analysis of the catches proved an outbreak of two chironomid species: the *Chironomus-plumosus*-group and *Glyptotendipes paripes*. In unusually high densities the sphere shell *Sphaerium corneum* and the crustacean *Corophium curvispinum* were found, too. Until today the productivity of the impoundment Geisling has still remained high. But it seems now that the community begins to stabilize.
Key words: Chironominae, *Sphaerium corneum*, *Corophium curvispinum*, River Danube (Germany), faunistic studies

Introduction

River Danube is navigable as a Federal waterway on the reach from the entry of the Main-Danube Canal to the German-Austrian border downstream of Passau. The earliest anthropogenic interferences with River Danube date back to the 15th century ("B'Schlacht near Straubing"). The year 1850 marked the beginning of the mean-water regulations involving the break of riparian forests, numerous river corrections and cut offs. It was followed in 1922 by the low-water training of the river, many groynes were built, and wide sections of the banks were secured by rip-rap rocks. At some accretion banks, however, larger accumulations of gravel remained preserved. The Danube river system experienced further interventions when several impoundment weirs were erected:

As early as 1918, were the first plans devised to build a weir for hydropower generation at the end of the 21-km reach shared by Germany and Austria, near Jochenstein. However, this project was postponed then in favour of the plan to build an impoundment near the "Danube-Kachlet", a rocky reach upstream of Passau, which was much more beneficial for navigation. This project was implemented in 1922. Then, through the energy shortage after World War II the harnessing of hydropower at Jochenstein again gained special importance, so that the impoundment there became operational already in 1956. The period between 1952 and 1984 a whole chain of 15 weirs for energy generation had been constructed upstream of the Federal waterway. Further river regulation in the Federal waterway served mainly the purposes of navigation and was closely related to the construction of the Main-Danube Canal as part of the Rhine-Main-Danube waterway (cf. Fig. 1).

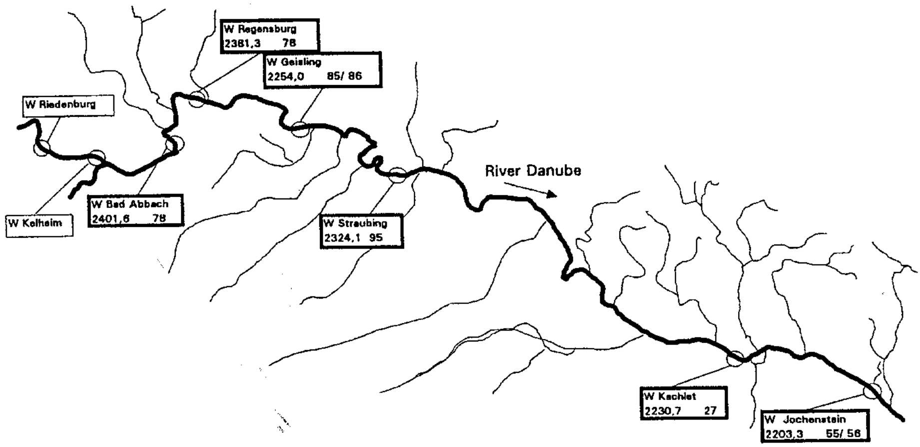

Fig. 1. The River Danube. The figure shows the part of the Federal waterway with the finished water retaining structures. (W = weir; 2401.6 = position of weir at rkm 2401.6; 78 = year of damming up)

River impoundments and their consequences

The impoundment at Geisling, that was completed in 1985, extends from the weir at Danube rkm 2354.0 to the impoundment weir at Regensburg 30 km upstream at the rkm 2381.33. Under mean water conditions the head of the impoundment Geisling is at the upstream end of the city area of Regensburg approximately at rkm 2378. At mean high water it is situated at the upper third of the impoundment around rkm 2374. The construction work at this first impoundment downstream of Regensburg began nearly 20 years ago. Fig. 2 shows that embankment dams were built along both banks. Because of the fact that in the immediate headwater of the weir the water level is about three metres above the terrain, these dams were lined with an internal sealing and all banks were secured by rip-rap rocks. Dredging of the flood plain additionally widened the discharge cross-section. Thus, the width of River Danube has more than doubled to 300 m.

Before the impoundment, the mean velocity of flow ranged usually between 0.8 and 1.2 m/s, the damming-up reduced it over long stretches to less than 0.2 m/s; under low-flow conditions it drops in the immediate headwater even to 0.08 m/s (cf. Fig. 3). The drastically modified flow conditions had a similar changing effect on the grain-size distribution in the bed load of the river. Originally, the gravel fraction occasionally with bed-load transport dominated on the bottom of River Danube. In contrast to a free-flowing river, where the sorting of the sediment takes place in a small-scale – often mosaic-like – interlocking – manner, large sediment zones can be distinguished in the dammed-up reach. Here, a flow velocity of 20 cm/s constitutes a limit below which the tractive force of the flowing water wanes (Einsele 1960). Consequently, finer material sinks to the bottom and forms larger silt or mud zones. Since the flow in the headwater of the Geisling impoundment is reduced most in comparison with other impoundments, and as the silt content is high, the most severe impacts on the benthic fauna have to be expected here. Moreover, the river continuum is

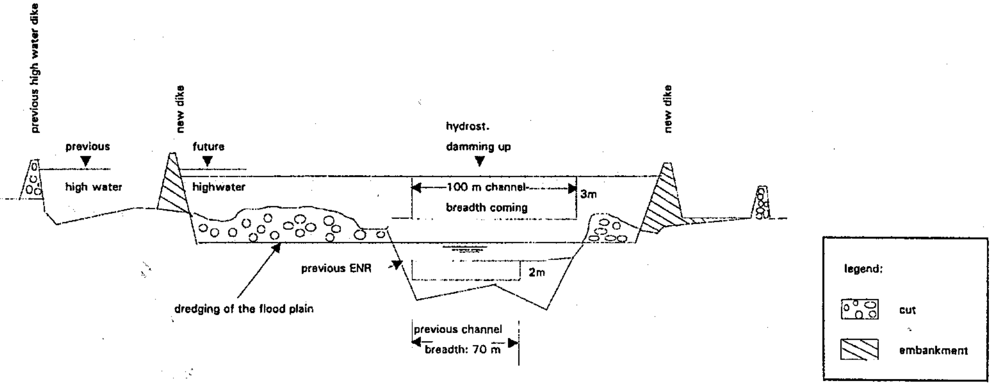

Fig. 2. Sectional drawing of the Geisling impoundment

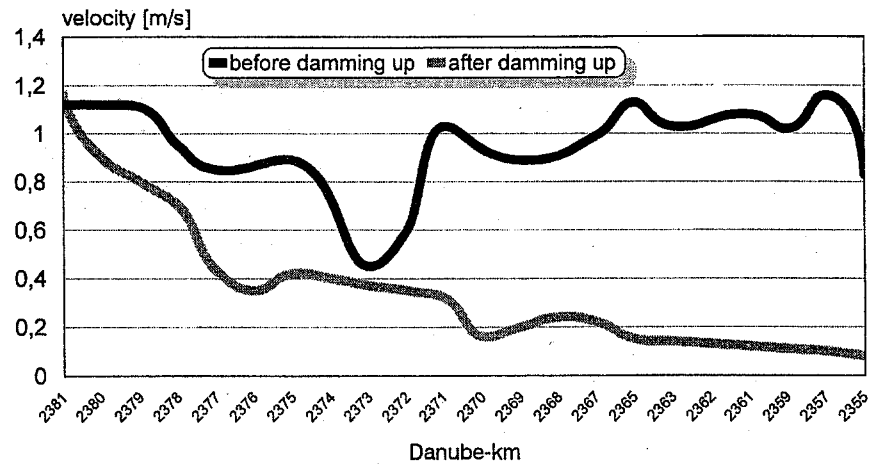

Fig. 3. The mean velocity under low-flow conditions

interrupted not only by the weir itself but also by the extreme reduction of flow velocity and by the accompanying changes in the structure of the river bed.

The macro-zoocoenosis before the damming-up

Before the construction of the impounding weir Geisling, the community was dominated – especially in the 1960's and 1970's – by wastewater-tolerating species. Water quality maps from 1950 to 1984 show this reach always in quality class III. Until 1977, during the winter months, the more upstream Danube reach near Kelheim was even rated a quality class III to IV (Bayerisches Staatsministerium für Landesentwicklung und Umweltfragen 1985). Faunistic inventories made by the Federal Institute of Hydrology (BfG) during these two decades revealed again and again temporary mass occurrences of the "sewage fungus" *Sphaerotilus natans.*

Meanwhile, the improvements in industrial and municipal wastewater treatment have also gradually improved the water quality, so that the present River Danube in the Geisling impoundment can be characterized by quality class II, i.e. "moderately polluted". Nevertheless, this remains even today the most heavily polluted reach of the River Danube in Bavaria. Moreover, here the mean transport duration of 45 min/km is nearly double compared to the other impoundments (Schmid *et al.* 1994). The long retention time of the water and its shallowness in many sections are responsible for the presently high trophic status of the river here. The ample supply with nutrients originates especially from industrial discharges in the Kelheim and Regensburg areas.

Because of the pollution in River Danube at the time before the impoundment, the prevailing macrozoobenthic community could not be characterized as a natural or near-natural potamal community. At that time generalists dominated; besides the "sewage fungus", e.g. the snail *Bithynia tentaculata* or the isopod *Asellus aquaticus* were frequently observed.

At that time, a few stenoecious species of running waters had only a small share in the species spectrum. Today, most of them continue to settle widely in the non-impounded reaches of the River Danube. Furthermore, they can be found in the head-zones of the impoundments, sometimes in high numbers. An example is the so-called "Donauisopod" *Jaera istri.* This isopod was first found in the German reach of River Danube in 1958 directly downstream of Passau (Kothé 1968). Nowadays, *Jaera istri* inhabits the entire reach of the Federal waterway in the Danube (Fig. 4). Fig. 5 shows its present occurrence in the Geisling impoundment. Larger populations of *Jaera istri* can be found in the head of the impoundment at Danube rkm 2376 and 2370, while *Jaera istri* avoids the zones where the fine substrate settles and where the flow velocity is low (Leuchs *et al.* 1991).

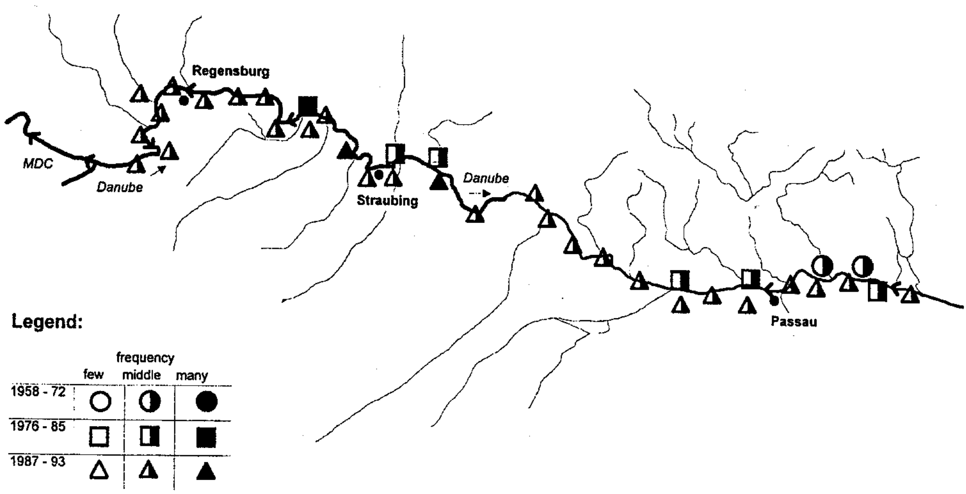

Fig. 4. Localities of *Jaera istri* in the Federal waterway on the reach from rkm 2414.5 to 2202.5

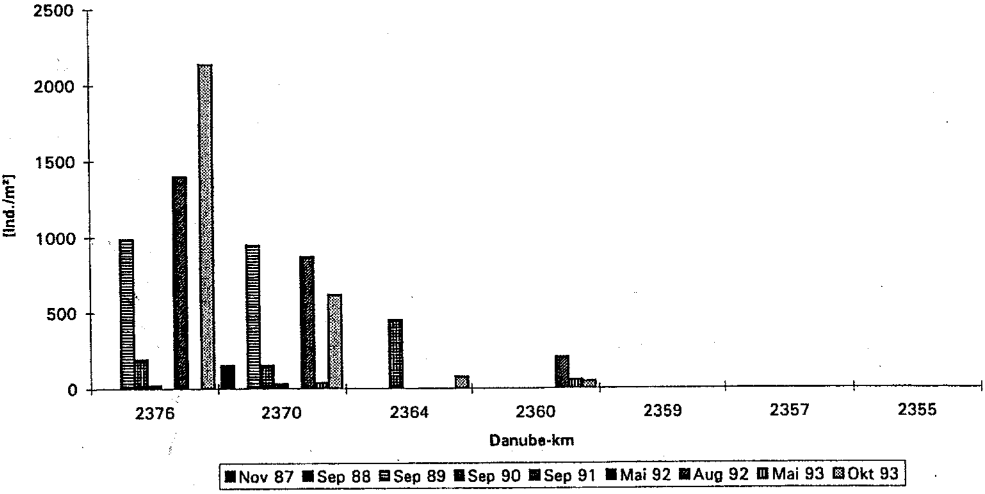

Fig. 5. Present occurrence of *Jaera istri* in the Geisling impoundment

Another example of the running water fauna in River Danube is the rheophil caddisfly *Hydropsyche*. Among the *Hydropsyche* species occurring in River Danube, *H. contubernalis* is the one with the greatest ecological tolerance and the widest distribution. It inhabits nearly all larger watercourses and has become meanwhile also in River Rhine one of the most frequent caddisflies (Schöll & Becker 1992). Fig. 6 illustrates its present occurrence in the Geisling impoundment. Here again, the drastic decrease in abundance towards the

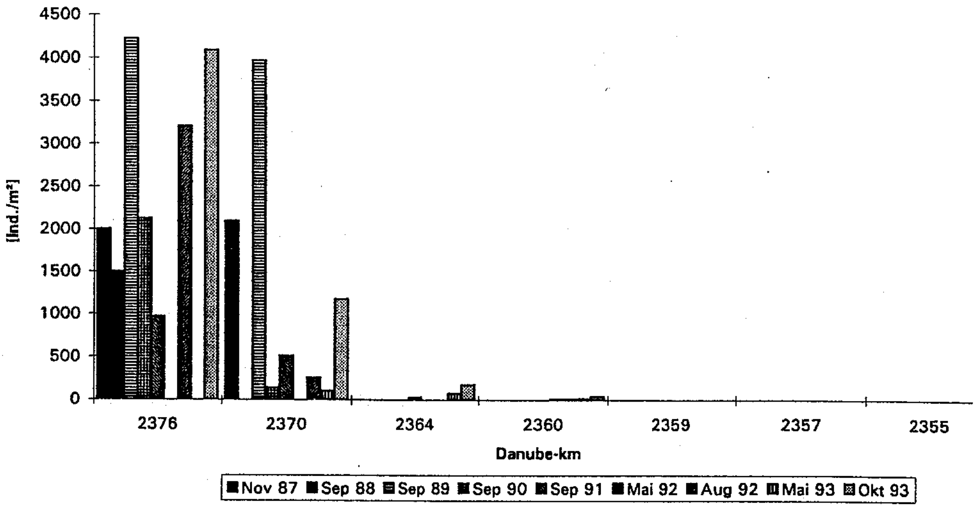

Fig. 6. Present occurrence of *Hydropsyche contubernalis* in the Geisling impoundment

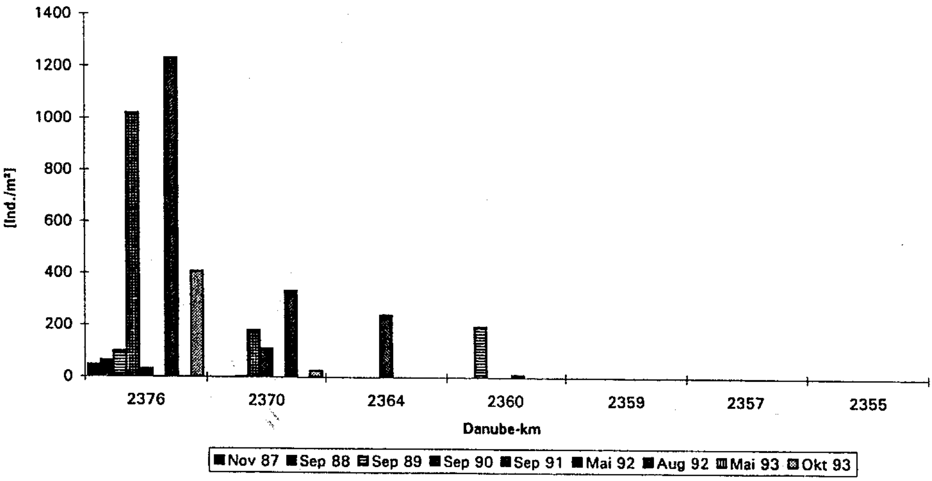

Fig. 7. Present occurrence of *Brachycentrus subnubilus* in the Geisling impoundment

impoundment weir is noticeable. Even this euryoecious species is not able to inhabite the entire impoundment because of the low flow rate.

Another caddisfly, confined to zones with sufficient flow, is *Brachycentrus subnubilus*, which is rather frequent in River Danube in comparison with other major watercourses. The second and the third pair of legs of the larvae bear long hairs which allow to filter food particles directly from the water. The strong dependence on water current can be seen also in the distribution pattern of *Brachycentrus subnubilus* in the Geisling impoundment (Fig. 7). Here again a more or less continuous decrease in population density towards the impoundment weir can be observed. Anderwald (1991) made a detailed study on the biology of this caddisfly in the head zone of the impoundment of the Altenwörth hydropower plant in Austria. He found that the velocity of flow has highly significant impact, and the sediment grain-size significant impact on the population density of *Brachycentrus subnubilus.*

Structure and dynamics of development of the macro-zoocoenosis after the damming-up

The beginning of damming-up was in October 1985, and the first filling of the impoundment was reached in January 1986. In the spring of this year, the first massive appearance of chironomid populations occurred in the area of the Geisling impoundment.

The insects formed vast swarms on the banks of River Danube and flew – depending on the weather and wind direction – into nearby settlements. Because the beginning of the mass occurrence and the first impoundment of the river coincided, a causal relation between these two events was assumed. In early 1989, the Federal Institute of Hydrology (BfG) was commissioned to study the underlying causes of this outbreak. The crucial questions were whether and to which extent the causes can be ascribed to the damming-up. Moreover, proposals on how to mitigate the "insect pest" were demanded. The studies consisted on the one hand of a quantitative inventory of the larvae in both the longitudinal and the cross profiles during spring, early summer, and late summer. On the other hand, once a month samples were caught by landing net along the banks of the Danube and its associated small water bodies, and three stationary light traps were erected.

The analysis of the catches proved an outbreak of two chironomid species: the *Chironomus-plumosus*-group and *Glyptotendipes paripes*. Outbreaks of both of these species were reported elsewhere.

An impressive description of the occurrence of great swarms of *Chironomus-plumosus* on the Baltic haff-coast in July 1935 was reported Johannes Thienemann, it can be found in Thienemann (1954): "All our life is dominated by the "Haff-midge" now. Besides the bird migration, these swarms of midges can be counted among the outstanding natural spectacle to be seen on the "Kurische Nehrung" (the land between the Kurland Lagoon and the Baltic Sea). They do not come every year. Now we had a pause of about six years, and this year the midges appear again in vast numbers. Sometimes the swarms are so dense that you have to force your horses to go through when riding or driving the coach. For hens and ducks the arrival of the midges is the beginning of a great feast, just like for the wild birds, especially the starlings. They all swallow the "Haff-midges", as do the bathers sometimes involuntarily, who then curse and grumble. One can gather bucketfuls of midges for bird food. All through the day the midges sit under leaves or on the walls of houses and stables, but at dusk they rise and begin to swarm. Then one hears a single continuous high-pitched tone in the fine summer evenings. This year the midge outbreak lasted for 9 days, beginning on 15th of July."

The "Haff midges" of the Baltic Coast and the chironomids that were observed in masses on River Danube belong probably to the same species from the group of *Chironomus-plumosus*. The adults show all species characteristics of *Chironomus-plumosus*, but in the case of larvae of both the "Haff midge" in 1935 and the midges from the Geisling impoundment in 1989 it was found that the four tubuli of the 11th segment are reduced in contrast to those of "original" *plumosus* larvae. According to the system by Ryser *et al.* (1983), these *Chironomus-plumosus* types are classified as *Chironomus muratensis/nudiventris*.

Moreover, Thienemann (1954) reports that chironomids of the genus *Glyptotendipes* also occur very frequently in the coastal lagoons of the Baltic Sea. As a whole, epidemic occurrence of *Glyptotendipes paripes* has rarely been observed in Central Europe. However, numerous reports came from the United States where *Glyptotendipes paripes* had even been controlled with insecticides in some cases (Patterson *et al.* 1966, Nielsen 1962). Wundsch (in Thienemann 1954) reports densities of *Glyptotendipes paripes* larvae of some 2,000 individuals per square metre in the river lakes of the Havel. By examining the intestinal contents he found that the larvae of this species do not feed on detritus like *Chironomus plumosus*, but on fresh, settling phytoplankton. Furthermore, these larvae prefer not too deep but nutrient-rich waters. In the river lakes of the Havel, sandy-gravely bottoms in depths between 3 and 5 m form most of the area of the water area.

The average population densities of chironomid larvae that were observed in 1989 in the longitudinal profile of River Danube are shown in Fig. 8. It becomes clear that the focus of occurrence of the larvae is not in the immediate headwater of the weir but lies some 10 km upstream thereof. The maximum with some 80,000 individuals per square metre was observed in July on the bed near the right-hand bank at rkm 2369.

The following three figures show the abundance values plotted in dependence on various parameters: They suggest that the chironomid larvae prefer the characteristic bottom substrate of River Danube consisting of sand, gravel, and fine material (Fig. 9). Moreover, the larvae

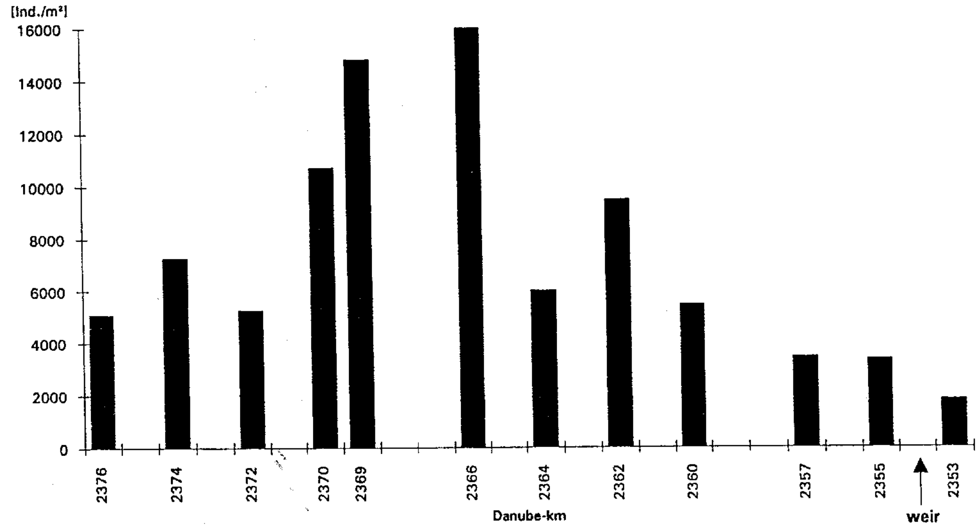

Fig. 8. Average population densities of chironomid larvae in the longitudinal profile of the Geisling impoundment (examination in April, July and September 1989)

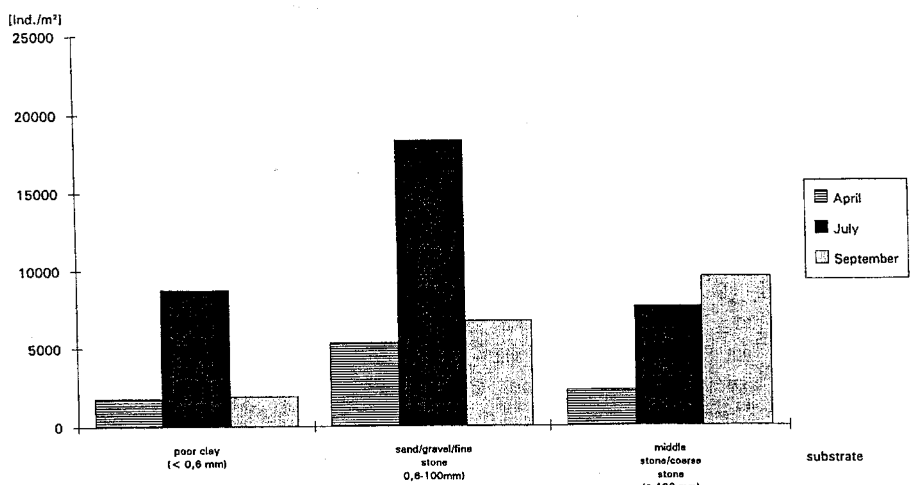

Fig. 9. Average population densities of chironomid larvae (subfamily Chironominae) in dependence on substrate (examination 1989; rkm 2354-2376)

avoid both the areas of extremely low velocities of flow with silt deposits and the zones where flow velocities are higher, in the range typical for running waters. The maximum of larvae was found in areas of middle velocities of flow between 0.2 and 0.3 m/s (Fig. 10). Fig. 11 shows certain preference for water depths between 2 and 5 m. As it was mentioned before, in the Havel river lakes *Glyptotendipes* larvae also preferred such areas, as Wundsch (in

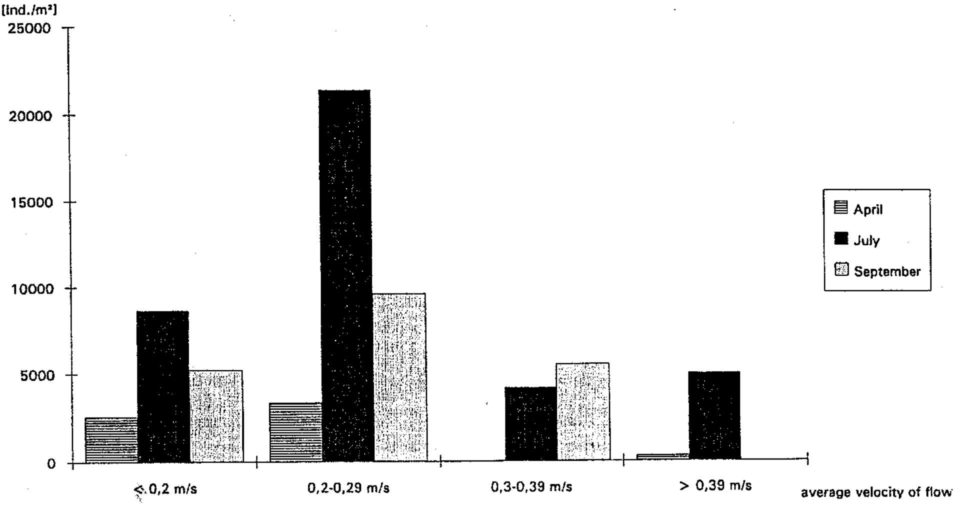

Fig. 10. Average population densities of chironomid larvae (subfamily Chironominae) in dependence on velocity of flow (examination 1989; rkm 2354-2376)

Fig. 11. Average population densities of chironomid larvae (subfamily Chironominae) in dependence on water depth (examination 1989; rkm 2354-2376)

Thienemann 1954) pointed out. The enormous widening of the cross section during the regulation of River Danube has created vast areas with that relatively shallow water depths (cf. Fig. 2).

In 1989 in the Geisling impoundment not only chironomid larvae were found in sometimes unusually high densities. For instance, the phytoplankton-feeding sphere shell *Sphaerium corneum* reached abundances with maximum densities of 120,000 individuals per square metre, while the crustacean *Corophium curvispinum* was observed in some areas in densities up to 350,000 individuals per square metre. The enormous populations of this detritus feeding sphere shell, and of the chironomids reflect the high productivity of this impoundment. This leads to the conclusion that the interaction of such factors as low velocity of flow and simultaneaous supply of great amounts of organic and inorganic substances was responsible for the population outbreak. In addition the extension of the areas with water depths between 2 and 5 m had a promoting effect on the food supplies of plankton feeders and detritus feeders.

Although the chironomid outbreak had reached its climax already in the summer of 1988, direct control actions were demanded by the people living in the area, including an association for midge pest control, which was formed and registered meanwhile. For some time it was discussed whether the *Bacillus thuringiensis israelensis* (abbreviated B.t.i.) which is regularly used on the Upper Rhine to control Culicidae, should be employed. However, because of considerably higher amounts and concentrations that would have been necessary here, the consequnces for the entire benthic fauna would have been incalculable, so that the idea of B.t.i. application was finally abandoned.

As an ecologically reasonable action for controlling the outbreak it was suggested to reduce the nutrient load and additionally to promote predators (Tittizer *et al.* 1989). As a short-term measure, the Federal Institute of Hydrology (BfG) recommended the stocking of the impoundment with Prussian carp (*Carassius carassius*) and wild carp (*Cyprinus carpio*). However, the fishery associations objected against these two non-predatory fish species. Finally, in late August 1989, 150,000 little female eels were released. Consequently, in September 1990 the average population densities of chironomid larvae had dropped to merely one tenth of the values of September 1989.

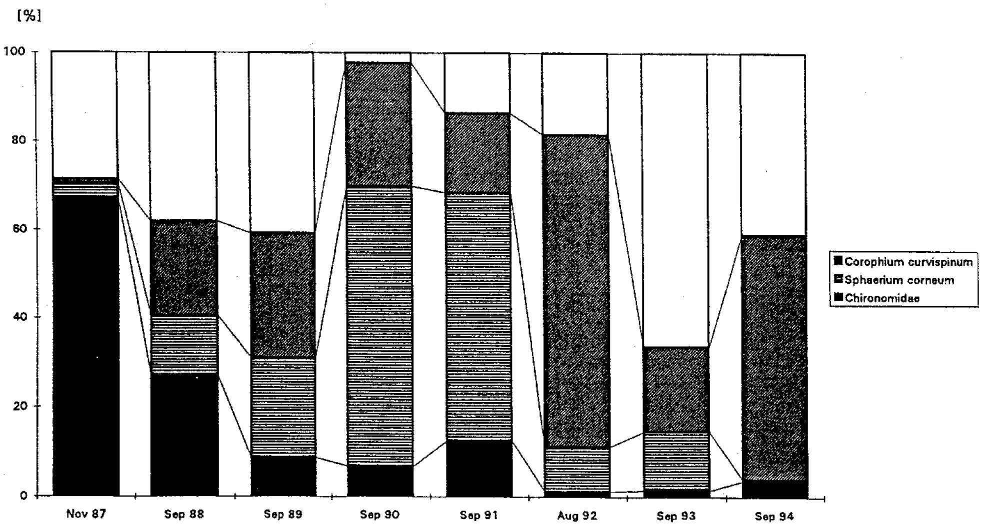

Fig. 12. Percentage of the three dominant taxa of the whole settlement on the river bottom (rkm 2355-2370)

Nearly all experts involved agreed that the stocking with fish could only be a unique action of short-term effect. That is why in late May 1992 on four embankment reaches rip-rap rock was dumped in different dimensions. This was a pilot project with the aim to promote the development of a more or less intact fish fauna and to provide shelters for the fish fry. Studies on the effectivity of the action are still going on.

Nevertheless, the productivity of the impoundment has still remained high. A look at the dominance structure on the river bottom (Fig. 12) reveals that a change in populations had taken place here. In November 1987 chironomids had been highly eudominant (67 %), then in the Septembers of 1988 and 1989 the most individual-rich elements of the benthic biocoenosis were nearly evenly distributed between the three main taxa, i.e. chironomids, the sphere shell *Sphaerium corneum* and the crustacean *Corophium curvispinum*. The communities that were observed in the late summers of the two following years, were marked by the high eudominance of the sphere shell *Sphaerium corneum*, with 63 % and 56 %, respectively. In late August 1992 finally, *Corophium curvispinum* was predominant. In the inventories made in the late summer of 1993 for the first time none of the species was eudominant. The highest dominance, with now 19 %, was again that of the crustacean *Corophium curvispinum*, whereas the share of chironomids even dropped to the class of recedents. Although in September 1994 *Corophium curvispinum* was dominant again it seems that eight years after the beginnning of the damming-up the life community on the bottom of River Danube slowly begins to stabilize with the maximum of settlement being shared by several subdominant species.

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