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Comparison of Organic Matter in Bedsediments of 2nd and 9th order streams

(Oberer Seebach near Lunz/See and Danube near Vienna)

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4 Figures and 2 Tables

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Organische Substanz in Bettsedimenten von Fließgewässern 2. und 9. Ordnung

1. Zusammenfassung

In Fließgewässerökosystemen ist die allochthone organische Substanz eine der wichtigsten Energiequellen. Diese organische Substanz ist für die Konsumenten zumeist nicht unmittelbar verwertbar. Mikrobielle Prozesse bereiten die allochthone organische Substanz für die Fließgewässerfauna auf. Die Mikrobiozönose bildet mit ihren exozellulären Polymeren den Biofilm, der sämtliche Oberflächen, organisch und anorganisch, überzieht. Die Bettsedimente des naturbelassenen Oberen Seebaches bei Lunz (ein Bach 2. Ordnung in den nördlichen Kalkalpen) und der verbauten und belasteten Donau bei Wien (Fluß 9. Ordnung) werden untersucht. Die Korngrößenverteilungen der Schottersedimente beider Fließgewässer sind ähnlich, und werden von der Korngrößenklasse > 10 mm dominiert. Ein großer Teil der organischen Substanz in den Bettsedimenten ist in Biofilmen gebunden und wird als organischer Kohlenstoff (TOC) und Stickstoff (TON) bestimmt. Die Quantität der Biofilme ist mit dem Angebot an besiedelbarer Kornoberfläche positiv korreliert. Der größte Teil von TOC und TON wurde in der Korngrößenklasse < 1 mm gefunden, obwohl diese in beiden Gewässern weniger als 10% der Sedimente stellt. Überraschenderweise sind die TOC-Gehalte (mg/kg Trockengewicht) 7 bis 9 mal und die TON-Gehalte 2 bis 4 mal höher im naturbelassenen Oberen Seebach als in der verbauten und belasteten Donau. Die Trennung der Augebiete vom Hauptgerinne durch die Regulierung und die dadurch reduzierte Retentionskapazität und erhöhtes Transportvermögen der Donau ist eine der möglichen Erklärungen. Die niederen Werte könnten aber auch auf höhere Umsatzraten der Mikrobiozönose zurückgeführt werden.

2. Abstract

Allochthonous organic matter is the main energy source in running water ecosystems. The biofilm community transforms the organic matter into a state which is available to consumers. A natural limestone gravel stream (Oberer Seebach near Lunz, 2nd order) is compared with the regulated and polluted Danube near Vienna (9th order). The sediments are very similar with a highly dominating grain size class >10 mm. Most of the organic matter (measured as TOC and TON) in sediments is biofilm and the amount of this biofilm is correlated with the amount of colonizable grain surface area. Most of TOC and TON is found in the grain size class < 1 mm, although this grain size class amounts to less than 10 % of total sediments. Surprisingly, TOC contents (mg/kg dry weight) are 7 to 9 times and TON 2 to 4 times higher in the natural Oberer Seebach than in the highly regulated and polluted Danube. An obvious explanation is the separation of the flood plains and the reduction of the retention capacity by the regulation from 1867. Higher microbial processing rates are another explanation.

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3. Introduction

The main energy source in lotic ecosystems is allochthonous organic matter (e.g. BERRIE, 1976; CUMMINS, 1974), including aerial drift (e.g. leave litter, twigs) and imports of bank run-off. In order to be available to animal consumers, organic matter has to be processed by the microbial community (mainly fungi and bacteria). The main energy pathway goes from organic matter to the microbial community and to the benthic consumers. The biggest part of the microbial community is concentrated in the so called biofilm, which is defined by MARSHALL (1984) as a biomass of micro-organisms (fungi, bacteria, protozoa, a.s.o.) and their organic excretions (exocellular polymers) attached to surfaces. In bedsediments, the grain surfaces are colonized by biofilms. Biofilm development is therefore dependent on the supply of colonizable surface, which is negatively correlated with grain diameter (LEICHTFRIED, 1985 and 1986).

Organic matter is processed on and in the bedsediments. The bedsediments are defined as channel forming sediments quantitatively dominated by epigeic faunal elements (BRETSCHKO, 1992). In many streams, also in the Oberer Seebach and Danube investigated in this paper, the zoobenthic community dwells preferentially in bedsediments (e.g. BRETSCHKO & KLEMENS, 1986; HYNES, 1974). This community exploits the organic content of the sediments, composed mainly of biofilms and their associated communities (e.g. meiofauna).

In the present study, the amount of organic matter in bedsediments of two different streams is investigated:

- ➪ 2nd order stream – Oberer Seebach, unpolluted, slightly influenced by man, no regulation
- ➪ 9th order stream – Danube near Vienna (Freudenau), heavily polluted and used by man, regulated.

Tab. 1
Characteristic abiotic data of Oberer Seebach near Lunz (Ritrodat-Lunz study area) and Danube near Vienna (stream-km 1921,3).

	Oberer Seebach Ritrodat-Lunz	Danube near Vienna
Order	2nd	9th
Width (m)	15	300
Pollution	no	high
Regulation	no	since 1867
Surface water		
velocity (m/s)	0.25-0.70	1.6-2.5
depth (m)	0.01-1.00	4-7
Mean discharge (m^3/s)	0.7	1920
Mean cond. (μS/cm)	217	290
Water temp. (°C) ann.mean	6.9	11.3
Temp.extremes (°C)	2-12	0-19
Oxygen saturation	100%	90%

4. Study sites

The unpolluted 2nd order stream Oberer Seebach is situated near Lunz, roughly 100 km south-west of Vienna, on the low lying slopes in the easternmost part of the Northern Calcareous Alps (Fig. 1). The section of stream under consideration is the Ritrodat-Lunz study area, the open air laboratory of the Biological Station Lunz, Institute of Limnology, Austrian Academy of Sciences. The karstic catchment of about 20 km² has no inhabitants and therefore the stream is unpolluted. Characteristic abiotic data are given in Tab.1.

The stretch of the 9th order stream Danube is situated near Vienna, Freudenau, stream-km 1921.3 (Fig. 1). The river is polluted, used for shipping and has been regulated since 1867. Characteristic abiotic data are shown in Tab. 1. At the sampling site, the Danube is about 300 m wide, which is about 20 times wider than Oberer Seebach. The surface water velocity is significantly higher in the Danube than in Oberer Seebach (Tab.1).

5. Methods

5.1 Sampling

OBERER SEEBACH: Sampling was done (monthly over a two year period 1988, 1989) with the freeze core technique in three hydrographically different strata: in the main channel and up- and downstream of a gravel bar inside of the Ritrodat-Lunz study area.

The freeze core technique uses liquid nitrogen (-196°C, 77°K) to achieve bedsediment cores up to a length of about 1 m (around 25 cm in diameter). The used corer is a steel tube 1.5 m long and

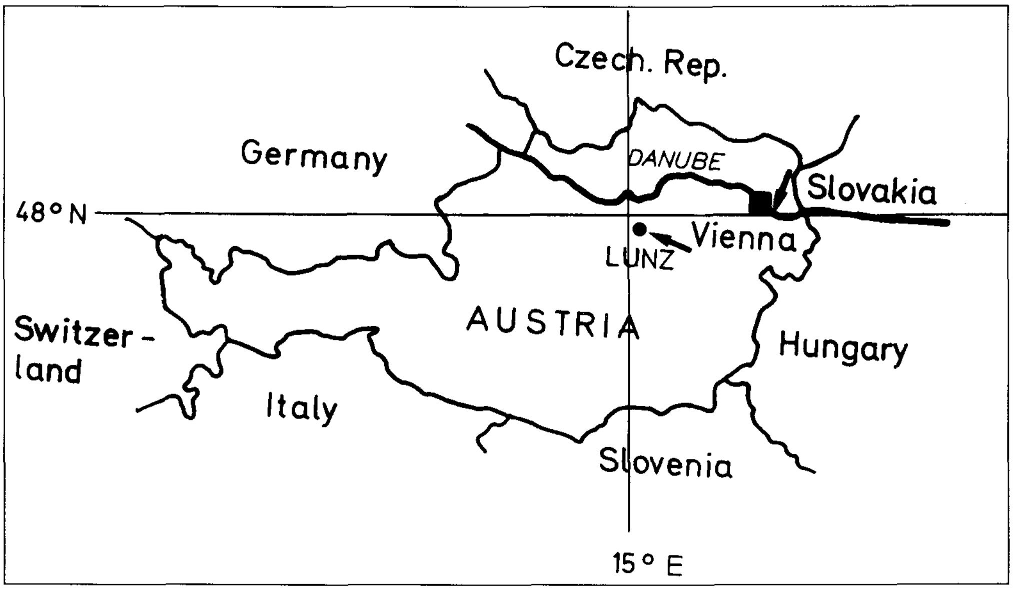


Fig. 1
Geographical situation of Oberer Seebach near Lunz (Ritrodat-Lunz study area) and of Danube near Vienna (stream-km 1921, 3).

50 mm wide. The lower end is sealed with a compact steel tip. This corer is hammered into the sediments down to the desired sampling depth. The protruding part of the corer is covered with a wooden collar to prevent heating. A large sheet metal frame is placed around the corer to protect the sampling area against water currents. About 10 litres of liquid nitrogen are necessary to achieve a 60 cm long core at water temperatures not exceeding 15°C. As soon as the sediment-water complex is frozen to the outside of the corer, it is extracted together with the core with the help of a tripod and block and tackle, with standing weights of 2-3 tons. Finally, the core is segmented into 10 cm layers, using chisel and hammer. A detailed description is given in BRETSCHKO & KLEMENS, 1986 and LEICHTFRIED, 1986. The uppermost layer of 10 cm sediment is taken for this comparison.

DANUBE: The freeze core technique described can be employed only in shallow waters up to a depth of about 1.5 m. Therefore, the deep and fast flowing Danube had to be sampled with vacuum-sampler (slurp-gun) as described by HERRIG (1975). A 5 litres sample compartment is connected to an ingestion pipe (diameter 60 mm) by a flap valve. The slurp gun is mounted horizontally in a heavy stabilizing steel frame with a long tail fin to keep the roughly 100 kg heavy apparatus parallel to the current. The sampling compartment is evacuated prior to deployment. As soon as the ingestion pipe hits the river bottom, the flap valve is opened electrically. Around 2-5 kg (DW) sediments are sucked into the sample compartment. During heaving, the slurp-gun swings into an upright position to avoid sample losses. In relation to freeze core samples, the slurp-gun overestimates slightly grain sizes <6.3 mm and underestimates slightly grain sizes >15 mm (BRETSCHKO & LEICHTFRIED, 1990). HERRIG (1975) notes that in gravel sediments the sample is collected from a circular area with an average diameter of about 25 cm and sediment depth of about 10 cm. Sampling was done near the banks and midstream across a profile (stream-km 1921.3) at four different seasons of the year 1988.

5.2 Processing

Immediately after sampling, the sediment samples were dried at 80°C in the laboratory. Granulometric analysis was done with a Retsch sieving machine after MÜLLER (1964).

For chemical analysis in 3 grain size classes (<1 mm, 1-10 mm, >10 mm), the sediments are homogenized and pulverized with a mortar mill (Retsch, Type MS). Total organic carbon (TOC) and total organic nitrogen (TON) are analyzed in a LECO CHN 600 Analyzer. TOC is taken as an indicator of the quantity of organic matter and TON is used to estimate the nutritive value of the organic matter. The discrimination between organic and inorganic carbon and nitrogen is done according to BRETSCHKO & LEICHTFRIED, 1987. A simple acidification of the sample transforms inorganic carbon into gaseous CO_2, which is easy to extract quantitatively, e.g. with CO_2 free air.

In comparison to carbon, no simple chemical methods are available to differentiate between organic and inorganic nitrogen. In gravel sediments, inorganic matter by far exceeds organic matter. Consequently, the behaviour of organic nitrogen may be completely obscured by inorganic nitrogen, even when the concentrations of the latter are very low. Keeping certain assumptions in mind, an approximate discrimination between the two forms of compounds is possible:

- Only organic matter, free or attached to the surface of sediment grains, is accessible to the biocoenosis. Organic matter enclosed in sediment grains is not accessible and can be treated as if inorganic.
- Larger stones are the source of smaller sediment grains. The innermost part of larger stones is therefore identical to the innermost part of all other grain sizes.
- Dissolved inorganic N-salts are neglected because of their low concentrations relative to particulate nitrogen.

The surface layer of stones with a diameter of at least 20 to 25 cm, is carefully chipped away and the centerpart is analysed. TOC and TN found in the centerpart is taken either as inorganic or as inaccessible organic matter for the biocoenoses. The organic carbon content of the centerpart of large stones is most probably of fossil origin. Centerpart TOC and TN is simply deducted, according to the weight of the analysed sediment sample. As long as the inorganic matter of the sediment exceeds the organic matter by some orders of magnitude, the actual weight of the organic matter can be neglected without introducing any noticeable error. Since the bulk of organic matter is attached to the surface of the sediment grains and the surface area increases tremendously with decreasing grain size, the relative amount of inorganic or inaccessible OC and N decreases rapidly with decreasing grain size.

6. Results

Coarse gravel is predominant at both study sites and in all sampled reaches of the Oberer Seebach and Danube. The ecologically important grain size class, <1 mm in diameter, comprises less than 10% (Fig. 2) at both sites.

Analytical results can be expressed in two ways:

- CONCENTRATION: the measured parameter in milligrams per gram dry weight of the grain size class analysed.
- CONTENT: the concentrations in each grain size class of the analysed parameter times the relative amounts of the relevant grain size class in 1 kg of sampled sediment.

In the Oberer Seebach, as well as in the Danube, by far the highest TOC and TON concentrations are found in the grain size class <1 mm in diameter. With increasing grain sizes, the concentrations decrease dramatically, similar to the relationship between grain surface and grain diameter (Fig. 3, HARGRAVE, 1972; LEICHTFRIED, 1985). These findings accord well with the dominance of biofilms in gravel stream ecosystems (KASIMIR, 1990; MARSHALL, 1984). Consequently, the distribution of organic matter is positively correlated with the distribution of colonizable surface areas. Organic matter contents closely follow the distribution of the grain size class <1 mm, because grain surface areas increase potentially ($y = 362,15.x^{-0.658}$, LEICHTFRIED, 1985) with decreasing grain diameter (Fig. 4). These relationships readily explain the surprising fact that the grain size class <1 mm, which comprises less than 10%, but dominates the distributions of organic matter, is the most important parameter (Fig. 2 and 4), ecologically. Larger grain size classes, comprising more than 90% of the sediments, have nearly no influence on the distribution of organic matter (Fig. 2, 3 and 4).

Larger sediment grains, like gravel and cobbles, form the interstitial spaces and with it the conductivity for water. The latter is a further prerequisite for the sediment biocoenosis. Larger amounts of small grain sizes start to fill the interstitial spaces completely, reducing the flow through of water drastically. The negative effects of a low water flow through counterbalances the availability of colonizable surface area (BRETSCHKO, 1994).

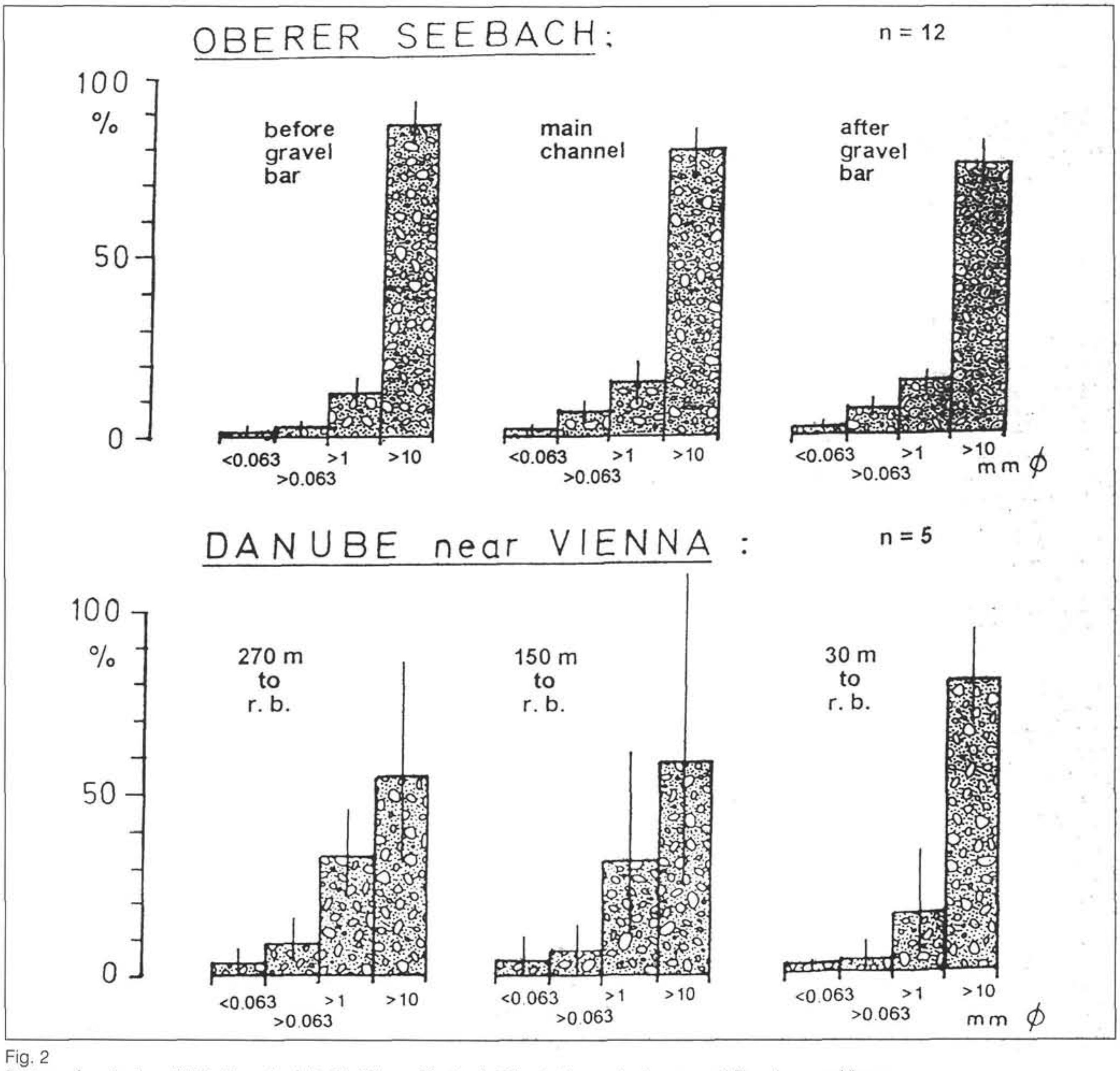


Fig. 2
Pattern of grain size distributions (weight %): Oberer Seebach, Ritrodat-Lunz study area and Danube near Vienna.

It is very surprising that TOC and TON concentrations and contents are significantly higher in the unpolluted and unregulated Oberer Seebach than in the polluted and regulated Danube (Fig. 3 and 4). A comparison of the total contents of TOC and TON in bedsediments of the Oberer Seebach and Danube showed that organic carbon is 7 to 9 times higher and organic nitrogen 2 to 4 times higher in the unpolluted and unregulated Oberer Seebach than in the polluted and regulated Danube (Tab. 2, top).

	CONTENTS	
Bedsediments	TOC (mg/kg DW)	TON (mg/kg DW)
TEMPERATE ZONE		
UNPOLLUTED		
Oberer Seebach	807-2075	31-99
POLLUTED		
Danube	115-225	17-28
RATIO	7-9	2-4
TROPICAL ZONE		
UNPOLLUTED		
Awu River I	483	123
POLLUTED		
Awu River II	274	20
RATIO	2	6

Tab. 2
Comparison of total TOC and TON contents in temperate Oberer Seebach (Ritrodat-Lunz study area), Danube near Vienna and tropical Awu River (Java) at polluted (I) and unpolluted (II) sites.

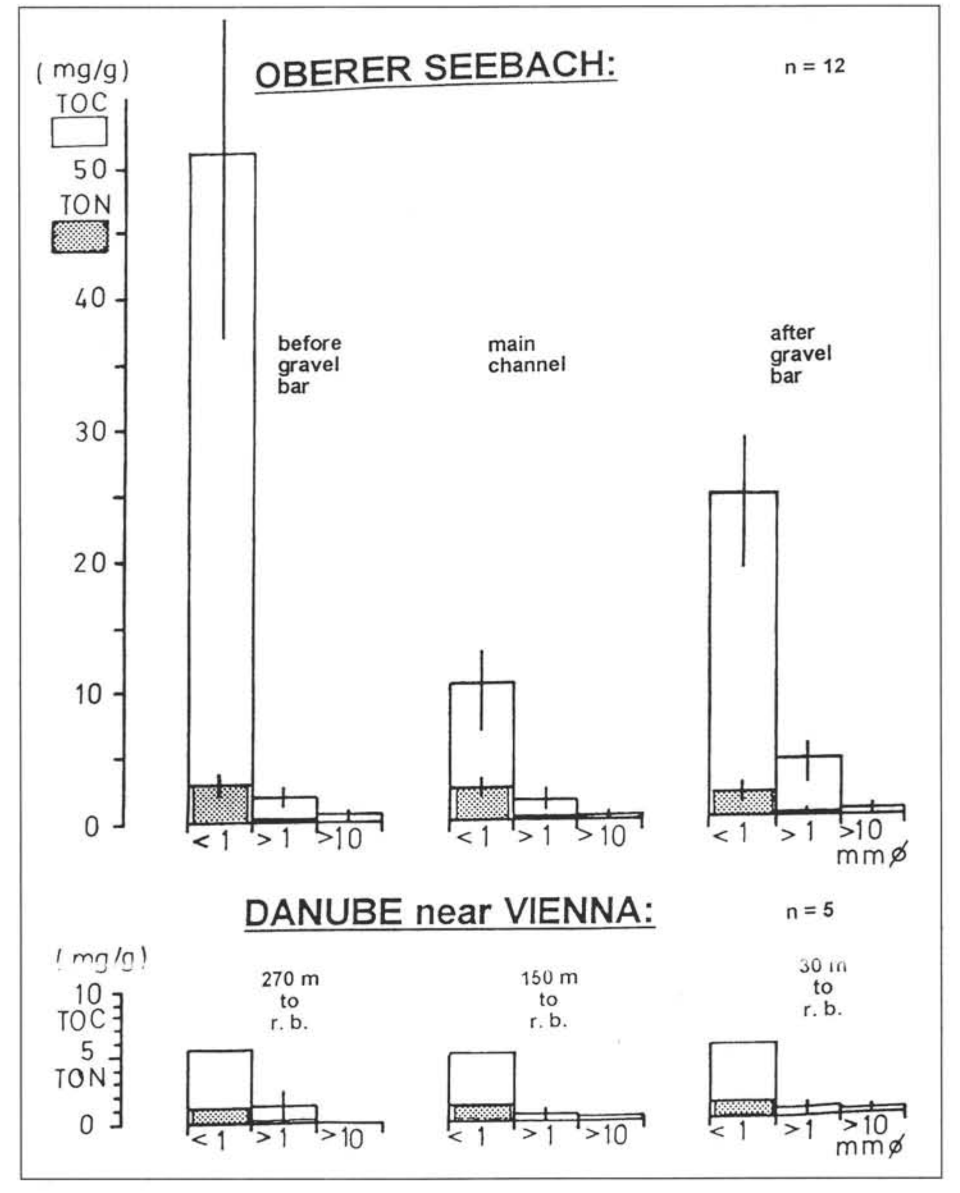


Fig. 3
Pattern of TOC and TON concentrations (mg/g) in unpolluted Oberer Seebach, Ritrodat-Lunz study area and polluted Danube near Vienna.

So far, the available data are not sufficient for a satisfying explanation, but there are two possibilities to be discussed:

- Imports and retention of organic matter are reduced, because of the regulation and the separation of the flood plains.
- Measurements of organic carbon and organic nitrogen reflect the standing crop of organic matter. In case of high processing rates, the standing crop can be low in spite of large imports.

7. Discussion

Investigations of organic matter in gravel bedsediments of rivers are in its infancy. Ongoing studies of the bedsediments of the tropical Awu river in Java, Indonesia, reveal a situation which is surprisingly similar to the one found in the temperate Oberer Seebach and Danube: the headwaters of Awu river drain a virgin forest and are completely unpolluted and unregulated. Further downstream, the river is constrained by a narrow gorge and is highly polluted. The sources of the pollution are a few villages and intensive agriculture using fertilizers and pesticides (LEICHTFRIED & KRISTYANTO, 1995). Organic matter contents are much higher in the headwaters than in the polluted downstream parts, surprisingly similar with the comparison of Oberer Seebach and Danube (Tab. 2).

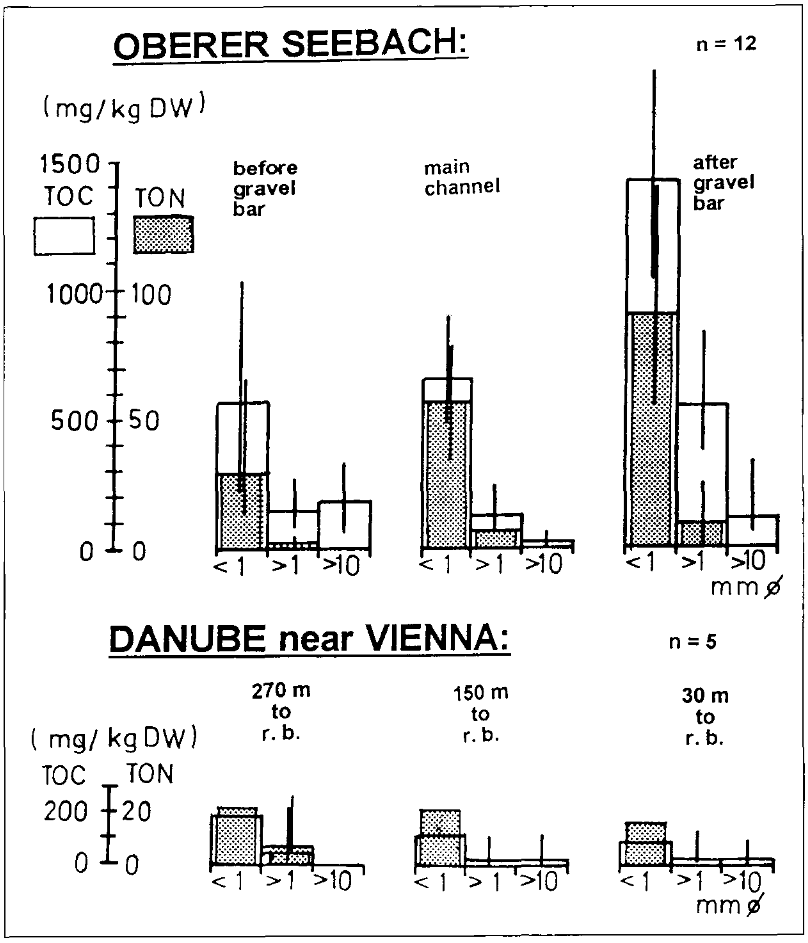
The organic matter contents are balanced by three very important river processes, namely ***decomposition, retention and imports:***

- ***Decomposition*** is not measured, but it could be higher in polluted streams, because microbial metabolism depends on the availability of nitrates and phosphates. Both concentrations are higher in polluted streams. It is not possible to correlate standing crop measurements of organic matter with organic matter ***imports***, as long as nothing is known about the rate of actual microbial activities. For the time beeing, only the possibilities are to be discussed.
- Organic matter ***imports*** from adjacent terrestrial vegetation are most probably reduced in constrained or regulated rivers. The ***imports*** from upstream stretches via particle drift are not influenced. But most likely, the total above surface ***imports*** are reduced. The knowledge about the subsurface ***imports*** is still to small to be taken into consideration here (BRETSCHKO & MOSER, 1993; FIEBIG & LOCK, 1991; FIEBIG e.a., 1990). In heavily regulated rivers, as in the case of the Austrian Danube, dams along the banks interrupt the subsurface inflow of organic matter, too.
- In constrained river sections, as well as in artificially cannalized rivers, ***retention*** capacities for organic matter are greatly reduced, because of larger current velocities, the paucity of topographic structures and the relatively small size of stream areas that are only periodically flooded (BILBY 1981; BRETSCHKO, 1990).

The obvious tendency of both processes is the reduction of organic matter contents. This would readily explain the findings presented here. But the discussion has not taken into account organic matter imports in the form of sewage and other antropogenic wastes. These sources are probably higher than the natural organic matter sources, in the Danube and in Awu Rivers. The lower standing crop of organic matter in these river sections could therefore be the effect of the third process:

- ***Decomposition*** is mainly the result of microbial metabolism. The metabolic rates of microbes are not only dependent on the availability of organic substrata, but also on the

Fig. 4
Pattern of TOC and TON contents (mg/kg dry sed.sample) in unpolluted Oberer Seebach, Ritrodat-Lunz study area and polluted Danube near Vienna.



availability of inorganic nutrients like nitrates and phosphates. Sewage contains not only organic matter but also these inorganic nutrients. Without human interference, nutrient concentrations are very low in rivers and often limiting parameters. It is therefore to be expected, that the metabolic rates of the microbial biocoenosis are enhanced in polluted rivers, as long as no poisoning effects occur. First results confirm this suggestion (TRAUTERMANN pers. comm.).

The low standing crop of organic matter in the bedsediments of constrained and polluted river sections is probably the result of lower organic imports and higher microbial metabolic rates than in natural rivers.

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