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The effects of recreated instream and ecotone structures on the fish fauna of an epipotamal river

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Key words: river restoration, instream structures, land/water ecotone, fish fauna

Abstract

Investigations of fifteen sections of seven Austrian epipotamal (barbel region) streams between 1981 and 1984 demonstrate the impact of instream river bed structures on fish communities. Reduced spatial heterogeneity due to river straightening resulted in decreasing species number, diversity, stock density and biomass. Reincreased variability of the river bed in the frame of a subsequent restructuring project improved all community-specific values significantly within a 3-year investigation period (1988–1990). Besides the regained habitat variability in form of riffle pool sequences and other instream structures, the newly created riparian zones obviously provided important niches, e.g. as refuge areas during flooding and as nursery grounds for fish fry. The positive effects of the recreated land/water ecotone are discussed with respect to river restoration projects.

Introduction

Structural variety of the habitat is one of the most important conditions for the existence and development of well-balanced aquatic communities (Lelek and Lusk, 1965; Hynes, 1968; Sheldon, 1986; Karr and Schlosser, 1978; Dudley and Karr, 1979; Tarplee *et al.*, 1979; Ward and Stanford, 1979; Schoof, 1980; Meffe and Sheldon, 1988).

After the 2nd World War, Western and Central Europe experienced a boom in the straightening of rivers in many cases with disastrous consequences for the fish fauna. Today more than half of the endemic fish species have either become extinct or are seriously endangered mainly due to straightening and/or damming of rivers. In the 1980s various studies on the ecological impact of reduced river bed structure proved the negative effects of monotonous aquatic environments on fish stocks in Austria (Jungwirth, 1981, 1984). Those studies finally entailed plans for the restructuring of a monotonously straightened section of one of the rivers investigated, the River Melk in Lower Austria. This 5th-order stream with a catchment area of 285 km^2 and a mean annual discharge of 3.5 $m^3\ s^{-1}$ showed an absolutely monotonous straightening (Fig. 1), the river bottom being continuously paved. The low flow channel was 10 m wide and about 0.3 to 0.6 m deep along the whole length, its shoreline formed by rip rap.

The most important restructuring measures comprised enlargements of the cross section, structuring of the bottom and shorelines by partial removal of the pavement and rip rap as well as the construction of groynes and bedfalls. Legal restrictions confined the restructuring measures to the low flow channel and its shoreline, but omitted the surrounding landscape (Fig. 2). This

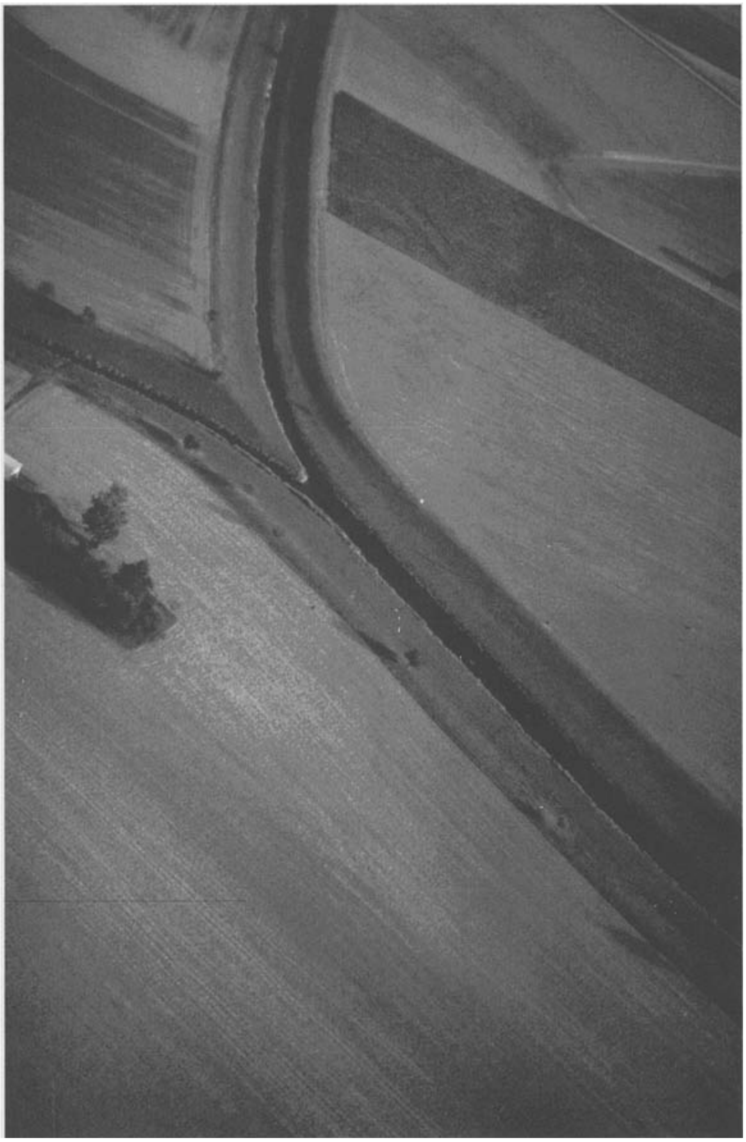


Fig. 1. The straightened Melk River.

limitation explains why the pilot study was designated a 'restructuring' rather than a revitalization project. During the planning stage the correlation between the variance of the maximum depths (as a measure for the structural variety of the river bed, see Fig. 3) and the number of fish species (Jungwirth, 1991) was used to control the project and to forecast the possible development of the fish stock. In addition, a special examination program was elaborated to cover a period of three years after completion of the restructuring measures. It involved investigations of the effects of the various constructions on river morphometry, the fish stock and the benthic community (Jungwirth, 1991). The present paper presents the results of these studies with respect to the instream structures relevant to fish ecology and deals with the newly created land/water ecotone, which, apart from other effects, serves as a nursery niche for fish fry and as a refuge area during floods.

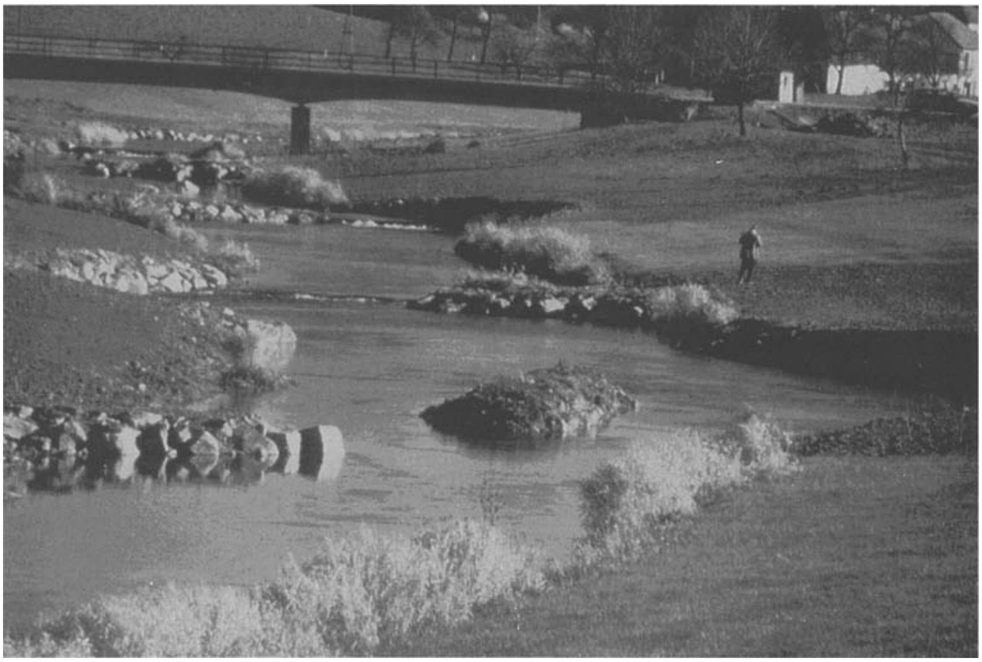


Fig. 2. After restructuring in autumn 1988 the Melk River shows a strongly increased spatial variety of the river bed (compare Fig. 3).

Methods

Fifteen sections of seven Austrian epipotamal streams were investigated with regard to morphometry of the river bed, current and substrate pattern. The widths of at least 25 successive cross sections (distance 5 m) per test site were measured; water depths, flow velocities and substrate types within each cross section were determined at 2 m intervals. Among other parameters, river bed structure was described by the variance of the maximum depths (VMD) and correlated with the number (NFS) and the diversity (according to Brillouin; Pielou, 1975) of fish species (FSD); the latter were calculated from stock estimates by electro-fishing following the De Lury method (Bagenal, 1978). In order to document the development of morphometric and hydraulic conditions as well as of fish community parameters after restructuring, further investigations were conducted using the above-mentioned methods. Finally, the fry and young of the year fishes in shallow littoral zones as well as the adult fishes within the riparian vegetation during floods were sampled by special electric gear (for details see Jungwirth, 1991) following the catch-per-unit-effort method. During the three-year investigation period a still straightened section of the river was sampled as a reference site.

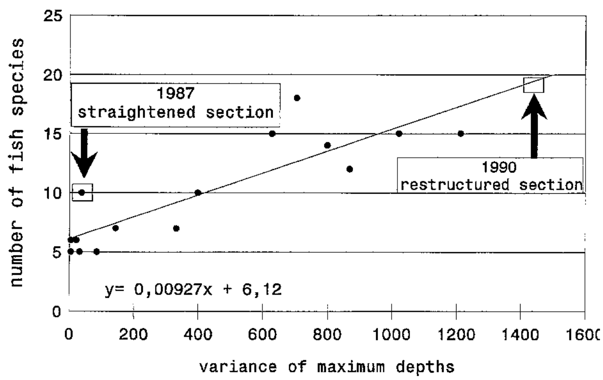


Fig. 3. Variance of maximum depths (VMD) versus number of fish species (NFS) of 15 test sites in 7 Austrian epipotamal streams ($r = 0.861$) investigated between 1981 and 1984. Plotted squares: The formerly straightened and restructured Melk river (compare Fig. 4 and text).

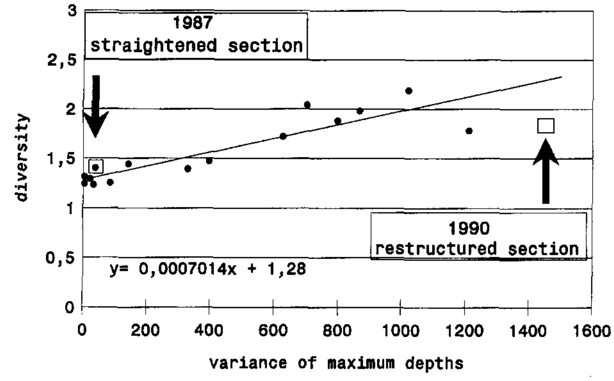


Fig. 4. Variance of maximum depths (VMD) versus fish species diversity (FSD) of 15 test sites in 7 Austrian epipotamal streams ($r = 0.897$) investigated between 1981 and 1984. Plotted squares: The formerly straightened and restructured Melk river (compare Fig. 3 and text).

Results

Instream structures and fish stock

The comparison of 15 straightened and unstraightened epipotamal stream sections of different rivers with great differences in spatial heterogeneity demonstrated clearly the importance of river bed structure for the fish community (Figs 3 and 4). Natural instream structures such as riffles and pools, gravel banks, woody debris etc., were reflected by high VMD values, which in the models corresponded to high numbers and diversities

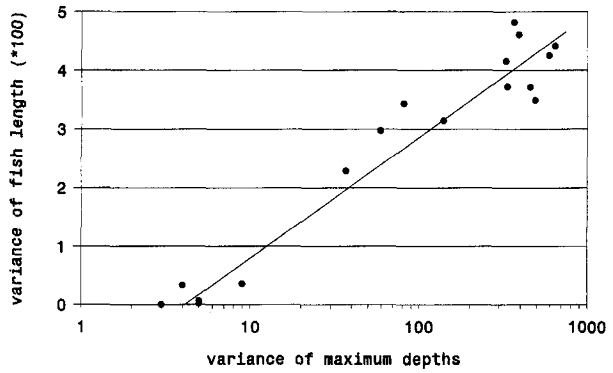


Fig. 5. Variance of maximum depths (VMD) versus variance of fish lengths (brown trout): correlation of 16 headwater test sites of river Ferschnitz, Lower Austria ($p < 0.001$, $r = 0.97$; compare text).

of fish species. In many headwaters of the upper rhithral zone (trout region) the fish community comprised only a few species. Occasionally these waters were inhabited exclusively by brown trout, Salmo trutta. In the latter case the VMD was significantly correlated with the variance of the observed fish lengths, assuming that variable instream structures offer favorable niches for various age classes. Reduced spatial heterogeneity, on the other hand, led to the dominance of only one or few age classes characterized by a low variance of fish lengths (Fig. 5).

The effects of recreated instream structures

Physical effects

Restructuring of a 1.5 km stretch of the Melk River in 1988 resulted in significant changes of the hydrologic and morphometric conditions. The straightened reach only displayed depths between 0.2 and 0.6 m (Fig. 6), whereas depths along the restructured section ranged from <0.1 to 2 m (Fig. 7). The mean current speed of the straightened section showed an 80% dominance of the category 0.4–0.5 m s^{-1}, whereas the restructured section regained a wide range of flow velocities (Figs 6 and 7). The heterogeneous pattern of flow velocities was reflected by more differentiated substrate types as well: both the straightened and the restructured river section were dominated by coarse sediments (Fig. 8), but the latter also exhibited the categories sand and mud.

Fish community

Quantitative sampling of the fish stock following the De Lury method showed that the fish fauna reacted relatively rapidly to the changed instream environment. Two electro-fishings within the straightened section in 1980 and 1987 revealed the same 10 fish species (Table 1). One year after restructuring, NFS already increased to 16. By 1990, 19 species occurred, while NFS in the still straightened reference site remained restricted to 10. Density and biomass of the total fish stock also showed an obvious recovery. Both parameters tripled during the period of investigation

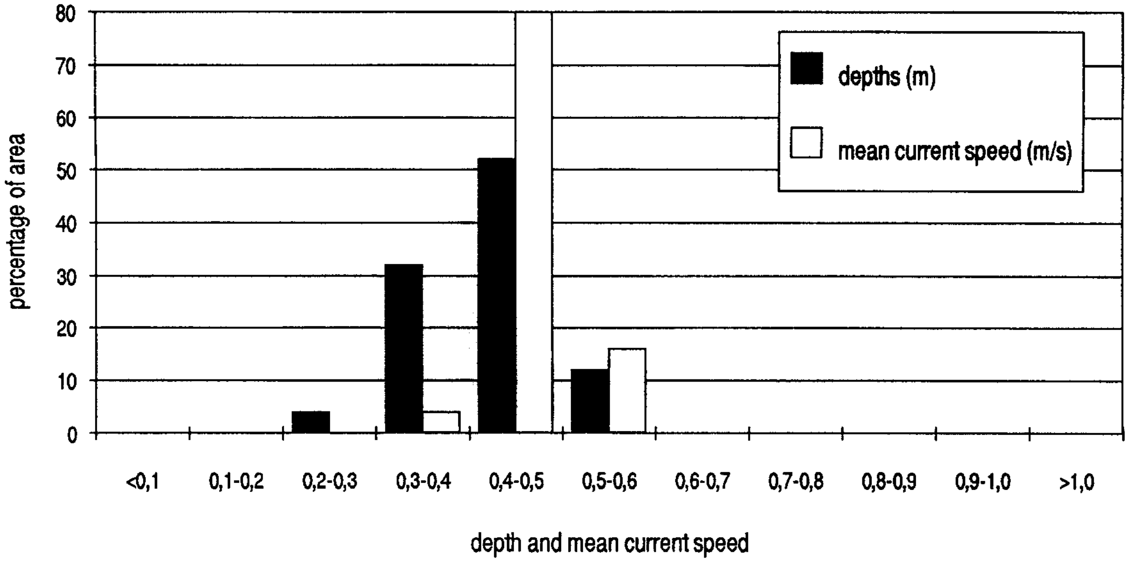


Fig. 6. Depths and mean current speeds in the straightened reference section of Melk River indicate a monotonous environment (compare Fig. 7).

(Fig. 9). At the same time the abundance of the individual species changed considerably. For instance the 66.2% dominance of *Leuciscus cephalus* and the 27.1% dominance of *Gobio gobio* in the straightened section declined by about 50% in the restructured section. This fact, together with the increased NFS demonstrated a more balanced proportion between the individual species; this was also reflected in the diversity index, which increased from an initial 1.40 to 1.87. With re-

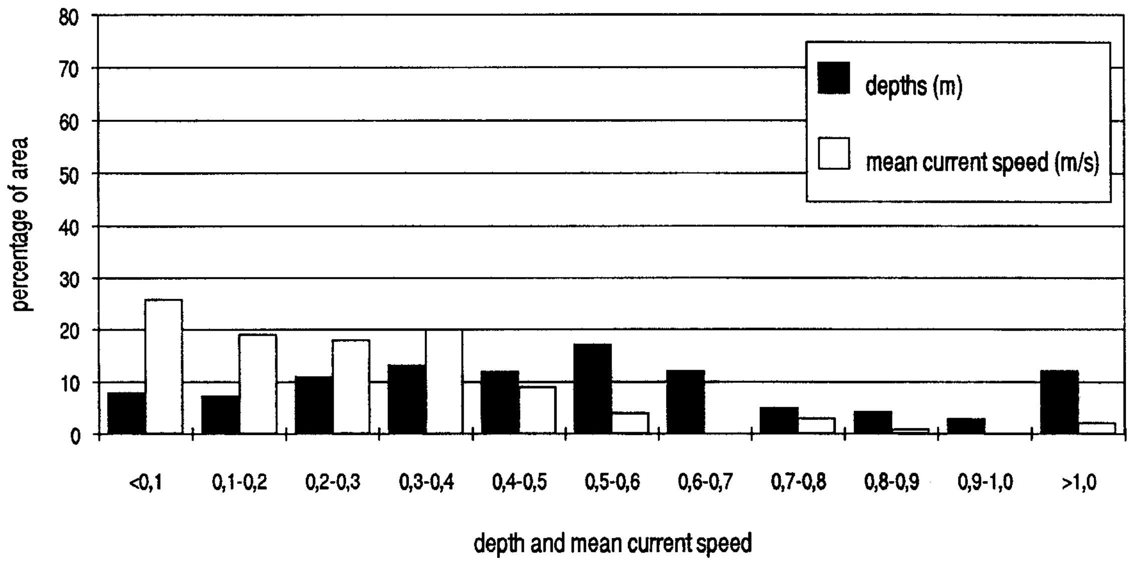


Fig. 7. Depths and mean current speeds in the restructured section of Melk River illustrate a strongly increased range of both parameters (compare Fig. 6).

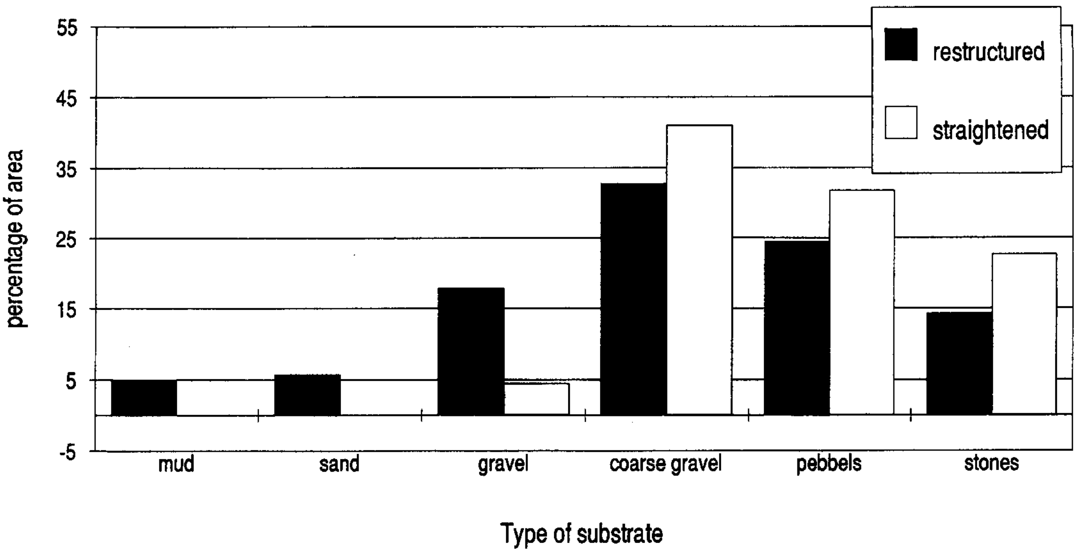


Fig. 8. Coarse substrates dominate in the straightened and in the restructured Melk River, whereas mud and sand are entirely restricted to the restructured sites (for choriotope classification see Moog, 1991).

spect to the VMD/NFS correlation, the restructured river section developed according to the model until 1990 (Fig. 3). The FSD index, however, remained below the value corresponding to the VMD (Fig. 4).

Table 1. Fish species of Melk river sampled in straightened and restructured sections between 1980 and 1990.

Fish species	1980 straightened	1987 straightened	1988 straightened	1988 restructured	1990 straightened	1990 restructured
Salmo trutta forma fario, L.	*	*	*	*	*	*
Salvelinus fontinalis, M.				*		
Hucho hucho, L.			*			
Oncorhynchus mykiss, W.	*	*	*	*	*	*
Thymallus thymallus, L.	*	*	*	*	*	*
Leuciscus cephalus, L.	*	*	*	*	*	*
Barbus barbus, L.	*	*	*	*	*	*
Rhodeus sericeus amarus, B.						*
Phoxinus phoxinus, L.	*	*	*	*	*	*
Gobio gobio, L.	*	*	*	*	*	*
Leuciscus leuciscus, L.	*	*	*	*	*	*
Cyprinus carpio, L.						*
Chondrostoma nasus, L.				*		*
Rutilus rutilus, L.				*		*
Scardinius erythrophtalmus, L.					*	
Alburnoides bipunctatus, B.				*		*
Noemachilus barbatulus, L.	*	*	*	*	*	*
Cobitis taenia, L.				*		*
Cottus gobius, L.	*	*	*	*	*	*
Carassius carassius, L.						*
Number of species	10	10	11	16	10	19

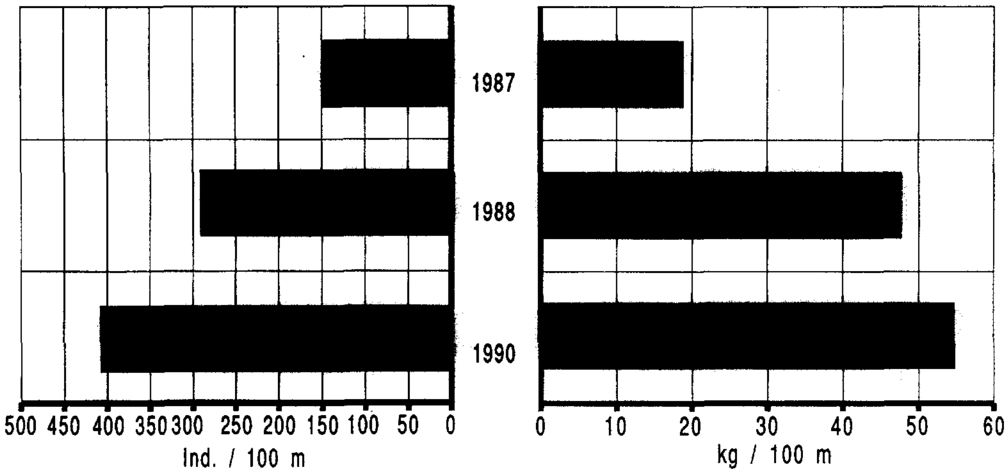


Fig. 9. Density and biomass of the total fish stock (1987: straightened section before restructuring; 1988 and 1990: after restructuring).

Recreated land/water ecotone and fish stock

Physical effects

As mentioned above, legal limitations confined the restructuring measures of the Melk River to the low flow channel and its adjacent riparian zones. Ecotone-relevant structures therefore only comprised the shoreline and their adjoining vegetation but not the surrounding landscape.

The formation and dynamic development of natural littoral structures characterizing a complex land/water interface presuppose variable width conditions of the river bed, which can be described by the variance of the widths (VW) of successive cross sections. The straightened Melk river section showed a VW of 5310 at a mean width of 867 cm, while a still unmodified reference site had a more than five-fold greater VW at a mean width of 1146 cm (Table 2). After restructuring, the mean width increased to 1226 cm and the VW even exceeded that of the nearly pristine reference site by about 50%. The same held true 2 years later, indicating that the restructuring measures maintained the high variability of the environment.

Table 2. Mean widths and variances of widths of different test sites of the Melk river (distance of cross sections 5 m)

	Mean width (cm)	Variance of widths
Almost unmodified section 1981	1,146	29,700
Straightened section 1981	867	5,310
Restructured section 1988	1,226	47,600
Restructured section 1990	1,220	44,906

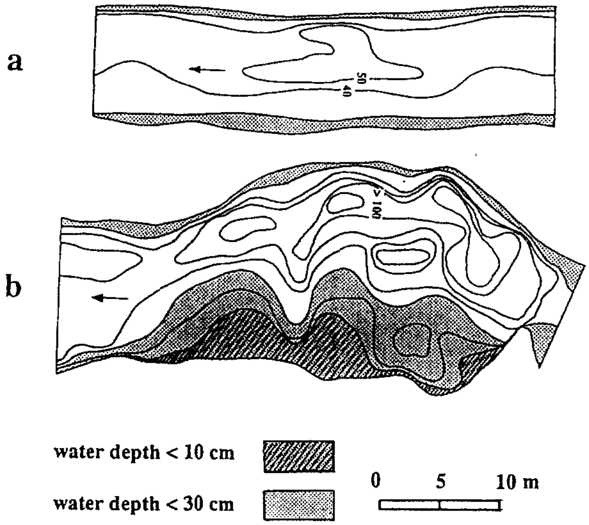


Fig. 10. Distribution of depths (a: still straightened and uniform reference site; b: restructured subsection.Compare Tab. 3).

Table 3. Percentages of dominating substrate types and area of shallow water (< 30 cm depth) in % of total surface area of a still straightened versus a restructured Melk River section (compare Fig. 10)

	Shallow water area in % of tot. surface	% mud	% sand material	% coarse
Straight. sect.	14.5	0	36	64
Restruct. sect.	37.4	50	18	32

Due to channelization the straightened reference site lacked variable shallow areas, depths < 30 cm only representing about 15% of the total surface area (Fig. 10). On the other hand, a characteristic subsection of the restructured Melk River showed a comparatively large shallow water area of about 37% (< 30 cm depth). Within this zone, areas shallower than 10 cm, with very low currents and/or backwaters constituted about 30%, their bottom being mainly formed by sandy or muddy material (Table 3).

The smooth slope of the slip-off banks and their littoral zones enabled the development of a complex land/water boundary. Typical pioneer vegetation was found mainly at the transition from the low flow to the mean flow channel, where inundation and/or erosion or sedimentation occurred several times a year. On the other hand, higher bushes and trees of the adjacent vegetation belt, such as willow, *Salix sp.* and alder, *Alnus sp.*, were restricted to the upper parts of the cross section (above the mean flow level) inundated only during floods (Fig. 11).

Fish community

The fish community of the Melk River showed an overlap of rhithral and epipotamal elements (e.g.

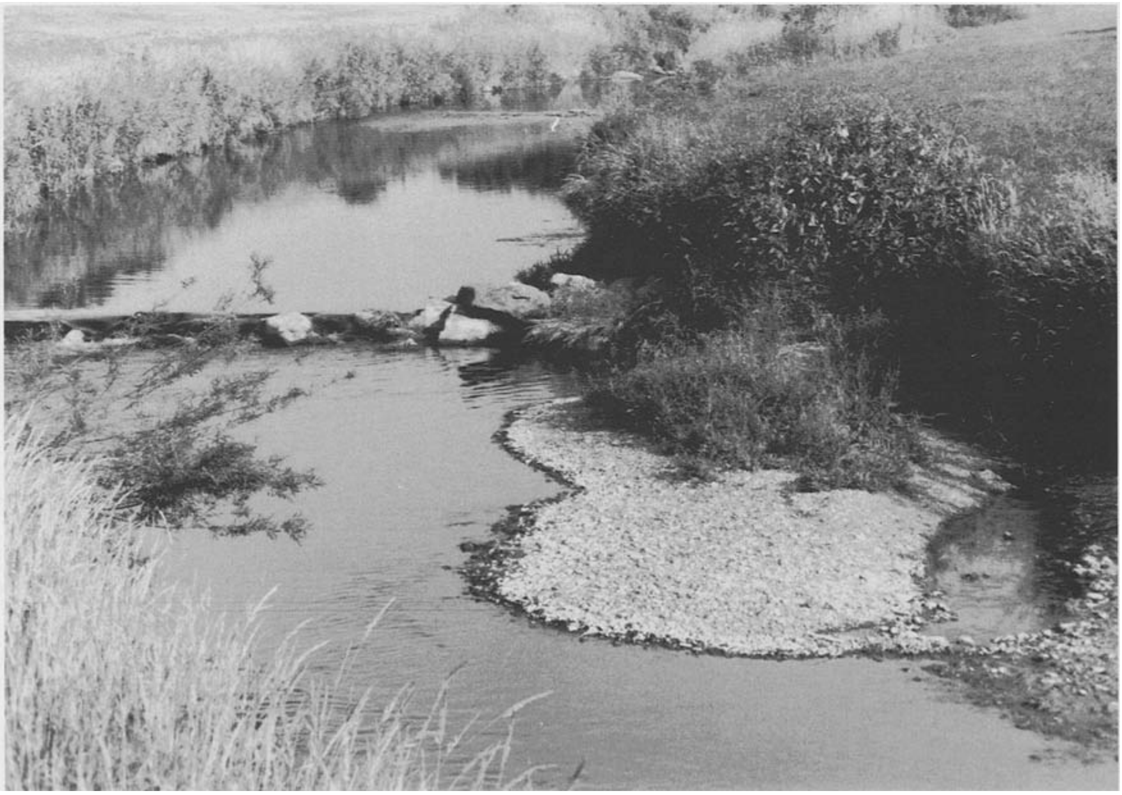
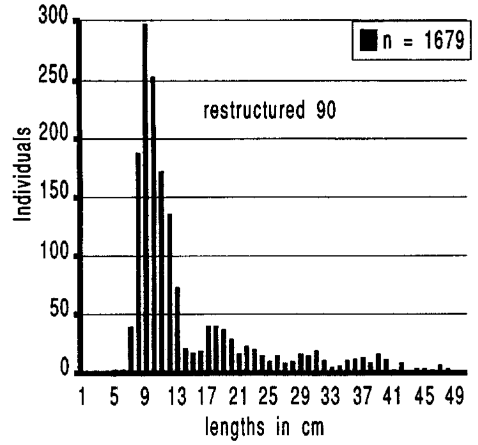


Fig. 11. Restructured Melk River: A gravel bank develops within a widened cross section downstream of a groyne and offers shallow water areas with smooth and inverse currents.The adjacent pioneer vegetation is restricted to the upper parts of the low flow channel; higher bushes and trees grow above the mean flow level.



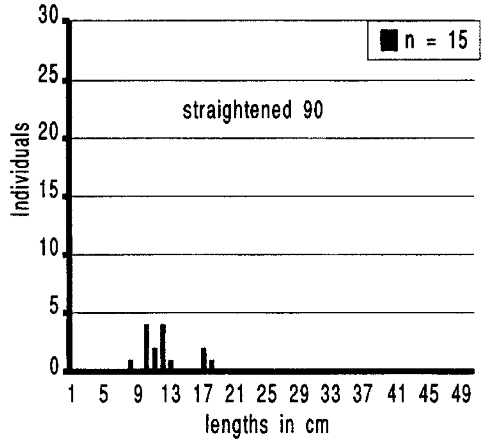


Fig. 12. Length/frequency diagram of barbel within the still straightened and restructured Melk River sections in 1990.

trout; bullhead, *Cottus gobio*; grayling, *Thymallus thymallus;* barbel *Barbus barbus;* nose, *Chondrostoma nasus;* chub, *Leuciscus cephalus*; compare Table 1). Successful reproduction and development presuppose a wide range of species-specific spawning places and nursery grounds for fry and juveniles. With regard to the spawning requirements of both rhithral and epipotamal species, the newly created riffle pool sequences, gravel banks, bays and backwaters of the restructured Melk River obviously offered adequate niches (comp. Figs 2 and 11). Since successful reproduction of both ecological groups generally led to an increased number of fish species (Table 1), most of the typical riverine species (e.g. barbel), now show a much more balanced population structure (Fig. 12). The survey of juveniles and small fish species (e.g. minnow, *Phoxinus phoxinus* and loach, *Noemacheilus barbatulus*) within the shallow water areas provided further evidence for the enhanced supply of adequate niches for fry and young of the year fishes. Comparing the mean catches within the littoral zones of 3 straightened and 9 restructured river sections during different seasons showed clearly the generally higher stocks along restructured shorelines (Fig. 13). Densities

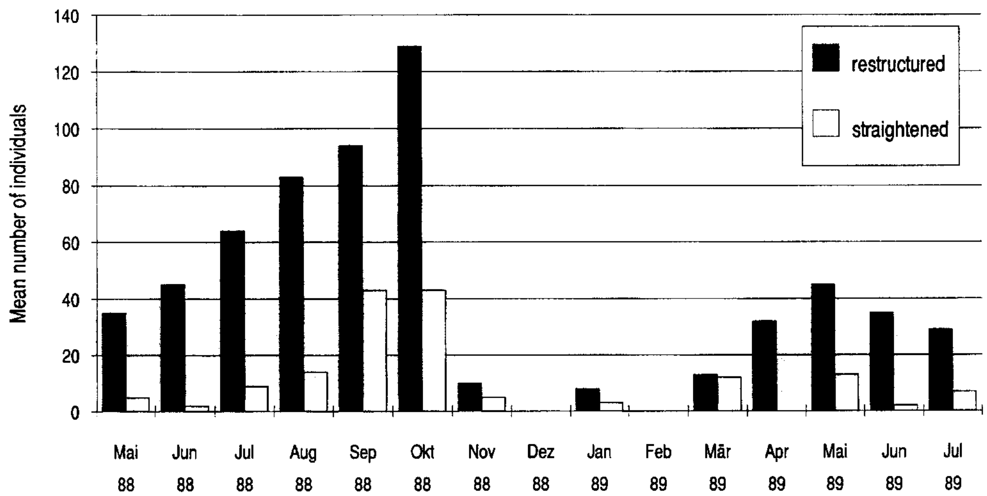


Fig. 13. Mean number of juveniles and small fish species sampled within the shallow water zones of 9 restructured and 3 still straightened Melk River sections during different seasons.

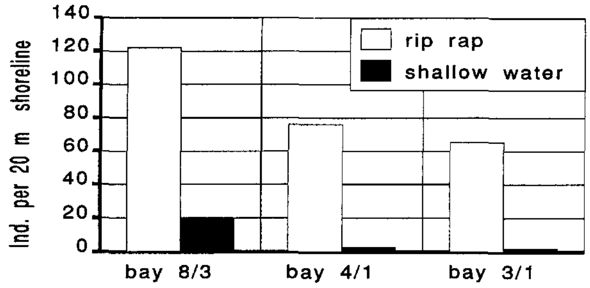


Fig. 14. Juveniles and small fish species sampled within rip rap and shallow water of 3 bays in winter.

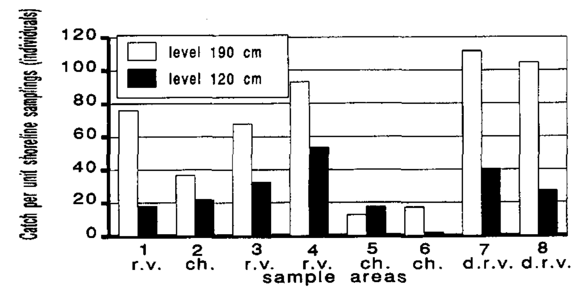


Fig. 16. Fish stock at 8 differently structured littoral sites at mean (level = 120 cm) and high (level = 190 cm) water discharge (ch = channelized, r.v. = riparian vegetation, d.r.v. = dense riparian vegetation).

of juveniles and small fish species increased in these flat water areas from spring to late summer, but the fish disappeared abruptly in late autumn. The results of samplings along the rip rap of 3 bays versus those from 3 shallow water areas in January (water temperature < 1 °C) showed that the young of the year and/or small fish species preferred stony or woody structures in winter (Fig. 14). Current stress was obviously a main reason for this demand for shelter during the cold season. Comparison of the fish samplings of all 12 sections in October 1988 according to 3 different classes of current speeds, showed that more than 80% of the fishes concentrated in areas with flow velocities below 15 cm s^{-1} (Fig. 15).

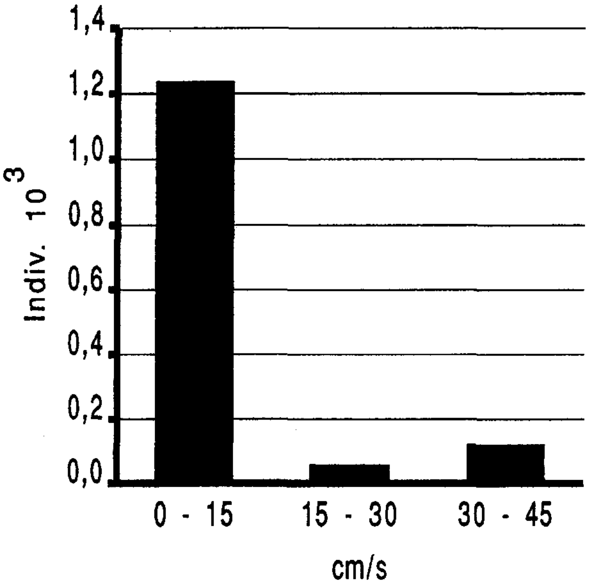


Fig. 15. Juveniles and small fish species sampled within the shallow water zones of 9 restructured and 3 still straightened Melk River sections in October 1988 according to flow velocities.

Another important function of the land/water interface is the supply of adequate shelter during floods. Such shelter consists largely of woody debris and/or higher vegetation within the upper parts of the cross sections. The comparative catch-per-unit-shoreline samplings in eight differently structured littoral test sites at mean and high water discharge (Fig. 16) showed that fish stocks generally increased in littoral areas during flood periods ($p < 0.05$; student's *t*-test). This applied especially to littoral test sites 7 and 8 with dense riparian vegetation. On the other hand, less structured test sites typical for the channelized Melk River (sections 2, 5 and 6), showed low densities (independent of water level) or only a small increase at high water discharge.

Discussion

Numerous authors have reported that high natural variety of the river bed is one of the most important conditions for the development of well-balanced aquatic communities (Lelek & Lusk, 1965; Hynes, 1968; Sheldon, 1986; Karr and Schlosser, 1978; Dudley and Karr, 1979; Tarplee *et al.*, 1979; Ward & Stanford, 1979; Schoof, 1980; Jungwirth & Winkler, 1983; Zerz & Moog, 1991). Unmodified rivers with type-specific riffle pool sequences, gravel banks, woody debris and dynamic development of the littoral zones contain a broad spectrum of instream habitats as well as a highly complex land/water interface. Channelization results in monotonous aquatic habitats and a quantitative and qualitative decrease of the fish stock. The present results demonstrate that the variability of instream structures can be described fairly well by the variance of maximum depths (VMD) of successive cross sections. This measure showed a highly significant correlation ($p < 0.001$) with both the number of fish species (NFS) and fish species diversity (FSD); it is therefore a practical instrument for the evaluation of water management projects. The VMD/NFS model can also be used to forecast the effects of river restoration plans. The Melk River project showed that regained spatial heterogeneity of the river bed led rapidly (1987–1990) to a significant recovery of the fish stock. Due to the improvement of the aquatic environment with respect to variable depths, flow velocities and substrate types, the number of fish species developed exactly in correspondence to the VMD/NFS model and both the density and biomass of the total fish stock tripled. Species diversity increased as well, but did not reach the value predicted by the VMD/FSD model; this was an indication that fish communities need more time to regain balanced proportions.

In addition to instream structures complex land/water interfaces are key features for the existence and development of natural fish communities. Essential functions of these ecotone zones include nursery grounds for fry and/or young of the year fishes and shelter during floods. Since the location of the land/water boundary changes strongly with the magnitude of discharge, the seasonal availability of relevant ecotone structures differs in quantity and quality. In the restructured Melk River, the variance of the maximum widths described fairly well the increased variability of the width conditions. High values corresponded to a high supply of shallow water areas with low flow velocities and fine substrates.

The importance of the recreated shallow water zones as nursery grounds for young stages and as a habitat for small fish species (e.g. minnow, loach) was obvious from spring to late summer. During the warm season, fishes occurred here in high densities. In autumn, however, these fishes (stages) disappeared abruptly from shallow littoral zones and migrated to other habitats. During winter the main concentrations were found in stony or woody shelters with current speeds < 15 cm s^{-1} and low hydraulic stress. Other critical ecotone-specific structures were bushes and trees or woody debris above the mean water level of the restructured Melk River. In contrast to straightened river sections, such living or dead woody materials prevented fry and adults from being washed off during floods. The combined results presented here prove that heterogeneous instream structures are particularly important for fish communities dominated by rheophilic species. This appears to be valid for headwaters exclusively inhabited by brown trout and/or bullhead, where VMD showed a significant correlation with population-(age-) structure parameters (see Fig. 5), as well as for streams corresponding to the barbel region, where VMD is strongly correlated with the community parameters NFS and FSD (see Figs 3 and 4). In small headwaters, however, the instream structures overlap strongly with the land/water interface. A differentiation in instream and ecotone structures therefore only makes sense in larger running waters of increased stream order.

Most of the rheophilic fish species accomplish their whole life cycle within the river itself. Instream structures oftering a broad spectrum of adequate species- and stage-specific niches (e.g. for spawning, embryonic development, etc.) are therefore of utmost importance. On the other hand the instream structures alone cannot provide adequate niches for all species and/or stages and their habitat requirements. This appears to be particularly true with respect to hydraulic stress (Bretschko, 1995), which increases with decreasing stream order. Fry and young of the year of rheophilic species as well as small and/or stagnophilic species therefore require additionally the typical elements of the land/water interface (shallow water zones, backwaters, seasonally inundated littoral vegetation, woody debris etc.) as nursery grounds and for shelter. The adjacent vegetation above mean flow level for all species and stages serves as a vital refuge area during floods.

In potamal streams the mean size of instream areas with uniform hydraulic stress increases parallel with increasing stream order (Bretschko, 1995). These areas alone represent a comparatively monotonous environment for fish communities.

On the other hand, regular inundation of the surrounding landscape becomes a stream-specific phenomenon. Therefore the large and complex ecotone zones of potamal regions represent the classical environment for high diversity fish communities.

Based on this knowledge, planning of river restorations should take into account that every stretch of running water possesses its unique features. Consequently, restoration measures should orient themselves on the original situation of the unmodified river and not be confined to restructuring. From an ecological point of view the ideal strategy is a set of measures which allows the river to regain its characteristic instream and ecotone structures by dynamic processes corresponding to the type-specific conditions.

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