MONITORING OF FLOODPLAINS: LIMNOLOGICAL INDICATORS

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Abstract

Monitoring programmes are required in order to define the extent of natural variability, identify trends as a result of man-made perturbations and clarify the effects of restoration and management programmes.

A key factor for understanding the properties of floodplains is the hydrological connectivity between the river and alluvial zone via groundwater exchange and flood events. The nature of floodplain ecosystems is strongly dependent on the dynamic intersection and areal extent of flood pulses, which imply local and large-scale disturbances. This creates the mosaic of successional stages - aquatic to terrestrial - with its characteristic functional properties and high biodiversity.

On a larger spatial and temporal scale, monitoring the environmental status of floodplains can be done through wide-range mapping of habitat types using remote sensing or other large-scale monitoring procedures.

On a more detailed scale, which is required to define precise management procedures, a complex array of both physiographic and biological indicators will be necessary. Physiographic and biological data must be intercalibrated and analyzed in order to understand the causal relationships between the main functional properties of floodplain ecosystems (nutrient cycling, production and decomposition, import and export processes between river and floodplain, erosion and sedimentation, e.g. clogging of aquifer, terrestrification processes etc.) as well as the habitat conditions for a characteristic biota.

Schiemer, F.: **Monitoring von Flußauen: Limnologische Indikatoren**

Eine regelmäßige Erfassung des ökologischen Zustandes ist erforderlich, um die Auswirkungen anthropogener Störungen oder - im positiven Sinn - von Revitalisierungs- und Managementmaßnahmen auf Flußauen, vor dem Hintergrund der natürlichen Variabilität, beurteilen zu können.

Der Schlüsselfaktor für das Verständnis der Ökologie von Flußauen sind die hydrologische Vernetzung von Fluß und Au. Die ökologischen Gegebenheiten hängen stark von der zeitlichen und flächenmäßigen Ausdehnung von Hochwässern ab, die klein- und großräumige Störungen bewirken. Diese schaffen ein Mosaik von Sukzessionsstadien und eine hohe Biodiversität.

Für die Entwicklung von Revitalisierungs- und Managementkonzepten, ist ein komplexes Indikatorsystem erforderlich. Es soll die wesentlichen funktionellen Prozesse (Nährstoff-Kreisläufe, Produktion und Dekomposition, Austauschprozesse, Erosion und Sedimentation), und die Lebensraumerfordernisse für charakteristische Lebensgemeinschaften beschreiben. Über Erfahrungen mit physiographischen und biologischen Indikatoren an der Donau wird berichtet.

Schiemer, F.: **Monitorování říčních niv: biologické indikátory sladkých vod**

Monitorovací programy jsou významné zhlediska definování rozsahu přirozené variability, stanovení trendu vývoje v důsledku zásahu člověka, a vyhodnocení výsledků revitalizací a plánů hospodaření. Klíčovým bodem k porozumění základních vlastností říčních niv je znalost hydrologického režimu, závislého na propojení mezi řekou a aluviální zonou cestou výměny spodní vody a povrchových záplav. Charakter říčních niv je výrazně závislý na dynamickém průsečíku a plošném rozsahu záplavových pulsů, které v sobě zahrnují místní i velkoplošné rušivé zásahy. Toto vytváří mozaiku sukcesních stadií - od vodních k suchozemským - se svými charakteristickými funkčními vlastnostmi a vysokou biodiversitou.

Při rozsáhlejším plošném a časovém měřítku jsou k monitorování přírodního charakteru říčních niv vhodné družicové snímky jednotlivých typů lokalit. Při detailnějším měřítku je třeba použít medody fyzikálně-zeměpisné spolu s biologickými indikátory. Fyziografická a biologická data musejí být vzájemně porovnána a analyzována společně, jestliže chceme pochopit příčinné vztahy mezi hlavními funkčními vlastnostmi říčních niv (jako je koloběh živin, produkce a dekompozice, procesy importu a exportu mezi řekou a nivou, eroze a sedimentace, např. zazemňování atd.) a poznat životní podmínky organismů charakteristických pro danou lokalitu.

1. INTRODUCTION

Monitoring with appropriate indicators is required to recognize ecological change. This is particularly relevant prior to major management decisions. We need to know how - in which direction - and how fast ecological conditions are changing.
In setting up a monitoring programme, the aims must be clearly defined, otherwise irrelevant data sets will be collected.
The general objectives of a monitoring programme will determine to some extent its structure and the indicators chosen.

Objectives can be an assessment of:
a) the status quo of a wetland system and the extent of natural variability, or
b) ecological trends following man-made perturbations, or
c) effects of engineering, management and restoration programmes.

Monitoring can be orientated towards:
- **conservation** (conservation potential, extent of human alterations, "Hemerobie": distance from original conditions, habitat requirements for target species), or
- **resource use** (e.g. drinking water quality, self-purification).

The type of programme and the parameters selected will, on the other hand, largely depend on the spatial scale under consideration. Fig. 1. illustrates different scales of focus in the example of the Danube.

The programme can focus on the:
a) whole drainage basin (e.g. assessment of general levels of human impact in the drainage basin, remaining areas of alluvial forests and their status);
b) larger river sections (e.g. downstream of Vienna: controversy between hydropower and conservation options; this requires large-scale monitoring of conservation value and ecological functions);
c) smaller river sections (e.g. WWF area downstream of Vienna: interest to develop a floodplain restoration methodology); this requires more detailed assessment and monitoring procedures
d) reaches (e.g. in order to define habitat or microhabitat value for particular species or detailed functional processes).

2. KEY FACTORS OF FLOODPLAIN ECOSYSTEMS

The selection of efficient indicators requires an understanding of the functioning of floodplain systems. One key factor is floods.
It is widely recognised that lateral exchange processes between the river and its riparian zone dominate the longitudinal processes in the sense of the river continuum concept (CHAUVET & DECAMPS, 1989, NAIMAN et al., 1988, NAIMAN & DECAMPS, 1990, SCHIEMER & ZALEWSKI, 1992, SEDELL et al., 1989, WELCOMME, 1979). These lateral effects depend on the extent of the riparian zone, its geomorphology, and on river hydrology. With the duration and areal extent of flood waves, production and carbon dynamics are generally enhanced. This long-recognised relationship has recently been re-emphasized by JUNK et al. (1989) as the FLOOD PULSE CONCEPT.
Flood waves are not only significant for nutrient and carbon dynamics, but also determine the geomorphology and patch dynamics of the floodplain system. Floods are responsible for resetting early successional stages and - by controlling the population size of strong competitors - create a high, disturbance-mediated diversity level. A further significant aspect of floodplain ecology can be described as the CONNECTIVITY CONCEPT:
The hydrological connectivity of the river and its backwaters via surface and groundwater at the various water level

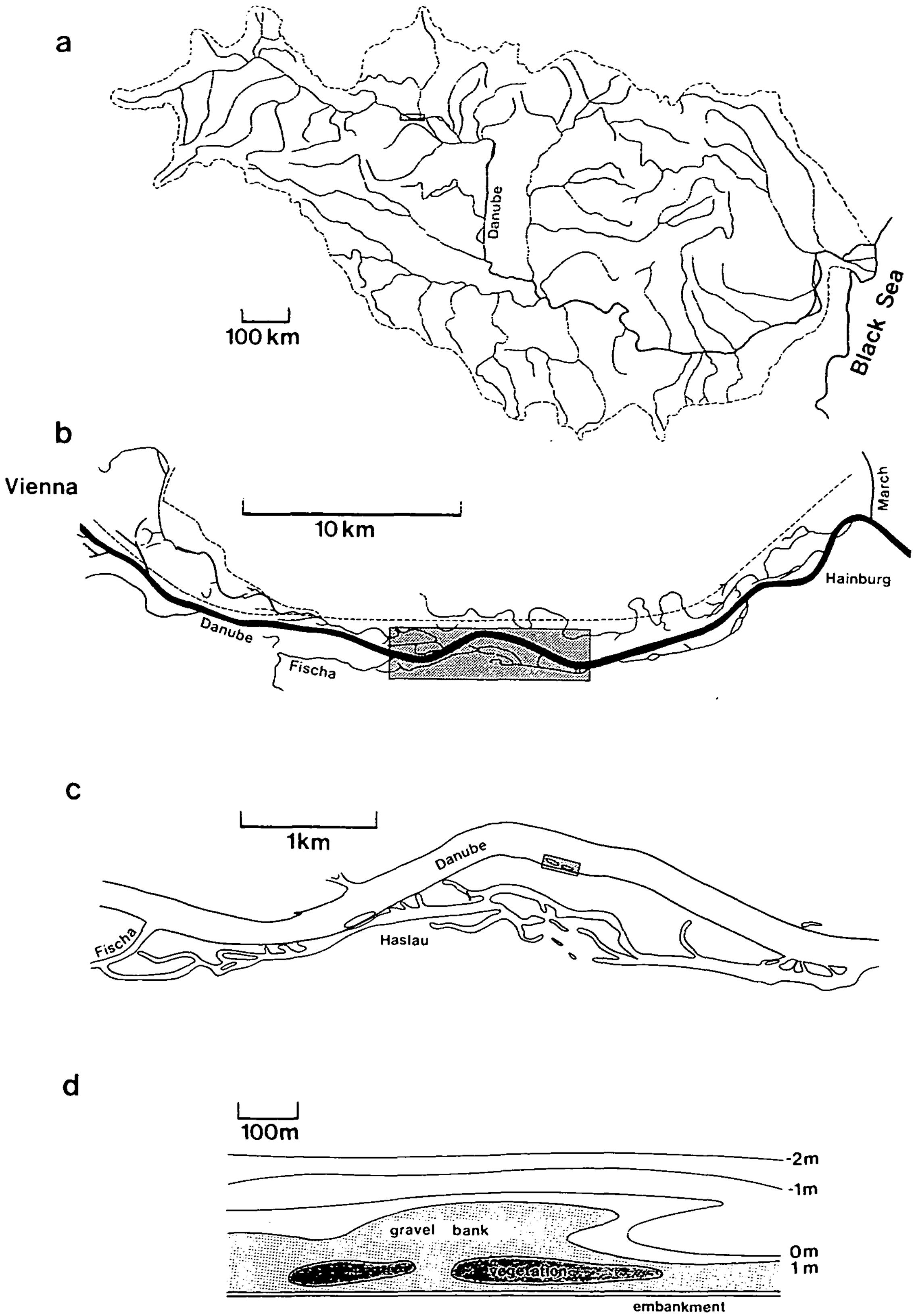

Fig. 1. Spatial scale of flood plain monitoring programmes in the example of the Danube. For explanations, see text.

stages is decisive for nutrient recycling, production, decomposition, sediment formation and clogging of the groundwater aquifer (e.g. AMOROS & ROUX, 1988, HEILER et al. 1994).

The hydrological integration between river and backwaters is a significant habitat parameter for species which require different aquatic microhabitats in the course of their life cycle, e.g. certain species of fish (SCHIEMER & SPINDLER, 1989).

The significance of the hydrological connectivity can be illustrated using the Danube as an example.

When we recall the original conditions of the Austrian Danube prior to the Danube regulation starting in 1875, the braided river system in the alluvial plains was characterized by a rich structure with regard to velocity pattern and substrate conditions. Temporary lentic conditions occurred in the elevated side arms. Floods resulted in an erosion and export of sediments. Water level fluctuations caused good aeration and flushing of the groundwater aquifer over a large lateral extent.

This original high degree of connectivity changed drastically in many European river systems at the turn of the century due to major regulation schemes designed to control floods and improve shipping conditions.

The straightening and enforcement of a main channel and abandonment of side channels had major effects on:

a) the ecological conditions of the river itself (increase in flow velocity, bedload erosion, and deepening of the river bed);
b) the exchange conditions between river and riparian zone; and
c) the relative proportion of alluvial habitat types (SCHIEMER & WAIDBACHER, 1992).

The ecological trends initiated by these large regulation schemes over a hundred years ago still continue today (e.g. terrestrification processes with concomitant vegetational changes).

The construction of a series of hydropower impoundments (as of 1954 in Austria), had even more serious ecological consequences and resulted in an almost complete disconnection between the river and its floodplains.

We have identified different types of disconnection between the river and its backwaters in the Austrian Danube (Fig.2):

a) In the free-flowing sections of the Danube the lateral connectivity and hydraulic exchange between river and former side-arms via groundwater is still high. In certain backwaters the hydrography exhibits strong fluctuations and sediments are temporally exported by through-flowing floods. In such dynamic backwater types the growth of aquatic macrophytes is generally low.

b) Exchange conditions are reduced in more highly elevated zones and behind flood levees (e.g. in the Lobau at Vienna). The erosive forces of floods are missing or strongly reduced, although a reduced hydraulic connection via the groundwater exists. The amplitude of the hydrography is lower, and sediments are accumulated and further inhibit exchange with the groundwater. Macrophyte growth plays a major role in nutrient exchange, sediment formation and accumulation. Higher water retention results in significantly increased internal loading processes.

c) In the former floodplains lateral to hydropower dams, the hydrological exchange can be almost completely absent; this fosters the above-mentioned sedimentation and clogging processes. The characteristic properties of floodplain systems are lost.

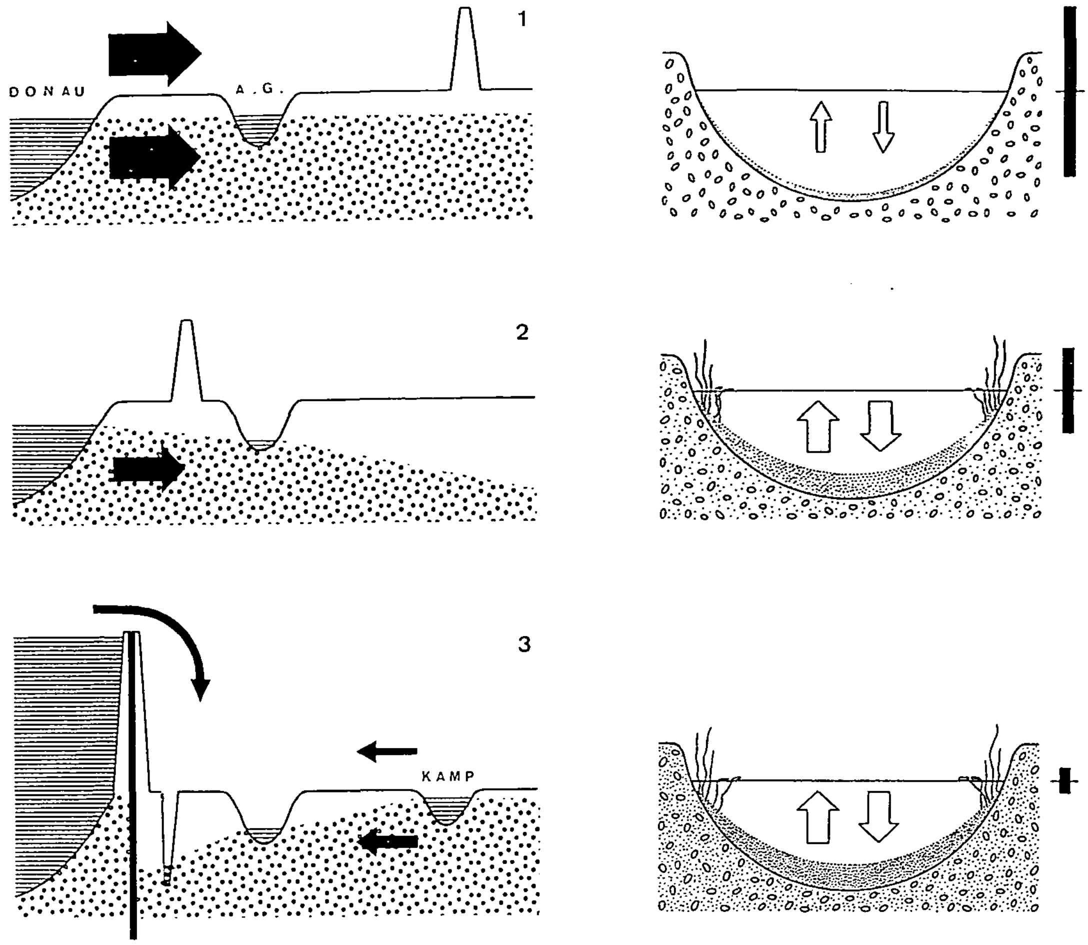

Fig. 2. Types of hydrological connections of the river and its backwaters in the Austrian Danube. Left side figures: black arrows = water exchange. Right side figures (limnological characteristics): vertical columns = amplitude of seasonal water level fluctuations. White arrows = nutrient exchange processes. Fine dots = fine sediment accumulation. Note the infiltration of the sediments in the groundwater aquifer under conditions of disconnection.

3. RELEVANT PARAMETERS IN THE ASSESSMENT OF FLOODPLAIN ECOSYSTEMS

Keeping in mind that flood pulses and hydrological connectivity function as key factors, we can define the relevant characteristics in the assessment and monitoring of floodplain ecosystems:

a) with regard to their functions (e.g. eutrophication and terrestrification processes, nutrient dynamics, etc.), and
b) with regard to the habitat requirements of characteristic species and communities of aquatic and semi-aquatic habitats (Table 1).

Depending on the specific objectives of the monitoring programme some parameters may be more significant than others (Table 2).

4. EXAMPLES OF INDICATORS

The indicative value of hydrochemical and faunistic data for monitoring floodplain ecosystems is illustrated using selected examples from the Austrian Danube.

Hydrochemical parameters

Geochemical values (e.g. conductivity, silicate) - in combination with hydrographic data - are good indicators of hydro-

logical connectivity or disconnection of the river and its backwaters.
Nutrient chemistry (e.g. P_{tot}, NO_3) consists of process-oriented parameters.

Table 1. Relevant characteristics in the assessment of floodplain ecosystems:

* **structural properties**
  patch structure (e.g. habitat distribution), ecotone pattern and packing
* **patch dynamics**
  extent and time scale of disturbances,
  successions
* **hydrological connectivity**
* **limnological processes**
  nutrient dynamics, production and decomposition, sediment formation & erosion, clogging of the aquifer
* **pollution levels**
  accumulation of toxic substances, e.g. heavy metals

Table 2. Significance (! = weak; !!! = high) of monitoring of various characteristics for conservation and resource use:

	conservation	resource use
structural properties	!!!	
patch dynamics	!!!	!
hydrological connectivity	!!!	!!!
limnological processes	!	!!!
pollution levels	!	!!!

In combination with trophic indicators like Chl a and macrophytic cover, they provide important information on the trophic state, production and decomposition processes. Chemical data allow short-term and small-scale resolution of processes. Sediment accumulation and sediment quality can be used as long-term indicators.
Figs 3 and 4 show chemical characteristics of various water bodies in the disconnected alluvial plains of the Danube upstream of the hydropower station at Althenwörth. The mean values (and variability) determined in a seasonal study in 1985 show the good discrimination between the different habitat types.

Biotic indicators

Biotic indicators can be specifically useful due to the species-specific, integrated response to many environmental variables. When autecological requirements of characteristic species associations are well established, they provide useful evaluation criteria for the structural and functional quality of rivers with reference to original conditions.

For assessing the habitat quality of backwaters we currently employ a system of fauna groups which integrate different qualities, for example (see Fig. 5)

- aquatic molluscs and water beetles with small-scale aquatic habitat linkages (1) (e.g. FOECKLER, 1990)
- fish which require littoral spawning sites and which species-specifically change their habitat requirements in the course of their life cycle (2) (e.g. SCHIEMER et al. 1991),
- heterotopic aquatic insects (3), amphibians (4) (e.g. BLAB, 1978, WARINGER & WARINGER-LÖSCHENKOHL, 1990) and aquatic birds (5) (e.g. DOBROWOLSKI, 1973) which require different combinations of aquatic and terrestrial habitats.

The combination of faunistic data therefore reflects, in an integrative way, ecological qualities of the aquatic/terrestrial transition zone (SCHIEMER, 1992; IMHOF et al. 1992). Fish communities are clearly good indicators of habitat structure as well as of the

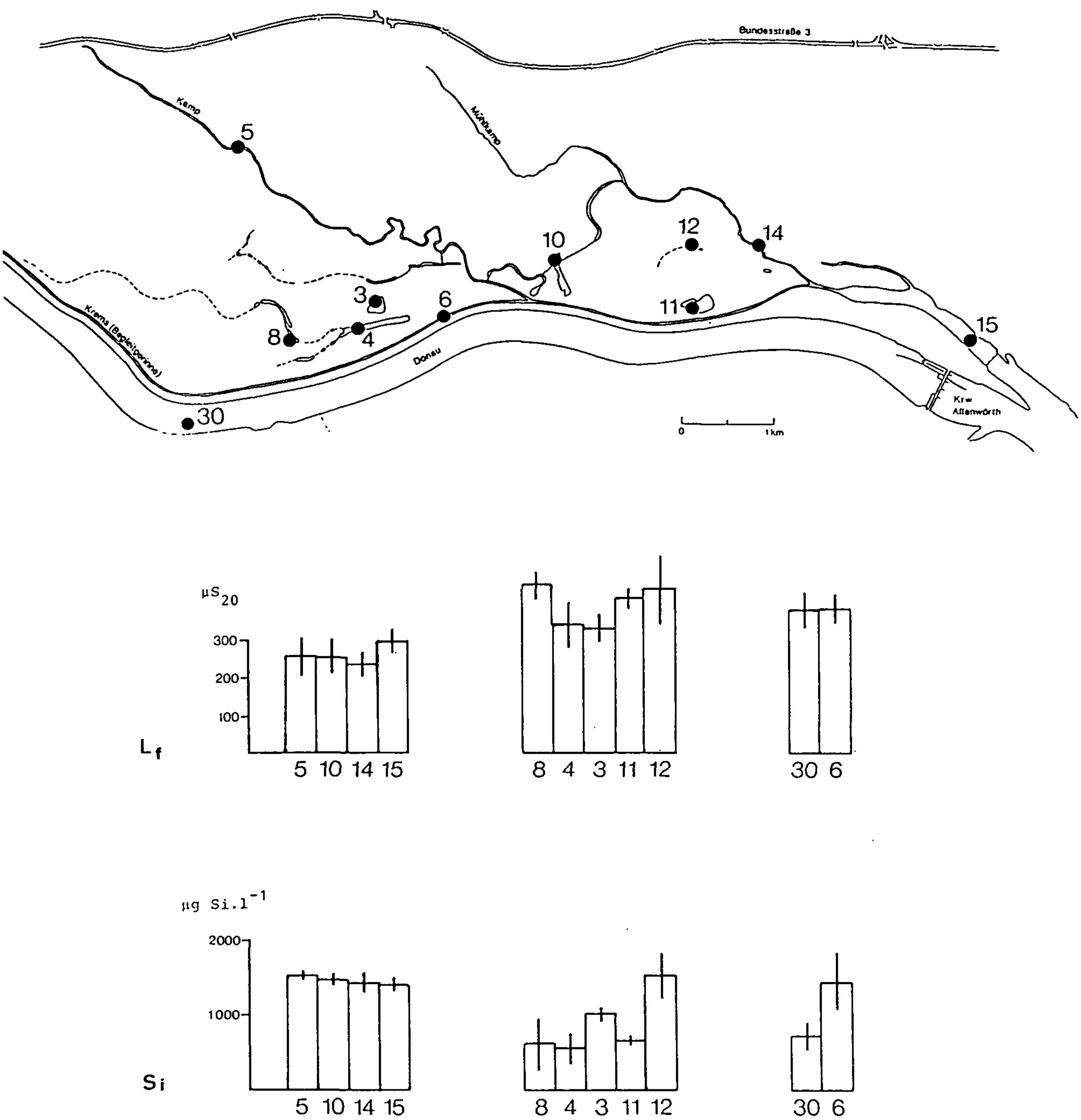

Fig. 3. Conductivity and silicates (mean values and seasonal variability in 1985) of various water bodies in the dammed alluvial plain upstream of the hydropower dam at "Althenwörth". Waterbodies are marked by numbers. The first group (5, 10, 14, 15) represents the Kamp river and backwaters connected to it. The second group (8, 4, 3, 11, 12) represents isolated backwaters and artificial gravel pits. The third group represents the Danube (30) and a small brooklet, Krems (6).

ecological integrity of large river systems because many species have complex habitat requirements in the course of their life cycle.

Fig. 6 shows in a simplified scheme the links of the fish fauna to the different zones of the alluvial plain of the Danube:

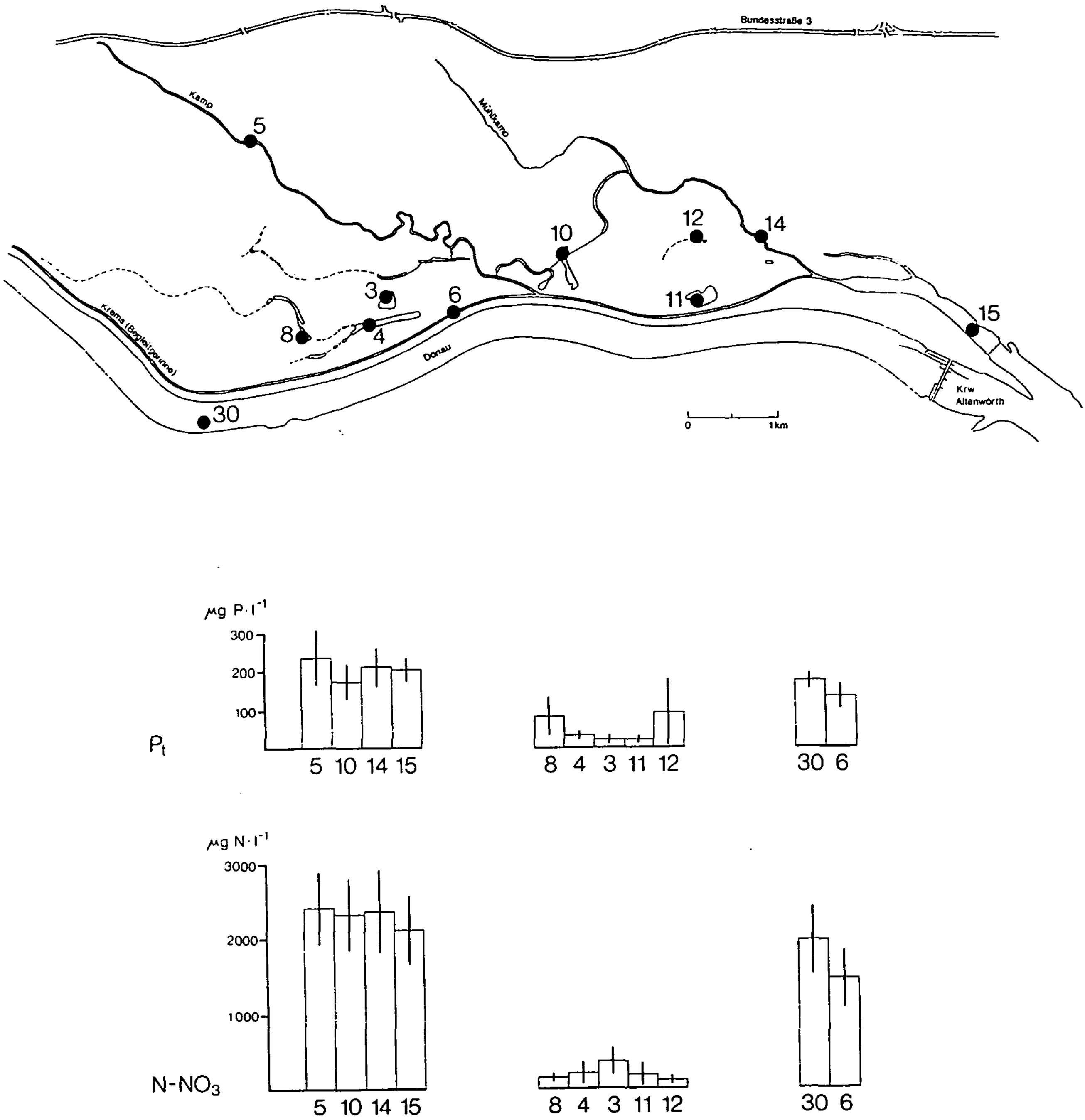

Fig. 4. Total phosphorus and nitrate of various waterbodies in the dammed alluvial plain upstream of the hydropower station "Althenwörth" (see Fig. 3).

- riverine species which are strictly bound to the river itself,
- riverine species which require zones of low flow, e.g. backwaters with open connections to the river, during certain periods of their lifecycle,
- species bound to disconnected branches of the river (with a high development of vegetation),
- eurytopic species found in different habitat types.

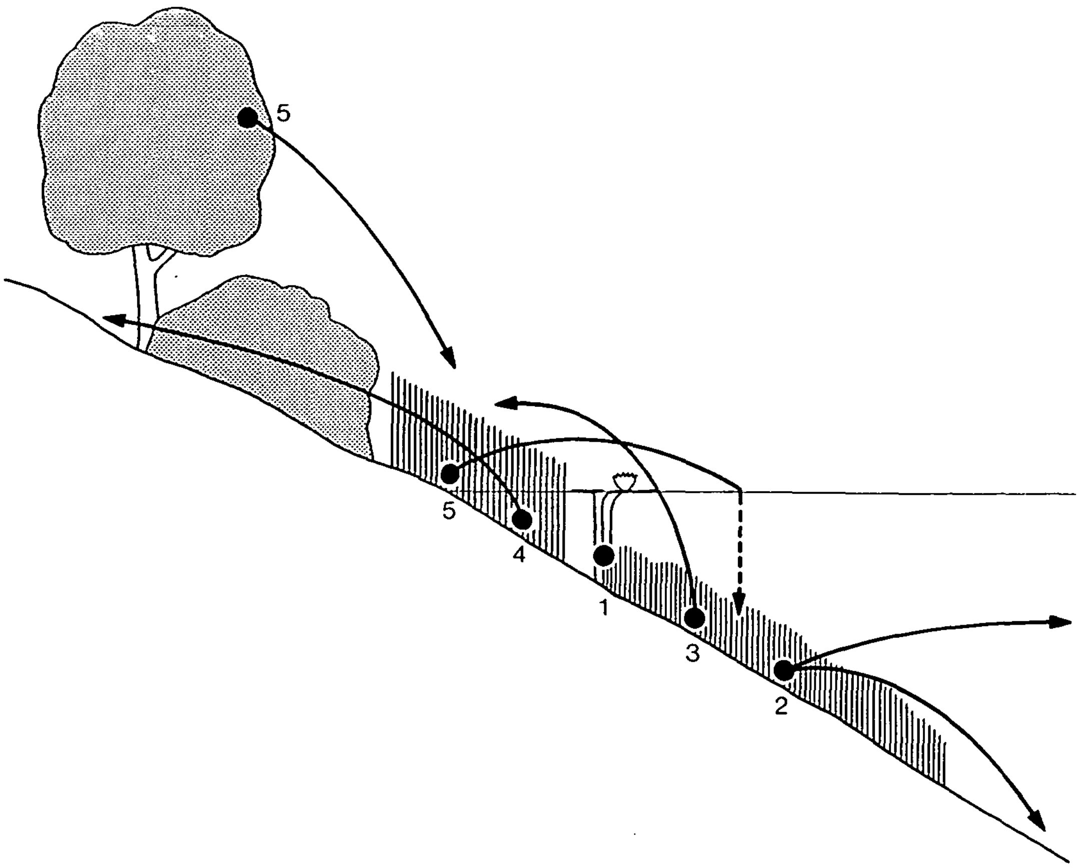

Fig. 5. Spatial dimensions and habitat complexity of selected indicator groups in the land-water ecotones of floodplains. Points = reproductive zone, arrows = habitats of older stages. 1: aquatic molluscs, 2: fish, 3. heterotopic aquatic insects e.g. odonates, 4. amphibians, 5. water birds. From SCHIEMER (1992)

The riverine guild was found to be most diverse and most endangered. The majority of these species are on the "Red lists" of endangered taxa.

Regulation and especially the construction of hydropower dams has resulted in severe degradation of their habitats. The changes induced by damming can be elucidated by a comparison of the fish stock in free-flowing sections and in impounded areas (Fig. 7). The fauna in the free-flowing river is characterized by a clear dominance of nose, *Chondrostoma nasus* (L.), followed by barb, *Barbus barbus* (L.). The percentage of eurytopic species is low. A comparison with the catch statistics in an impoundment (at Melk) 5 years after the dam was completed clearly demonstrated that the riverine species have already strongly declined and that the relative proportion of eurytopic forms (e.g. bream, *Abramis brama*, roach, *Rutilus rutilus*, and silver bream, *Blicca bjoerkna*) has increased.

Our studies revealed that important habitat links are due to the requirements during the early life history. In backwaters without connection to the river, the fish fry is composed of eurytopic and limnophilic species. Open backwaters are dominated by eurytopic forms. The 0+ stages of rheophilic species are found exclusively in the naturally structured littoral zone of the river itself. A high diversity and a large number

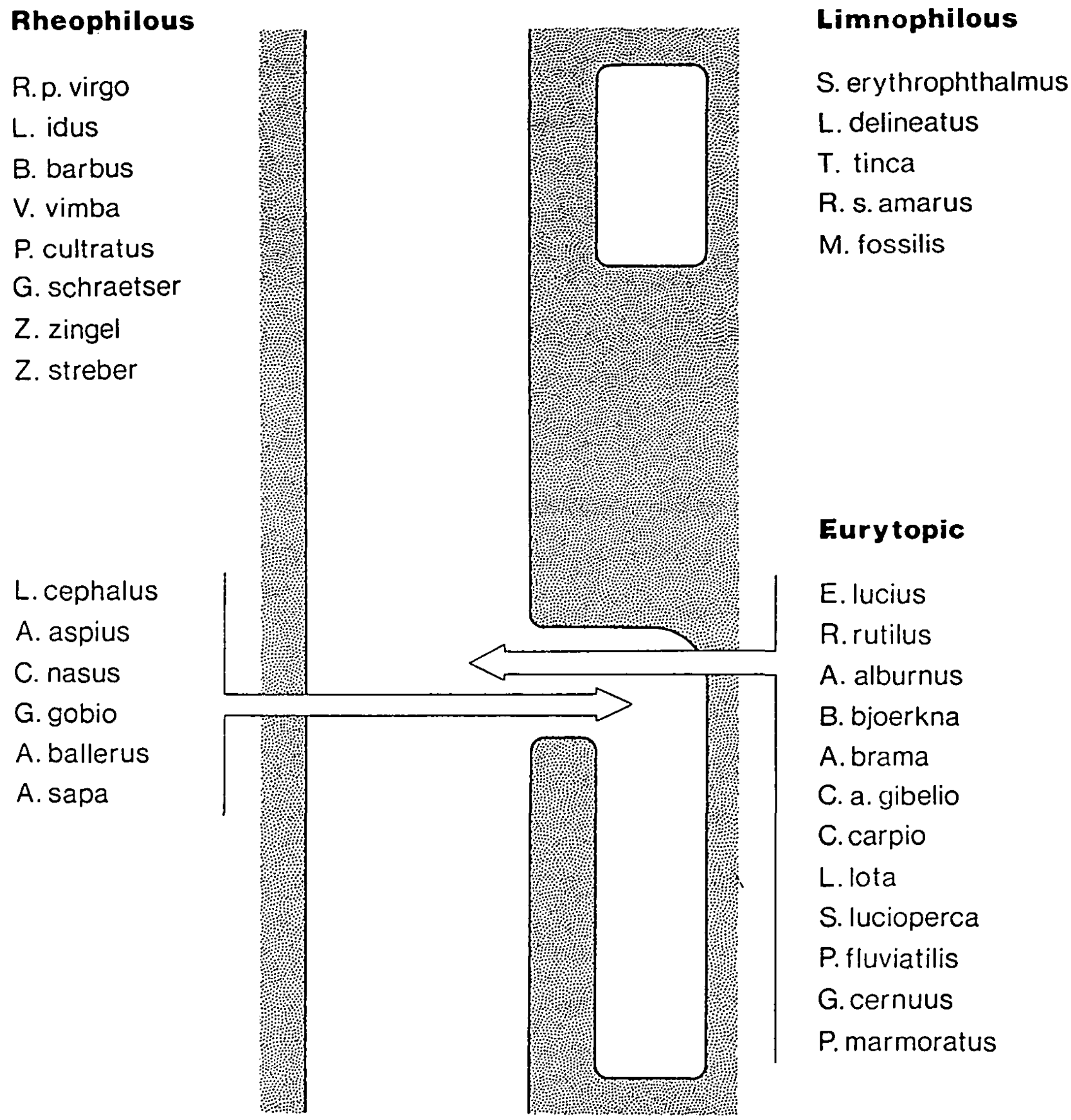

Fig. 6. Ecological guilds of fish species to be found in the different habitat types of the alluvial system (river, connected and disconnected backwaters). See text. (From SCHIEMER, 1988).

of endangered species were encountered among the 0+ population in small bays and shallow-sloped gravel banks of the river shore. The lowest population density and species diversity of the 0+ age class were found along the linear, artificial shorelines.

Two important results are immediately obvious from this comparison:

1. the fry of rheophilic species are absent in both backwater types and are found only in the naturally structured littoral zone of the river itself, and
2. the very lowest population density of fish fry and the lowest species diversity are found along the linear, artificial shorelines.

Several structural elements of the shore appear to be essential for fish recruitment. This is schematically illustrated in Fig. 8.

(1) The necessary stream bed structures for reproduction have to be in close proximity to the larval microhabitats.

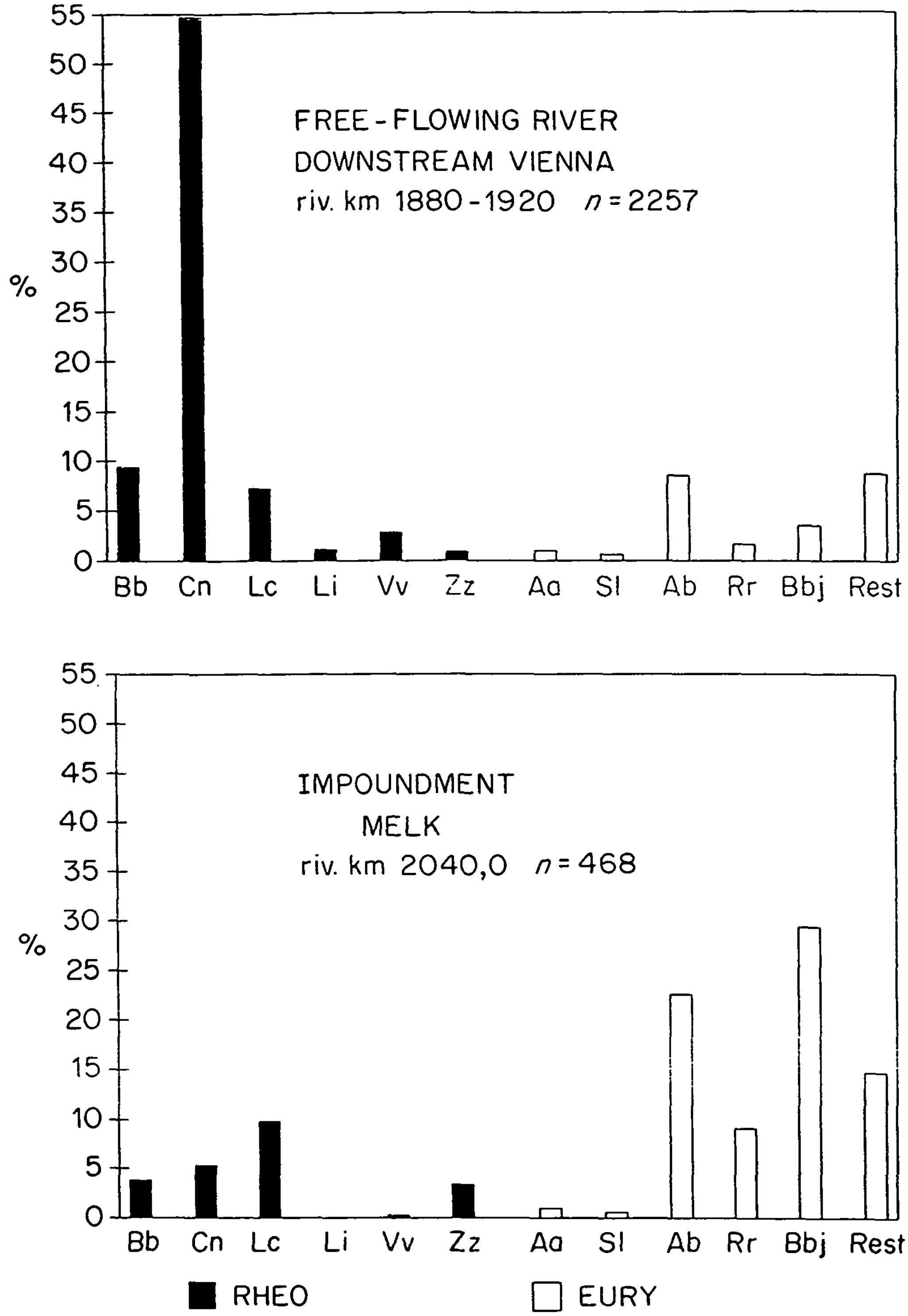

Fig. 7. Faunal composition (percentage of total catch) in the free-flowing section of the Austrian Danube downstream of Vienna and in the impoundment "Melk". The graph compares catch statistics of surveys carried out by electrofishing the adult fish population.
Bb = *Barbus barbus*, Cn = *Chondrostoma nasus*, Lc = *Leuciscus cephalus*, Li = *L. idus*, Vv = *Vimba vimba*, Zz = *Zingel zingel*, Aa = *Aspius aspius*, Sl = *Stizostedion lucioperca*, Ab = *Abramis brama*, Rr = *Rutilus rutilus*, Bbj = *Blicca bjoerkna*. (From SCHIEMER & WAIDBACHER, 1992).

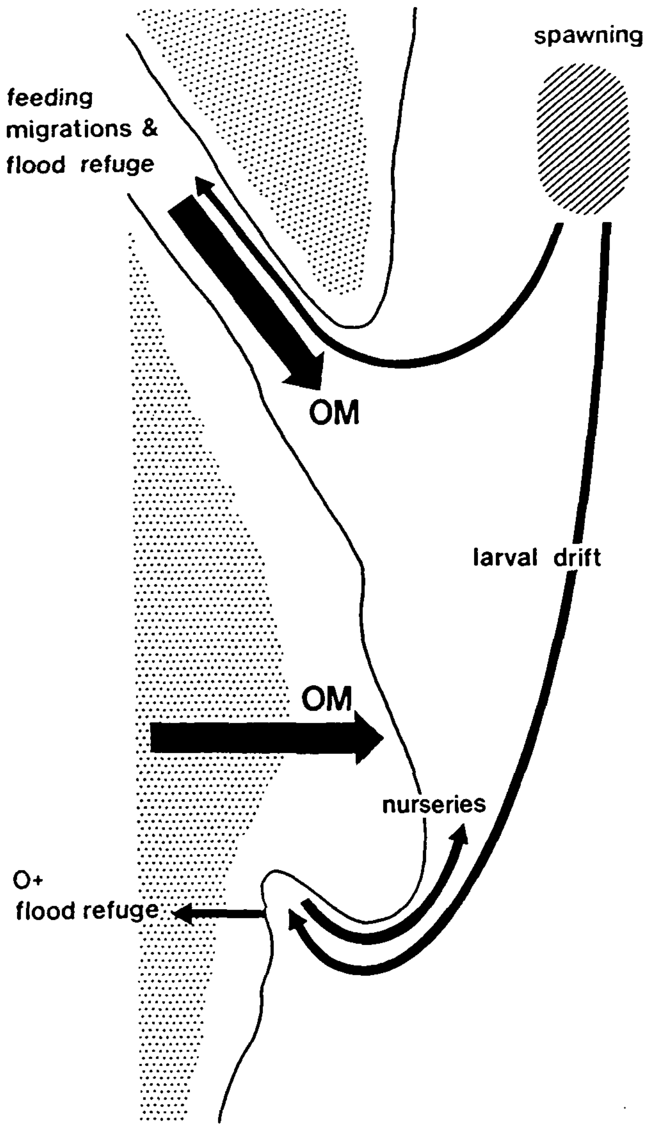

Fig. 8. Main interlinks between riverine fish and floodplains, based on results from the Danube (SCHIEMER et al. 1991). The scheme indicates the river shoreline with a connected backwater and gravel bar (hatched). Stippled area = vegetation. OM = organic matter. For further explanation see text.

(2) Microhabitat gradients to cover the ontogenetic niche change with regard to current velocity, substrate type and food.

(3) An important quality of the littoral zone is the proximity to backwaters openly connected with the river. Such lentic water bodies are major production zones for plankton; under conditions of falling water level, this plankton is released into the river and serves as essential food items for the early life stages of fish (SCHIEMER & SPINDLER 1989).

(4) An important structural quality determining year class strength is shallow-sloping embankments; they function as refugial zones to reduce the wash-out effect of larvae during high floods.

5. CONCLUSIONS

Although research and knowledge on floodplain rivers has increased during recent years, at present no general schemes on the ecological monitoring of riparian wetlands have been developed.

This is in contrast to the urgent requirement for such programmes due to increasing human pressures and the needs of nature conservation and management.

International efforts are required to develop concepts based on existing ecological understanding of such ecosystems. In parallel, research has to be intensified on ecosystem processes and the autecology of characteristic species.

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