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Supplement Volumes

Large Rivers

Volume 9

Archiv für Hydrobiologie

Suppl. Volume 101

With 182 figures and 64 tables in the text

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Supplement Volume 101

Large Rivers

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River dynamics and floodplain vegetation and their alterations due to human impact

By NORBERT MÜLLER

With 10 figures in the text

Introduction

In Europe the human impact on river ecosystems is very old. Already in the late days of the Stone Age the run-off of the large lowland rivers, those which have their main catchment area in the Low Mountains, was influenced by the change of landscape in the catchment area (BECKER 1982, LITT 1992, SCHELLMANN 1991). A great change in the structure of lowland river plains took place when during the Roman Times agriculture increased. The sedimentation of floodplain loam in the valley of the Weser, for example, is due to the increase in farming in the broad catchment areas, with their loamcovered hills. Before that time the floodplain of the Weser was dominated by gravel soil and the character of the whole area was totally different (STRAUTZ 1962). One assumes that already a hundred years ago in the upper reaches of the Danube the floodplains near the river had been cleared and used for agriculture (KONOLD 1993). Consequently the strong human impact on flora and fauna of the lowland river plains must have started long before the major civil engineering measures had taken place in the 18th century. Because of the lack of any bigger naturally conserved lowland rivers in Europe the reconstruction of their initial forms is difficult.

In contrast major intrusions on the natural water and bedload regime of the alpine rivers first started in the Middle Ages. However, more serious changes in the catchment area were caused by the increasing number of settlers in the alpine valleys. Since the 19th century many alpine floodplains have been fundamentally changed by consequent civil engineering measures. Despite these intensive measures there are still some river sections in the Alps which still show natural conditions (MARTINET & DUBOST 1992, MÜLLER 1991a).

Alpine floodplains are particularly suitable to answer basic questions on the function of floodplain ecosystems because they are the last still almost intact floodplains in Europe. Due to different investigations on the situation of floodplain vegetation before and after civil engineering measures (e.g. MÜLLER et al. 1992, SCHAUER 1984a, SEIBERT & ZIELONKOWSKI 1972) they offer good prerequisites to understand the changes of floodplains influenced by man.

The structure of the floodplain vegetation is the result of an interaction between abiotic and biotic factors, the cycle of life of species and the historic events.

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This research intends to show these interactions in natural floodplain ecosystems and to describe the impact of human influence. In particular the following questions are to be answered:

- Natural floodplains and river dynamics – how do they interact respectively depend on each other?
- Which strategies have plants developed to adapt to the special site-factors in natural floodplains?
- Which influence does river dynamics have on the structure of floodplain vegetation?

The second part of this research deals with the impact of man on floodplain ecosystems. With the help of alpine floodplains the following topics are to be emphasized:

- The impact of human influence on river dynamics.
- Longterm changes in the floodplain vegetation due to the change in river dynamics.
- Reasons for the change in flora and fauna caused by the influence of man.

The results presented are mainly based on investigations made at the large northern alpine rivers which flow into the Danube (MÜLLER 1995) and the largest yet existing natural alpine river landscape – the Tagliamento in the southern Alps (MÜLLER 1993, MÜLLER et al. 1994; comp. Figs. 1 and 2).

Basic recommendations for the conservation of nature and for restoration measures in floodplains have been concluded from the results.

2. Factors and effects of river dynamics

The biocoenoses in floodplains are generally divided into aquatic, amphibious and terrestrial biocoenoses.

All organisms which live in free water areas – e.g. waterplant-communities in rivers and old river bends – are part of the aquatic biocoenoses.

Part of the amphibious zone are all biocoenoses which are most strongly influenced by the change of inundation and desiccation – **woodfree** floodplain habitats and often flooded riverside softwood forests (in German: Weichholz-Auenwald). The following implementations focus on this field.

The terrestrial biocoenoses are due to the existence of episodic or flood water events (rarely flooded riverside hardwood forests [in German: Hartholz-Auenwald] and fossile floodplains).

Compared to other ecosystems the biocoenoses in natural floodplains are, due to the specific abiotic factors in this ecosystem, subject to extremely high dynamics. The factors can be divided in surface- and ground-water regime, **bedload** regime and **nutritionload** regime. The effects all these factors have together is known as river dynamics.

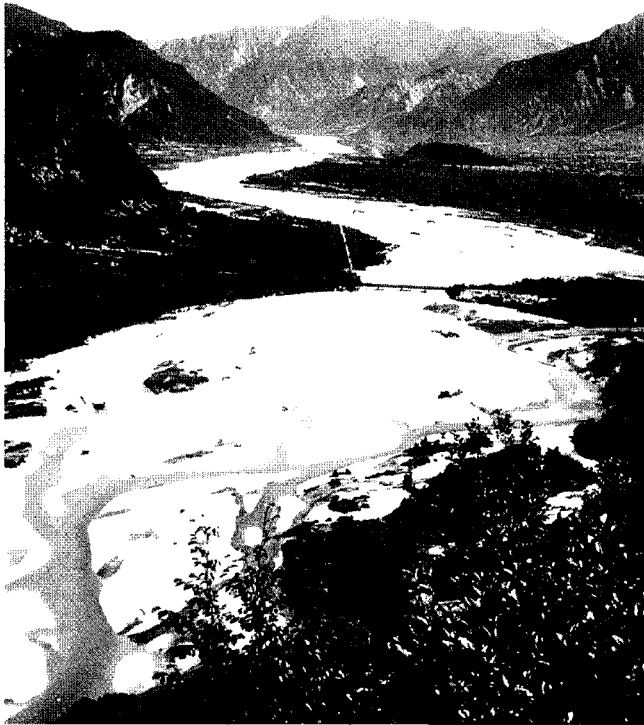


Fig. 1. The last large natural alpine river in Europe (Tagliamento in the southern Alps) – typical for this type of floodplain ecosystem (braided river) are gravel bars without vegetation and different communities of pioneer vegetation (Photography by N. MÜLLER 1992).

2.1 Hydrodynamics

Due to climate and relief European rivers have two different run-off regimes. Lowland rivers with their main headwaters in the Low Mountains (e.g. Main or Weser) have their run-off maximum in winter and spring. Alpine rivers, which are closer investigated in this study, rise in the Alps (e.g. Lech and Tagliamento) and have their run-off maximum in summer.

The length of inundation and the ground-water level are essential factors that characterize the sites in floodplains (HELLER 1969). Run-off and ground-water dynamics are closely correlated. A rise in the run-off causes a rise in the ground-water level.

Floodplain inhabitants have to adapt to the extremes of inundation and longer dry periods on their sites.

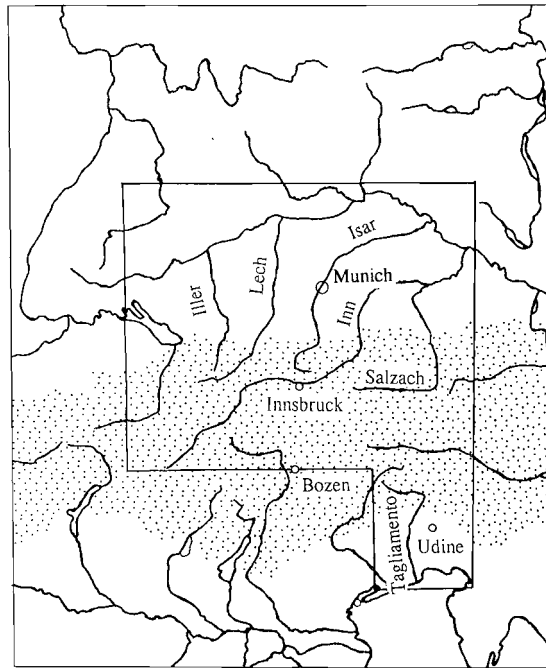


Fig. 2. Sites of the investigated rivers

2.2 Dynamics in morphology

The in- or decrease of the kinetic energy of the run-off water caused by the wide fluctuation of the quantity of the run-off itself make the erosion, the transport and the accumulation of inorganic and organic material possible. This process, responsible for the forming of the floodplains in the moderate zone, plays an important role in the fluvial morphodynamics.

Bedloads are divided into debris (gravel and coarse sand), suspension material (fine sand and silt) and floating debris, chiefly of organic origin.

Sediments rich with debris are for one thing characteristic for the upper and middle reaches of the northern and southern alpine rivers. Due to the fact that the limestone in the alpine catchment area weathers easily and coarsely, the share of debris in the solid material is high. In the upper reaches extremely big debris is transported if the slope is strong. These floodplain sites are characterized by gravel bars with coarse debris. Because of the mechanic crush of the debris and the decrease of the fluvial morphodynamics the share of sands and swimming particles increase from the upper to the lower reaches.

In times of flood water the main transport of material and the fundamental shaping of the river bed take place. Extremely flood water events inundate great parts of the floodplain and cover them with debris. Gravel and sand bars, results of former flood water events and already inhabited by plants, are flushed away and rebuilt at another place. When the flood water event is over the landscape has changed. The

river has shifted its valley and many gravel and sand bars situated in the floodplain close by the river have developed another form and location.

The change of the course of the river, caused by the river's morphodynamics, is especially drastic in the upper and middle reaches. For this reason big gravel bars free of or scarcely covered by vegetation are characteristic for this section. The changes in the river bed decreases towards the lower reaches. Whereas in the catchment area and in the upper reaches erosion predominate, erosion and accumulation are balanced in the middle and lower reaches. In the estuaries as well as in the lowland river plains sedimentation is predominant (comp. Fig. 3).

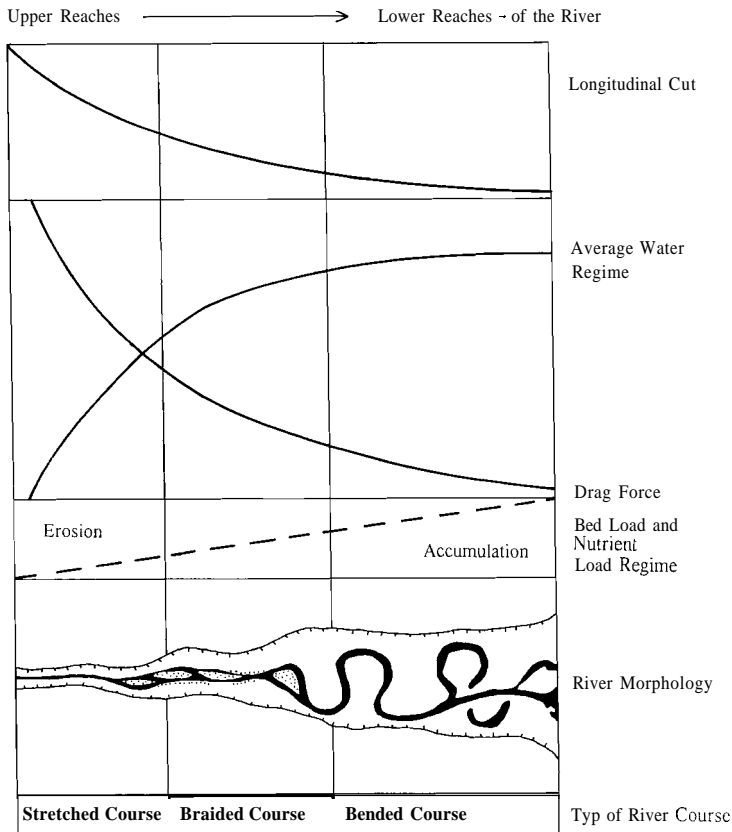


Fig. 3. Idealized presentation of natural types of river courses in Central Europe and different ecological factors (from MÜLLER 1995, according to BINDER 1979 and NIEMEYER-LÜLLWITZ & ZUCCHI 1985).

Corresponding to the effect of the morphodynamics one can divide the European rivers into three types (MANGELSDORF & SCHEURMANN 1980):

a) Stretched course

They develop in areas with a strong slope and a small river bed. In this case erosion predominates. Stretched courses are only found in short sections.

b) Braided course

They develop in wide valleys with a slope ranging from moderate to strong, yet being balanced. Erosion and accumulation of **bedload** are balanced over a longer period of time. The river banks are subject to severe changes. They are referred to as braided river landscapes. Rivers with braided course are predominant in the Alps and the pre-alpine region.

c) Bended course

They are typical for areas with little slope. The transportation of **bedload** takes place in the river bed where the water flows more or less homogeneously. Accumulation of mostly finer sediment predominates. Rivers with bended course dominate in lowland.

2.3 Nutritionload regime

The amount of nutrition which is available for plants differs. It depends on the catchment area, on the course of the river and the age of the floodplain site.

It is typical for the soil of the natural floodplain that in the areas closer to the river the humus horizon is overlaid and buried by the dynamics in morphology and run-off. That means that there is a disruption of soil development and a reset to a previous stage.

The small delivery of nitrate and phosphate in freshly deposited sediments of the alpine rivers is remarkable. Due to the fact that the sediment consists of gravel and more or less coarse river sand the share of humus is small. Sediments, deposited in the course of a flood water event in alpine and pre-alpine floodplains do not, in contrast to the depositions of the lowland rivers, increase the nutritionload regime (FRÖHLICH 1994, HADLER 1994, HELLER 1969). Generally the nutrition available to plants in river sediments and floodplain sites increase in the lower reaches of the river because there the amount of humus in sediments is higher.

In contrast to the young soil near the river the soil development in areas farther away from the river bed is in a more mature stage. The name of the type of soil which is not inundated any more is Rendzina. Here it is also true that the supply of nutrition available to plants of alpine rivers is relatively low compared to that of lowland river plains. KREUTZER & SEIBERT (1984) who made nutrition investigations in plants and soils have proved that the supply of the *Querco-Ulmetum* with phosphor and nitrogen is essentially lower at the lower reaches of the alpine Lech than at the Danube that already has the character of a lowland river plain.

3. Biology of plants in amphibious habitats

3.1 Effects of river dynamics on plants

Stress, disturbance and competition are basic factors used to define the strategies of higher plants (GRIME 1979). Their effect on the composition of the vegetation differs in dependence on site and supply of resources in the floodplains and must be judged differently.

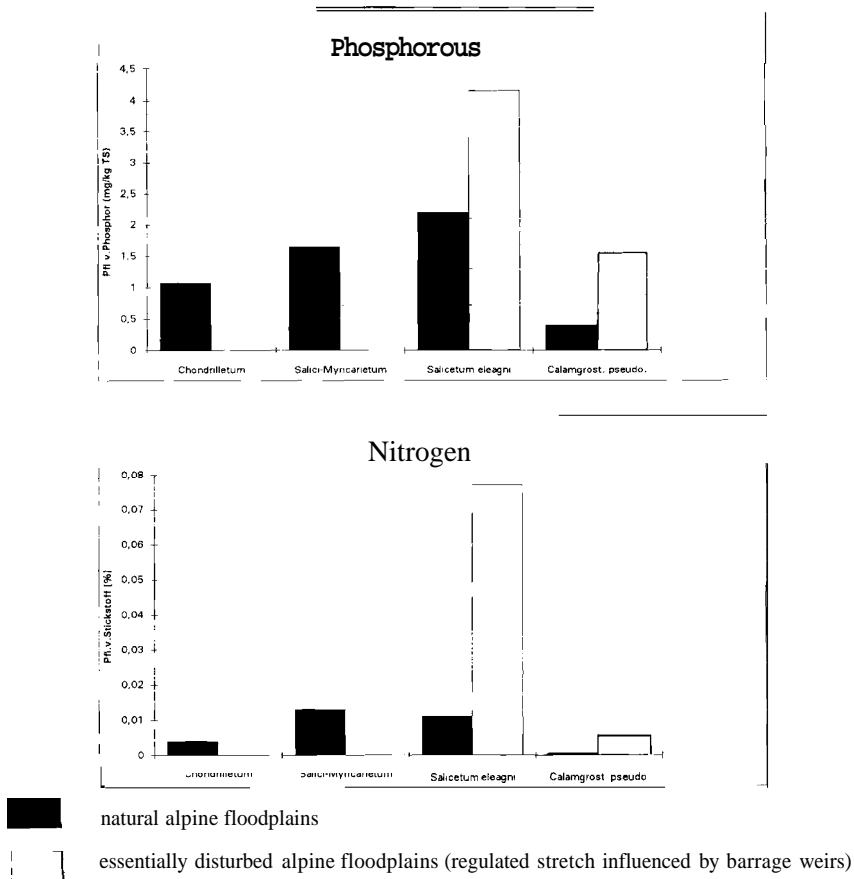


Fig. 4. Nutrition elements in the soil of typical plant communities of natural alpine floodplains (investigated at the upper reaches of the Lech in the northern Alps) and of essentially disturbed alpine floodplains (investigated at the lower reaches of the Lech) (according to FRÖHLICH 1994).

In the area of the alpine floodplain which is most intensely subject to the river dynamics stress and disturbance are at work.

For the plants in floodplain ecosystems stress can arise because of the change of inundation and dissication and the low amount of plant available nutrition in the soil. Whereas in times of the maximum mn-off in early summer a great deal of the floodplains is covered by water, water is a minimum factor on gravel bars which are rich in debris for the rest of the year. Investigations in different plant communities of the gravel bars of natural alpine floodplains have shown that the amount of nutrition elements in soils and plants are extremely low (comp. Fig. 4).

Physical disturbances are caused by morphodynamics and set the plant communities back to an earlier stage of succession or even back to the starting position. Because of this, plants that are strong competitors are hindered regularly on their way to domination so that plants which are weak competitors get the opportunity to

survive at the site (GRUBB 1985). Large gravel bars in the alpine floodplains, free or only covered partly by higher plants, make these effects visible.

It is only in habitats like the floodplains, which are no longer infected by the morphodynamics but which are mainly characterized by the hydrodynamics that the increasing competition is important for the organisation of plant communities.

3.2 Biology of the plants on gravel bars

Simplifying the factors mentioned above, a division can be made between habitats which are influenced by stress, disturbance and competition and which are inhabited by plants which have developed the corresponding strategies (after GRIME 1979).

Stress-strategists live in habitats full of stress, are mainly perennial, have a slow and low production of phytomaterial and have special strategies to exploit minimum factors (e.g. water or nutrition elements).

Ruderal-strategists live in regularly disturbed habitats, are annual, have the ability to develop masses of phytomaterial and have a high generative reproduction rate.

Competition-strategists are perennial, develop a dense leaf and root system and are characterized by low generative and vegetative reproduction rates.

Stress strategists are found mainly in the amphibious area of natural floodplains. They have to adapt to the change of inundation and dissication and to the shortage of nutrition (immature soils). According to the origin of the species one can distinguish three groups:

a) Species which come from other habitats also characterized by stress and disturbances such as e.g. alpine grassland communities and semi-arid grasslands in which nutrition elements and/or water are also limiting factors (e.g. *Dryas octopetala**, *Saxifraga caesia*) or debris communities in which the permanent soil movements require special adaptations (e.g. *Arabis alpina*, *Hutchinsia alpina*, *Linaria alpina*).

b) Species which are mainly distributed in floodplains or on sites with similar ecological conditions such as sliding hills (some *Salix*-species).

c) Species which live only in alpine floodplains and normally do not settle in substitute habitats (e.g. *Calamagrostispseudophragmites*, *Chondrilla chondrilloides*, *Myricaria germanica*, *Thypha minima*).

To serve as an example for a typical alpine floodplain species the biology of *Myricaria germanica*, a representative of the third group, will be explained in more detail.

Myricaria germanica grows only in river stretches where the natural gravel transport still exists and where the nutrition supply of the soil is poor. In the upper reaches of the Isar and the Lech the soil contains on average 1,5 mg phosphor/kg soil and 0,015% nitrogen (Fig. 4, FRÖHLICH 1994, HADLER 1994).

Myricaria germanica is adapted to the lack of water by a small leaf surface (protection from evaporation). Each plant has developed a long root system which

* The nomenclature of the latin plant names is based on EHRENDORFER (1973), those of the latin community names on OBERDORFER (1983).

allows them even in the case of low water level to reach the ground-water or the pressure-water.

Due to the fact, that the seeds of *Myricaria germanica* are distributed by the wind the plant is well adapted to space isolation and therefore able to inhabit immature soil sites along the river.

A longliving seedbank does not exist (OPITZ 1993). But due to a long life expectancy (up to some decades) *Myricaria germanica* is well adapted to temporal isolation (MÜLLER 1995).

If covered by debris *Myricaria germanica* is able to spread vegetatively by developing polycormones (OPITZ 1993).

Besides these adaptations to the site conditions in floodplains these species also make special demands on the habitat, which can only be fulfilled by a river with intact dynamics.

To establish its seeds *Myricaria germanica* depends on the period of time when the flood water is lowering away. The germination of the seeds only takes place in moist substrate and has to happen rather quickly. Investigations on germination proved that the first seeds start to germinate after four hours and after twenty hours already 94% have germinated (OPITZ 1993). The seeds make no special demands on the light conditions; they are able to germinate in light and darkness.

The different species of pioneer willows which grow in alpine braided river landscape (shortliving seedbank, wind distributed seeds, quick germination) show a similar strategy (*Salix ealeagnos*, *S. daphnoides*, *S. myrsinifolia*). Due to the shortage of nutrition in natural river stretches they grow very slowly and obtain only small growth above ground. In contrast to that, willows growing on sites with a better nutrition supply (e.g. in disturbed river stretches) can have a clearly higher annual growth. These plants are visibly thicker and higher (MÜLLER 1994 n. p.)

The plants are adapted to mechanical disturbances caused by the covering with gravel during flood water events by a strong ability of regeneration.

It is striking that in the amphibious area of natural alpine floodplains, in contrast to lowland river plains (comp. BERNHARD & POSCHLOD 1993), no ruderal strategists (e.g. field weeds and ruderal plants) and hardly any competition strategists are found. The same has been proved for several animal groups e.g. for grasshoppers (REICH 1991).

4. Structure and dynamics of the floodplain vegetation

4.1 Structuring of the floodplain vegetation

Generally the structuring of the floodplain vegetation is the result of the frequency of inundation or the water level (ELLENBERG 1978, HELLER 1969, MOOR 1958, SEIBERT 1958): When the water level is low, in the alpine rivers this happens mainly in autumn and winter, the gravel and sand bars in the river bed fall dry. At mean water level large parts of the river bed are inundated and in case of flood water even the higher placed wooded floodplains will be inundated. The areas which are reached only by flood water events limit the present floodplains (MOOR 1958).

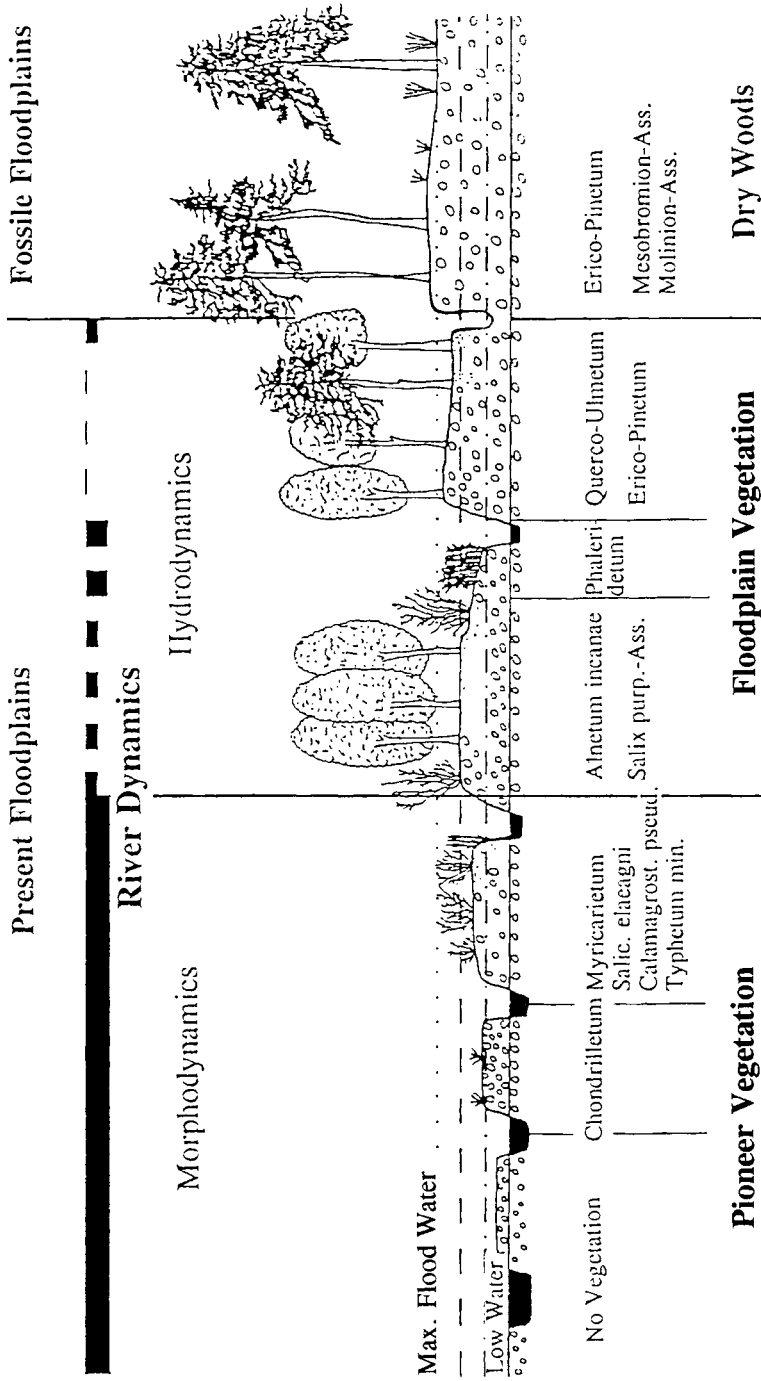


Fig. 5. River dynamics and structure of floodplain vegetation (simplified depiction) at the lower course of a northern alpine river (rich in debris) before river regulations (from MÜLLER 1995).

This way of structuring neglects the morphodynamics which are above all responsible for the organisation of the vegetation in the floodplains near the river.

Both, an ecological and a biological structuring of the floodplain vegetation has to be more differentiated. Including morphodynamics one can distinguish the following types of floodplain vegetation (comp. Fig. 5).

In floodplains close to the river (amphibious zone):

- Pioneer vegetation of the immature soil sites, which is characterized by strong periodical morphodynamic processes and by poverty of nutrition.
- The woodless flooding vegetation, which is organised by strong alterations in inundation and dissication. Morphodynamics only take place in form of sedimentation.

In the remaining area of floodplains:

- The silt-up vegetation of old river bends, which are characterized by the dynamics of groundwater.
- Periodically and episodically inundated floodplain forests, which are situated on higher river terraces.
- Vegetation, which initiated because of an early flood water event, but is nowadays situated outside the present river dynamics (fossile floodplains e.g. dry forests situated on old river depositions).

4.2 Spatial and temporal dimension of floodplain vegetation

To understand the structure of floodplain vegetation one has to consider the spatial and temporal dimension as well (FOECKLER & BOHLE 1991).

From the point of view of space natural floodplains are a mosaic built up of habitats which are organized by variable, frequent and intensive physical disturbances.

The temporal dimension is expressed by the different stages of development of the singular elements of the mosaic. Primary and secondary stages of succession are possible (BERNHARDT 1993, MÜLLER 1995). Extreme flood water events and the connected processes of erosion and accumulation initiate primary succession. Newly developed gravel and sand bars have to be inhabited by seeds coming from neighbouring areas. When already existing plant communities are partly covered with bedload the secondary succession begins.

The mosaic, depending on the conditions of the sites, of differently structured plant communities can clearly be seen in the amphibious zone of natural braided river landscapes, which is built up by more or less dense populated gravel bars and large areas free of vegetation. Looked at selectively the singular gravel bars (particles of the mosaic) show signs of high vegetation dynamics, but seen in connection with a larger area a great constancy is typical.

4.3 Plant communities

4.3.1 Pioneer vegetation of immature soil sites

Large, newly developed gravel and sand bars without vegetation or partly covered by pioneer vegetation are typical for the floodplains of alpine braided river landscapes which are situated close by the river. According to the frequency of inundation and that of being covered up by debris, the origin of substrate and the distance to the ground-water level one can, for example in the northern alpine area, distinguish between the following plant communities (comp. Fig. 5):

The *Chondriletum chondrilloidis* is the typical pioneer vegetation on fresh, coarse sandy sediments, which are situated just above the mean water level and are consequently inundated and covered up with gravel several times a year. When the water level is low these sites fall dry very soon because of the high porosity and the good aeration of the soil.

Another typical factor is the poorness of nutrition (comp. Fig. 4).

The *Calamagrostietum pseudophragmitis* inhabitates freshly sedimented sand deposits or alluvial channels, which are inundated several times a year or which are, at least, rather moist. Due to the circumstance that finer sands predominantly sediment in the current shadow of gravel bars, this community grows in general farther away from the main river bed than the *Chondriletum chondrilloidis*.

The *Juncetum alpini* grows in river channels which are inundated over a long period in summer and which in the case of low water level have connection with the ground-water at least from time to time. In contrast to the *Equiseto-Typhetum minimae* the channels consist mostly of a higher amount of debris.

The *Equiseto-Typhetum minimae* is the typical pioneer community growing on freshly developed old river bends that are connected with the ground-water or pressure-water. It grows on densely sedimented, fine-grain soil, which is constantly moist and badly provided with air when water is present in abundance (MÜLLER 1991c, VOLK 1938).

The *Salici-Myricarietum* is situated on fresh sand sediments with permanent high ground-water level which are periodically inundated and covered with debris. If the ground-water reaches the surface this community is even able to settle on gravel bars with coarse debris (MÜLLER & BÜRGER 1990, MOOR 1958). Because of the fact that the sites are located just above the water level in summer the surface of the sites can become very dry.

The *Salicetum elaeagni* grows on freshly sedimented alluvions consisting of coarse debris which are very dry in case of low water level and which are already inundated by mean water level. The typical formation is a low, regularly structured bush community, which often dominates big parts of gravel bars. It grows on gravel bars which are located slightly higher than the ones of the *Chondriletum*.

The *Salici-Hippophaetum rhamnoidis* grows on gravel bars built up of coarse debris and which are rather high, so that they will not be inundated periodically. Due to the fact, that even in case of flood water events the ground-water level remains one to two meters below the normal level, these sites are extremely dry (MOOR 1958).

Pioneer communities are specially adapted to the particular life conditions in natural alpine braided river landscapes. An analysis of the northern alpine area shows, that besides the *Juncetum alpini* these communities only exist in natural braided rivers.

4.3.2 Woodless flooding vegetation

Regularly inundated woodfree sites are characteristic for lowland river plains, where merely the draining water is the essential dynamic factor. They are characterized by the change of inundation and dissication, inhibiting the growth of forests.

In former days this group of vegetation found suitable life conditions especially in the lower reaches of alpine braided river landscapes. Due to slight slope and broad alluvions channels with slowly floating waters existed in the area distant to the river – in the transition to periodically inundated floodplains (comp. Fig. 5). Here the initial habitats of some communities of the woodless flooding vegetation are to be found. As comparative investigations in different gravel bar communities of northern alpine rivers show, the supply of plant available nutrition is higher in the soil of flooding vegetation than in that of pioneer vegetation (FRÖHLICH 1994, HADLER 1994).

Due to the construction of dams, causing the weakening of morphodynamics, the communities of flooding vegetation have been promoted in the remaining intact stretches. It has been documented for the Lech's gravel bars that, due to river engineering, pioneer vegetation has been substituted by flooding vegetation (MÜLLER et al. 1992 and point 6).

Important communities of the woodless flooding vegetation at northern alpine rivers are:

The *Barbarea vulgaris*-community grows on gravel bars rich in debris and is inundated by mean water. It often grows like a band at the contact zone between low- and mean water level.

The Rorippo-Agrostietum prorepentis grows on sandy and alluvial soils in the area of mean water level at the same level as the *Barbarea vulgaris*-community.

The Phalaridetum arundinaceae prefers coarse debris and sandy sediments with good air supply. It grows mainly a little above the mean water line and is inundated between 30 and 40 days of the year (HELLER 1969). In contrast to the *Phragmitetum* it is able to endure the mechanical burden of yearly inundations. It can quickly gain foot on newly sedimented soil.

The Phalarido-Petasitetum hybridum grows on depositions rich in silt and sand and full of nutrition in the zone of middle flood water level. According to the investigation in Switzerland it will be inundated on an average only 5 days a year (HELLER 1969).

The Dactylo-Festucetum arundinaceae grows especially in the zone of middle flood water level. In contrast to the Phalarido-Petasitetum it is situated on sandy depositions, in which the supply with nutrition is presumably bad.

The Tanaceto-Arrhenatheretum grows on yearly rarely inundated gravel bars with a great part of coarse debris. Inundations cause occasional disturbances which enable some competitive meadow species, especial Arrhenatherum elatius, to find good life conditions.

The Impatiens glandulifera-community shows a wide site amplitude. Preferred are gravel bars close to the mean water line.

Inside the present floodplain the *Solidago gigantea*-community has been observed up to now on episodically inundated sites in the area of flood water level. It is situated slightly higher than Impatiens glandulifera and prefers sandy depositions.

4.3.3 Silt-up vegetation of old river bends

Silt-up vegetation of old river channels can be divided into oligotrophic water plant communities (e.g. div. *Chara*-communities), sources and flat limemoors in channels provided by ground and pressure-water (*Astero bellidiastro-Saxijragetum mutatae* etc.) and eutrophic reeds and large-sedge swamps (*Phragmitetum australis*, *Caricetum elatae* etc.).

4.3.4 Periodically inundated floodplain woods

According to the original substratum the *Salicetum triandrae* and the *Salix purpurea*-community of northern alpine rivers are situated close to the amphibious area. Slightly higher grows the *Salicetum albae*. With increasing maturity of the soil it is substituted by the *Alnetum incanae*. The *Salicetum triandrae* and the *Salicetum albae* are characteristic for the middle and lower reaches, whereas the *Alnetum incanae* can be found from the upper to the lower reaches.

4.3.5 Episodically inundated floodplain woods

Woods of the northern alpine area, only inundated by extreme flood water events, could be divided into two vicarious communities. The *Querco-Ulmetum* in the planar and colline zone and the *Adoxo moschatellinae-Aceretum* in the montane zone.

4.3.6 Dry floodplain woods

On old river depositions, which are no longer influenced by river dynamics, soil development can continue unhindered so that in the long term zonale vegetation can develop. In this connection the gravel rich alluvions of the northern and southern alpine rivers assume a special position. There the soil development proceeds only very slowly so that various communities of the *Erico-Pinion* can gain a foot.

5. Human impact

5.1 Changes of landscape in the catchment area

As to alpine rivers, changes of river activities showing congruence with cooler and more moist climate phases have been proved for the holocene. It can, in addition to this, be assumed that since the late holocene human impact has led to an increasing activity in gravel transport in the alpine rivers. The formation of the three youngest river terraces at the lower Isar, for example, is due to human impact on the bedload regime since the Middle Ages (SCHELLMANN 1991).

The increased gravel transport of the alpine rivers coincides with the clearing phases in the mountains and the increasing settlement in the alpine valleys.

It may be assumed that the change of mountain forest to mountain meadows and pastures led to a more rapid draining away of rain and that during the time in which this alteration took place the bedload in the river increased because large quantities of soil were washed into it. Due to the increase in agriculture finer sediments in a

large extent (silt, loam and clay) and organic materials reached the river systems and were mainly sedimented in the lower reaches.

Even if there are no documents which show when the loam soils of the floodplains of the northern alpine rivers were erected, as, for example, exist for the Weser (STRAUTZ 1962), one can assume that large parts of the deposition of the floodplain loam in the lower reaches are due to human influence in the catchment area.

5.2 Nutrient input into the river system

Originally the mountain rivers were poor in nutrition (HELLER 1969). But especially since the beginning of the 20th century an increasing amount of organic and inorganic material (nutrition) were washed into the rivers, due to the increase of settlements of the landscape and the intensification of agriculture.

Nowadays natural river stretches at the alpine rivers are only found in the headwaters. Even the upper reaches are often more or less polluted. For example, in the German alpine area there is only a short stretch at the upper Isar which belongs to water quality grade class I. The remaining river courses are mostly, as the middle and lower reaches, polluted moderately up to critically (OBBS 1990).

5.3 Civil engineering measures

5.3.1 River regulations

Continuing river regulations were made relatively late on the alpine rivers. Only since the beginning of the 19th century the technical requirements have been available. At first river regulations were made to protect the settlements.

Rivers with a strongly braided course were straightened by the regulation. Due to the reduced cross-section of the river the result is an accelerated discharge. The increased transportation capacity of the river can only be compensated by picking up bedload from the regulated channel bed. The result is river bed erosion which, depending on the discharge and the construction of the river bed, can continue at a different speed (JAGGI 1990). The river bed of the Lech, for example, is now, 50 years after regulation, more than 5 meters deeper (BAUER 1979). Connected with the river's incision is the lowering of the ground-water level, which is effective in the whole catchment area (comp. e.g. BUCHWALD 1953).

Regulations include changes in the upper reaches of the alpine rivers as well as those in the tributaries. To protect the alpine areas with its increasingly dense population most braided rivers were regulated and deposit barriers were erected. The result was a severe lack of debris and bed load, causing further river bed erosions.

Due to regulations, river and floodplain habitats are divided functionally. Dynamic processes are limited to the straightened river course.

5.3.2 River stretches with reduced water regime

In the beginning of this century the construction of diversion sections at the regulated lower reaches were started to make use of the energy of the draining water.

In the course of this process the total amount of the water is normally diverted over a power station. Now the river bed itself only has water in times of high discharge, when the channel has reached its capacity limits.

Intense river bed incision takes place in regulated diversion sections (MÜLLER et al. 1992). In contrast, the erosion and accumulation will be balanced in unregulated diversion sections, in which in case of flood water, **bedload** will be diverted as well (SCHAUER 1984a). Regardless of the lack of water during times without discharge the ecological relations are similar to those in natural stretches where gravel transport takes place.

5.3.3 Power plant dams (Barrages)

Due to the increased demand for energy since 1940 additional hydroelectric power plants were built. In the northern area of the Alps, especially at the alpine rivers which are rich in water, e.g. Inn and Lech, a number of power plants have been erected.

In the reservoirs of power plants the river loses its character. Due to the interruption of the transportation of bedload, morphology processes are stopped.

Reservoirs have the following impact on downstream river stretches:

- Power plant dams cause reduced run-off and because of that the water warms up which leads to an increase in the primary production and consequently to an accumulation of nutrition in the water (DVWK 1981, MAUCH 1984).
- Dams have the effect of completely retaining the bed load gravel (BAUER 1979) and of being effective traps for suspension material. Due to the demand for energy, big reservoirs (so-called "headreservoirs") have been erected at the upper reaches of most northern alpine rivers which cause a change in the **bedload** regime of the river. Due to the lack of debris downstream of a dam, the river is forced to compensate its capacity of transportation by side and river bed erosion. The result is that in regulated and unregulated stretches the river digs itself deeper and deeper into the ground, it incises (BAUER & BURZ 1968). In unregulated stretches this is connected with a straightening of the river (VETTER 1992). Retainment of the debris is also responsible for the fact that in times of flood water only fine sediments are deposited at the remaining gravel bars, because coarser fractions can no longer be transported. Together with the reduced self-cleaning force of the water this leads to the circumstance that on gravel bars soil development continues rapidly and the supply of nutrition available to plants increases (FRÖHLICH 1994, HADLER 1994, comp. Fig. 4).
- Dams lead to a change in the discharge regime. Due to the reduction of run-off extremes the run-off is balanced and extreme flood water events which are mainly responsible for the forming of the river bed, do not take place any more (MÜLLER et al. 1992). This increase in time of the low water level (because of reasons connected with energy supply) leads to the fact that even in times of natural low water level the gravel bars will be partly inundated as well. When swell dams are in use the water level changes daily.

Due to retainment of gravel, the reduction of run-off extremes and the increase in time of low water level, the essential ecological attributes of braided river land-

scapes such as extreme changes between inundation and long periods of dissipation, periodical fluctuations of the ground-water level and high morphodynamics (and the connected deposition of immature soil sites) will be destroyed (MÜLLER 1995, MÜLLER et al. 1992).

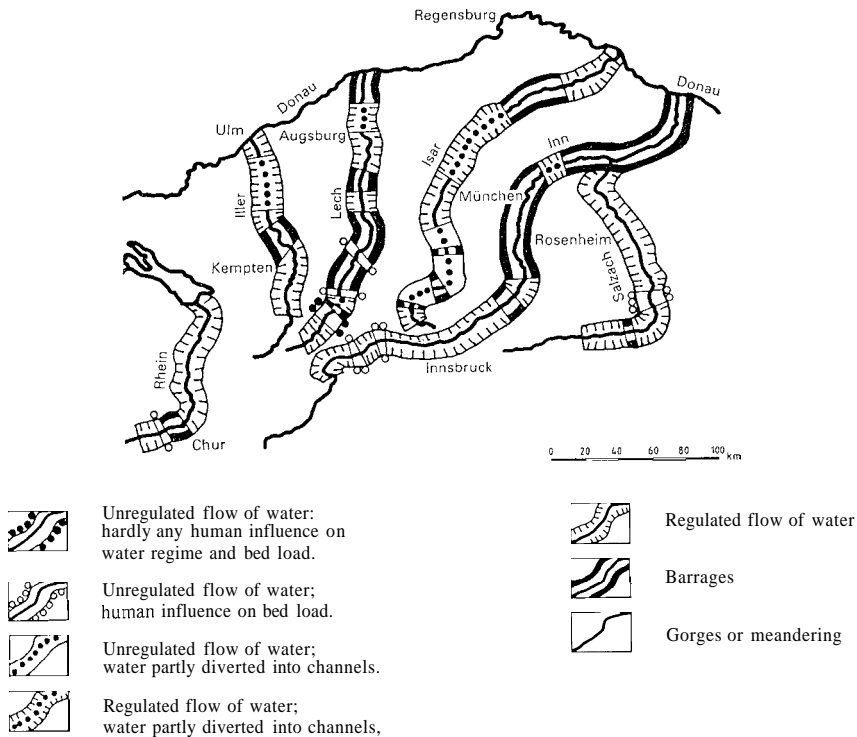


Fig. 6. Civil engineering measures at northern braided river landscapes (from MÜLLER 1991a)

5.4 Lack of biogeographical barriers

Man has influenced natural floral dynamics (distribution and retrogression of plants) since the early days of history. It has been assumed for Europe that man intentionally imported or unintentionally spread at least 12 000 fern- and flower plants. Due to that the amount of imported and spread species (hemerochores) surpasses the amount of local and wild growing fern- and flower plants (idiochorophytes) five times. As to the hemerochores only 2% were able to integrate in the natural vegetation (LOHMEYER & SUKOPP 1992). They are named agriophytes.

The phenomenons of hemerochy and agriophyty are the results of the loss of biogeographical barriers which are to be found world wide and have been at work with increasing intensity since the 16th century.

Generally speaking, human impact can be measured by the share agriophytes hold in the natural vegetation (SUKOPP 1962).

The inundation area of lowland rivers is characterized by an especially high share in agriophytes (LOHMEYER & SUKOPP 1993). Due to the fact that river dynamics were changed here at a rather early stage by man, it can not be reconstruct any more whether this favored the integration of new species.

In contrast to this the connections between civil river engineering and the spreading of species can be reconstructed more easily with the example of the last natural alpine rivers and the stretches which were changed by civil engineering measures.

6. Alterations of floodplain vegetation

6.1 Caused by changes of landscape in the catchment area

No data exist about the impact of forest clearings in the mountains during the Middle Ages and about the impact of increasing settlements in the alpine area on flora and vegetation of the alpine rivers. But it can be assumed that together with the increasing deposition of finer sediments in the lower reaches changes in flora and vegetation took place. In inundated areas communities of the flooding vegetation like the *Barbarea*-community and the *Phalarideturn arundinaceae* spread.

In areas farther away from the river floodplain, loamsoils developed favouring the *Alnetum incanae*, the *Saliceturn albae* and the *Quercu-Ulmetum*. It is assumed that since the Middle Ages an increasing immigration of field and ruderal weeds, as well as of hemerophytes into the floodplains took place.

6.2 Caused by civil engineering measures

6.2.1 River regulation and water diversion

The impacts of civil engineering measures on floodplain vegetation are documented in details for different alpine rivers.

The straightening of river courses dramatically reduces the area characterized by gravel transport and periodical inundations or supplied by pressure water (comp. Fig. 7). The pioneer vegetation strongly declines. Nowadays it only grows in small stocks on gravel bars located within the regulated channel. Outside of the regulated river soil development and floodplain succession to forest continue uninhibited (JERZ & al. 1986, MÜLLER 1991b, MÜLLER et al. 1992, SCHAUER 1984b, SEIBERT 1962). According to the substrate one can differ between two types of succession:

a) At alluvions with a great share of debris (Isar and Lech) different dry woods such as the *Erico-Pinetum* and the *Molinio-Pinetum* develop at the sites formerly inhabited by the *Chondriletum* (BRESINSKY 1959, MÜLLER 1991b, MÜLLER et al. 1992). In the pre-alpine region and in the warmer inner-alpine valley of the Inn the succession develops via the dry resistant *Salici-Hippophaetum* (GÖTTLING 1968). Due to the former grazing in floodplains, the secondarily developed heatlands were held open, so that semi-dry grassland-communities developed.

b) At alluvions with great share of sand the floodplain succession develops faster because water is not a limiting factor. The *Calamagrostietum* and the *Salici-Myrica-*

rietum develop to the *Salix purpurea*-community and to the *Alnetum incanae* and, eventually the place is taken over by the *Querco-Ulmetum*.

Nowadays the former braided courses are mainly covered with *Alnetum incanae*. Their overproportional share of area is due to:

- The unilateral sedimentation of sand in the area close to the river after the regulation which covered many former gravel sites (MÜLLER et al. 1992, OW 1952).
- The coppice woods of the floodplains favoured *Alnus* which is highly capable of regeneration so that the succession to the *Querco-Ulmetum* was inhibited (GOETTLING 1968, SEIBERT 1966).

But the *Alnetum incanae* is a degenerated formation which is at best inundated episodically and which already contains some dryness indicating plants in its weed layer.

The vegetation of old river bends is decreasing as well (comp. e.g. GEPP 1986). Due to the erosion of the river bed the ground-water level sinks, so that former river channels fall dry or are only temporarily filled with water. Old river bends dry up quickly and the *Alnetum incanae* spreads out.

As to the periodically inundated floodplain forests in the lower reaches the *Salicetum triandrae* and the *Salicetum albae* show considerable losses. Often they only build up a small wooden edge in front of the degenerated *Alnetum incanae* (e.g. MÜLLER 1991b, SEIBERT 1962).

In the area of diversion sections the situation for floodplain vegetation depending on ground- or pressure-water is even worse.

The area of the *Alnetum incanae*, the *Querco-Ulmetum* and the *Pinetum* increase due to regulation. But changes in the utilisation of land reduce them considerably in the course of the years. Land, in former days in areas of inundation, or sites close to the ground-water level have been transformed into intensive usable land by regulation. The utilisation of areas of the fossile floodplains in the lower reaches took place in this way. Semi-dry grassland and litter meadows were changed into intensive grassland and finally became arable fields. Settlements expanded into former floodplain sites.

Summing up, regulation measures above all led to changes in the quantity of the plant communities typical for river landscapes. Especially pioneer vegetation and the vegetation of old river bends show severe losses. In contrast, communities of the fossile floodplains increase. This can also be proved by investigations at other alpine rivers (BRAVARD et al. 1986, PAUTOU et al. 1991, PAUTOU & BRAVARD 1982, ROUX 1989).

6.2.2 Construction of hydroelectric power plants

The impact of hydroelectric power plants on floodplain vegetation is well documented at the northern alpine rivers (overview in MÜLLER 1995), especially for the Lech (MÜLLER 1991b, MÜLLER et al. 1992, SCHAUER 1984b, VETTER 1992), for the Isar (JERZ et al. 1986, SEIBERT & ZIELONKOWSKI 1972, SPEER 1977) and for the Inn (CONRAD-BRAUNER 1990).

Upstream of dams the river changes its character to that of a lake where dams exist. For this reason silt-up vegetation of eutrophic standing waters such as water

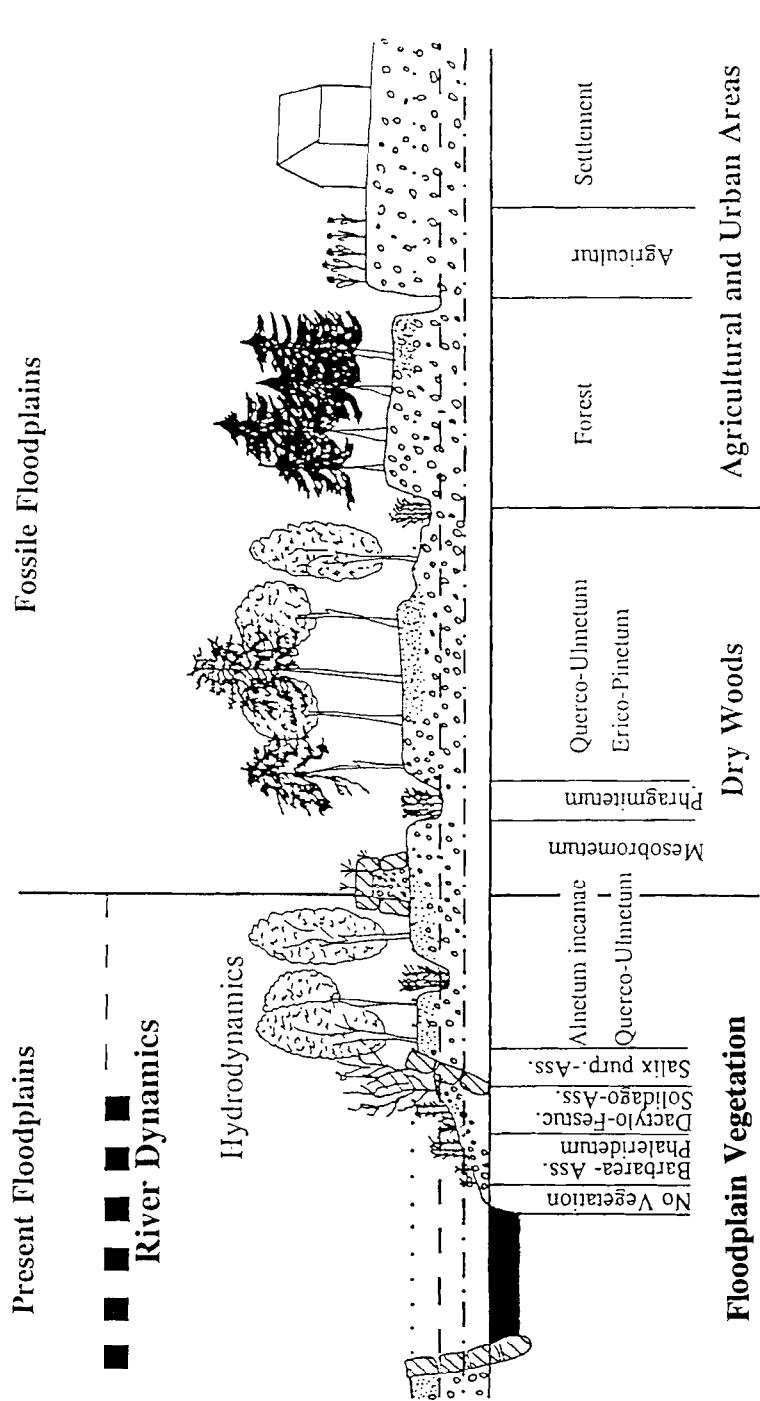


Fig. 7. River dynamics and structure of the floodplain vegetation (simplified depiction) of lower reaches of a northern alpine river (rich in debris) after river regulations (from MÜLLER 1995).

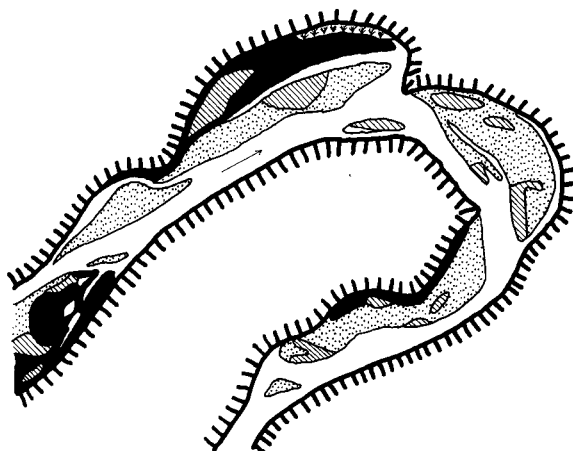
plant communities of the *Potamogetea*-class and reed swamps and *Typha latifolia*-communities grow in the amphibious zone nowadays (CONRAD-BRAUNER 1990). Societies similar to floodplain forests in general only exist in narrow bands along the river banks. Only in reservoirs, completely refilled with bedloads, communities similar to floodplain forests can develop in a larger extent, because a balance between erosion and accumulation will be secondarily established (CONRAD-BRAUNER 1990). But because debris will no longer be transported, there will only be communities growing on fine sediments rich of nutrition (e.g. *Salix* and *Alnus*-bushes and -forests and the *Phalaridetum*).

Hydroelectric power plants also have great impact on the downstream river stretches. This was documented in a large scale at the northern alpine Lech (MÜLLER et al. 1992). In unregulated stretches the floodplain vegetation has changed basically in the course of 40 years after the construction of dams in the upper reaches (comp. Fig. 8). Inside the gravel bar vegetation species weak of competition of oligotrophic plant communities (*Thlaspietea*, *Scheuchzerio-Caricetea furcae*, *Elyno-Seslerietea*, *Festuco-Brometea*) have decreased heavily. In contrast competitive species of nitrophile plant communities have strongly increased (*Phragmitetea*, *Agrostietea*, *Artemisietea*, *Chenopodietea*) (comp. Fig. 9).

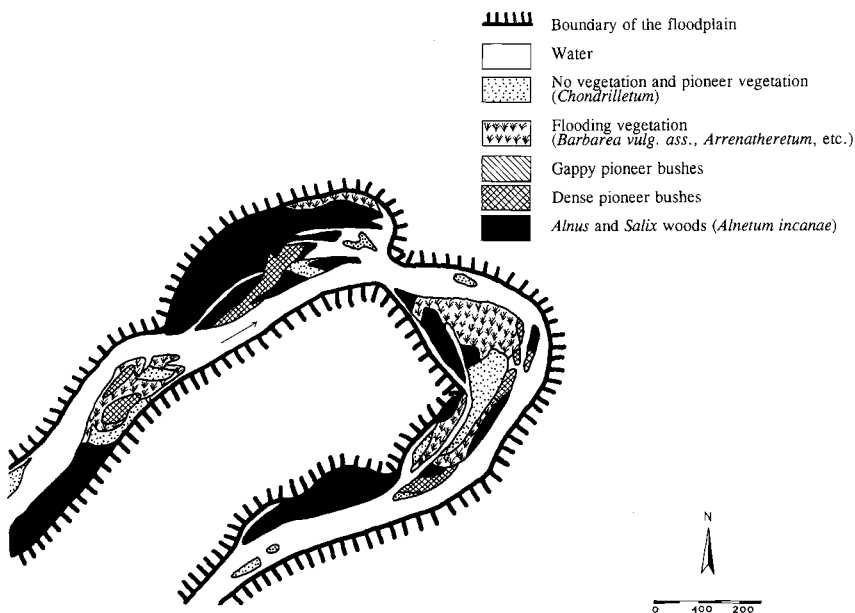
Because of the fact that debris is retained, erosion and accumulation do not take place any longer and soil development can continue in the amphibious area. This is connected with an increase of nutrition supply at gravel bars. Competition is becoming more and more important in the habitats. Stress-strategists such as e.g. *Chondrilla chondrilloides*, *Erigeron acris* subsp. *angulosus*, *Myricaria germanica* and *Typha minima* will be driven out by competition-strategists such as *Phalaris arundinacea*, *Festuca arundinacea* and others. Besides the improved nutrient conditions, changes in the structure of the soil and in the water regime are responsible for the decline of characteristic pioneer species. *Myricaria germanica* can serve as an example to show in what way civil engineering measures destroy "safe sites" (according to HARPER 1977) for specialized species.

Myricaria germanica is, as well as different pioneer willows, a type of strategist which is especially adapted to the life conditions in braided rivers (comp. point 4). They develop their seeds in the end of July when the annual flood water events are fading away. Due to the fact that the seeds are distributed by wind, they can quickly reach freshly developed sandy areas. In the first weeks the establishment of the seeds strongly depends on the water supply. The substrate has to be permanently moist, due to the fading away of the flood water or because of the good ability of the substrate to transport water. The short life of the seeds is remarkable. They live for 6 weeks at most. This is approximately the period of time, in which, due to the discharge of the flood water, the open sand bars are wet and therefore offer good conditions for germination exist.

If the river, due to a lack of debris, incises, the safe sites, essential for the establishment of seeds, are lost. This happens because the flood water is fading away quicker at gravel and sand bars. Seeds located on sand bars could germinate but then will dry out at an early stage. Germinated plants die because their roots do not reach the ground- and pressure-water any more. Even the probability of finding suitable growing places for the seeds becomes smaller, because with the increase of the regulated river stretches the amounts and areas of open gravel and sand bars decrease.



Floodplain vegetation in the year 1959 (mapping A. Bresinsky)



Floodplain vegetation in the year 1991 (mapping G. Vetter)

Fig. 8. Quantitative and qualitative changes of the floodplain vegetation due to the loss of river dynamics at an unregulated part of the Lech (northern Alps) (according to MÜLLER et al. 1992).

The decrease of *Myricaria germanica* at the northern alpine rivers is therefore directly connected with the degree of civil engineering measures on alpine rivers (comp. Fig. 6 and 10).

The change in river dynamics leads to the fact that in the areas farther away from the river, the floodplain succession continues unhindered to mature floodplain forest

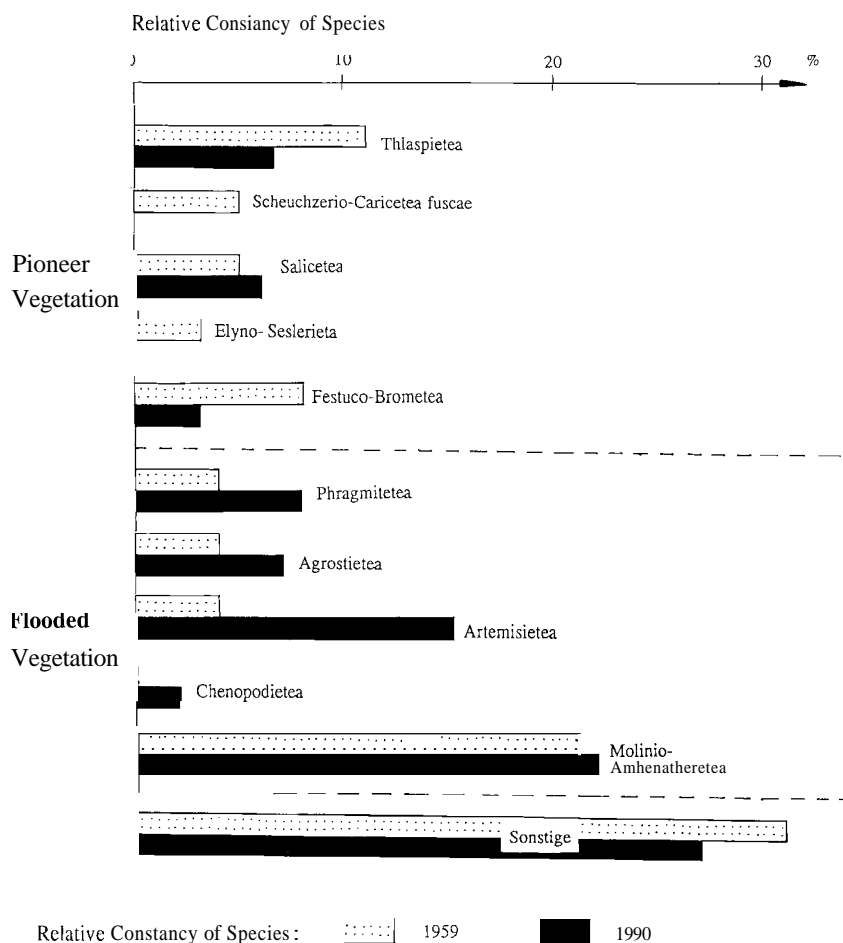


Fig. 9. Qualitative changes of the gravel bed vegetation due to the loss of river dynamics at an unregulated part of the Lech river (northern Alps) (from MÜLLER 1995).

communities. Consequently the *Alnetum incanae* and the *Quercus-Ulmum* increase in area (comp. Fig. 8).

The significantly smaller area of the amphibious zone is dominated by the woodless flooding vegetation because of the changed ecological conditions (MÜLLER 1995, MÜLLER et al. 1992). This is the reason why in the river course the *Barbarea*-community, the *Phalaridetum arundinaceae*, and other nitrophile communities of the lower reaches and of the lowland river plains can get as far as the upper reaches of the alpine floodplains. Competitive hemerophytes (e.g. *Impatiens glandulifera*, *Solidago gigantea*) find more and more sites with good growing conditions and built their own communities which are often similar to those found at places strongly influenced by man (ruderal sites).

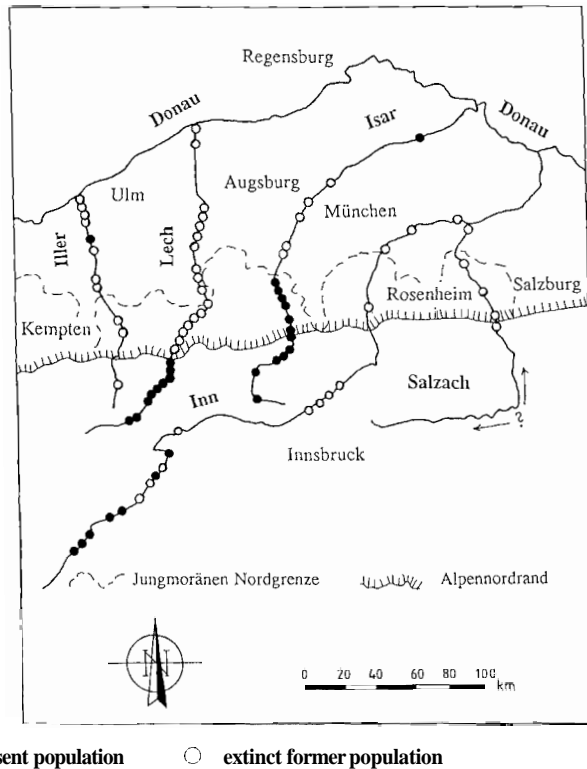


Fig. 10. Former and present populations of *Myricaria germanica* Desv. at northern alpine rivers (from MÜLLER 1995).

Connected with the loss of river dynamics is a large decrease in the vegetation of old river bends. Due to the change of water ecology even in unregulated stretches the typical oligotrophic communities of the original braided river landscapes, such as the *Caricetum davallianae*, *Primula-Schoenetum* and *Aster bellidiastro-Saxifragetum*, can not develop any more. Remaining old river bends are dominated by large-sedge swamps-communities and the *Phalaridetum arundinaceae* and dry out quickly due to the reduced river dynamics.

Summing up it becomes clear that river impoundment leads not only to quantitative but especially to qualitative changes in the floodplain vegetation. Species and biozoenoses adapted to the special conditions of alpine river ecosystems are dying out. Widespread communities of the central European rivers and communities influenced by man (ruderal communities) with euryoecious species are increasing (MÜLLER 1995).

6.3 Caused by the spread of hemerchores

Regarding the changes in floodplain vegetation, it becomes obvious that due to human impact two processes are under way:

On the one hand there is a strong decrease of stenoeccious species of the pioneer vegetation and on the other hand we can observe a spreading of common species of the moist and ruderal sites.

Especially ruderal communities consist, besides local species (idiochorophytes), of a number of species which came into our region because of the lack of biogeographical barriers. According to an analysis of plant sociological literature of northern alpine rivers, the floodplain vegetation consists of 40 hemerchores. The latter can, corresponding to the time when they arrived in Europe, be divided into older immigrants (archaeophytes) and new ones (neophytes). The following species can be definitely considered as established (agriophytes) and are common in floodplains (MÜLLER 1995):

<i>Acorus calamus</i>	<i>Dactylis glomerata</i>	<i>Melilotus alba</i>
<i>Arrhenatherum elatius</i>	<i>Elodea canadensis</i>	<i>Solidago canadensis</i>
<i>Capsella bursa-pastoris</i>	<i>Impatiens glandulifera</i>	<i>Solidago gigantea</i>
<i>Conyza canadensis</i>	<i>Impatiens parviflora</i>	

Comparing the different types of floodplain vegetation agriophytes have their center in the woodless flooding vegetation which means in vegetation which has increased largely due to civil engineering measures.

Especially the *Barbarea vulgaris*-community is able to take in agriophytes. There archaeophytes like *Capsella bursa-pastoris* have their center of distribution within the floodplain vegetation. A number of archaeophytes grow in the *Dactylo-Festucetum*, especially *Dactylis glomerata* and *Melilotus alba* have to be mentioned here. The *Tanaceto-Arrhenateretum* is characterized by *Arrhenatherum elatius*.

Nowadays the spreading of some neophytes at the gravel bars is most obvious. At the middle Isar *Impatiens glandulifera* has been spreading out widely since 1992 and inhabites gravel bars densely (MÜLLER 1995).

The competitive *Solidago gigantea* grows in the *Barbarea*-community, in the *Phalaridetum* and in the *Petasitetum hybridi* but has its main distribution center in the *Solidago gigantea*-community which is poor in species. Due to vegetative reproduction this species is able to infiltrate and replace the *Calamagrostietum pseudophragmitis* (MÜLLER et al. 1992).

According to the latest list of agriophytes in the vegetation of Central Europe (LOHMEYER & SUKOPF 1992) the greatest part of agriophytes grow in floodplain-communities. Responsible for this are on the one hand the generally good spreading conditions of open banks (food path of flora according to BŘEŠŇSKÝ 1965, MÜLLER 1990, TÜXEN & LOHMEYER 1950).

On the other hand there is a clear connection between civil engineering measures and the quick distribution and naturalization of hemerchores, according to all investigations on this subject (KOPECKÝ 1967b, MÜLLER 1995, SCHWABE & KRATOCHWIL 1991). Due to the loss of secure sites for species typical of braided river landscapes, the opportunities to inhabit open sites increase for the agriophytes. A number

of agriophytes have a high variability of populations and are therefore able to settle in different habitats (CORNELIUS 1987).

Presumably the increase of nutrition in the water supports the spreading of adventitious species, too. The Salzach, which among the northern alpine rivers is polluted the worst, attracts attention because here the share of agriophytes is rather high (MÜLLER 1995).

Hemerochore groups in the lower reaches of alpine rivers are especially widespread. This has been documented for the regulated northern alpine rivers (MÜLLER 1995, MOOR 1958, HELLER 1962) as well as for the unregulated Tagliamento in the southern Alps (MÜLLER et al. 1994). In direction of the upper reaches the number of adventitious species decreases continuously. The last undisturbed or only unessentially disturbed braided river landscapes in the Alps are in their upper reaches still free of agriophytes (MÜLLER 1988, MÜLLER & BÜRGER 1990, MÜLLER et al. 1994).

Reasons for the increase in agriophytes from the upper to the lower reaches of alpine rivers:

- Climatic reasons: A number of adventitious species came from warmer regions. In Europe agriophytes generally prefer lower locations, while they are rarer in hilly countries and mountains (e.g. LOHMEYER & SUKOPP 1992).
- Spreading centres: The larger settlements which are generally known as spreading centres for adventitious species concentrate in the lower reaches of alpine rivers.
- Anthropogenic disturbances: The intensity of civil engineering measures increase from the upper to the lower reaches. The connected disturbance of the river dynamics lead to a change in the floodplain communities and make the invasion of new species possible.
- The vegetation of the further valley: Investigations at the middle and lower Tagliamento make clear that natural river stretches are inhabited by adventitious species too, provided that larger populations exist in the valley (e.g. in settlements or in agricultural areas). Due to the fact that many agriophytes have good strategies for the distribution across widespread areas (distribution by wind) and are able to grow on rather different sites, they are able to settle in suitable sites within the floodplains. That is why even in floodplains with natural river dynamics safe sites of braided river specialists are destroyed by the invasion of foreign plants.

7. Questions concerning the understanding of the ecosystem of floodplains

Floodplains are generally known as particularly productive ecosystems, in which an abundance of nutrition exists especially in the amphibious zone (e.g. ELLENBERG 1978). The presented investigations show, at least for the alpine floodplains, that this richness of nutrition is due to the strong human impact on the landscape and on the changes in river dynamics. In contrast to that the most habitats of natural alpine floodplains are poor in nutrition.

Considering the long lasting human impact on lowland river floodplains, it can be assumed that in former days they were poorer in nutrition as well.

In this context the question must be raised, whether floodplains in general are the natural growing sites of a number of nitrophile field- and ruderal species (e.g.

LOHMEYER 1954). It can be assumed that many plants found suitable growing sites in floodplains only because of the change of abiotic living conditions. At least for the Alps this has been proved by these investigations.

Finally it has to be questioned how far natural floodplains are unstable habitats. The species of unstable habitats are usually composed of ruderal-strategists. But in natural floodplains especially stress-strategists are to be found. Only since the impact of man natural floodplain sites are increasingly dominated by ruderal- and competition-strategists. Another distinctive mark of unstable habitats are a high dynamics in flora and vegetation. This is only valid locally for natural floodplains. However, observing a large area, floodplains show a great constancy (comp. point 4).

8. Nature conservation

8.1 The situation of the alpine floodplains

According to a first inventory of alpine rivers, there is no larger river in the whole alpine area which has remained uninfluenced by man in its total length. Natural river stretches – which means river stretches upstream of dams with water grade I – are only rarely to be found in the alpine catchment area (MARTINET & DUBOST 1992). The last large alpine braided river landscape that is more than 100 km long, exists at the Tagliamento (Italy) in the southern Alps.

In the northern Alps the Lech is the last river containing stretches with natural river dynamics (comp. Fig. 6). Here the whole spectrum of floodplain vegetation of upper reaches rich in gravel is to be found.

According to a survey of the gravel bar vegetation in the northern alpine area (MÜLLER 1991a) the last deposits of typical pioneer vegetation are limited to short stretches in the upper reaches of Lech and Isar.

The gravel bar vegetation of the remaining river stretches in the northern alpine area has more or less been disturbed by river regulations or the construction of hydroelectric power plants. In the remaining natural stretches downstream from dams one can increasingly observe the decrease of pioneer vegetation and the spreading of flooding vegetation.

Next to their qualitative changes the loss of area within floodplain woods is especially drastic. An investigation in the northern alpine area by EDER & MAYER (1990) has documented the decrease of natural and partially natural floodplain woods to approximately 25% of their original area.

8.2 Consequences for conservation – and development measures

As this investigation shows, alpine braided river landscapes are very important for the conservation of the remaining natural floodplains in Europe. Due to human impact a great change of flora and vegetation has taken place. A number of typical species and communities have therefore, as well as the socialized fauna, died out or are shortly before extinction.

The first aim of nature conservation must therefore be to prepare international conservation and development conceptions for alpine rivers and to put them into action (comp. CIPRA 1992, GERKEN 1988, MARTINET & DUBOST 1992).

As a basis for conservation- and development conceptions, an inventory and assessment of alpine rivers according to a standardized method will have to be made. The inventory should equally take abiotic and biotic components into consideration, as it was, for example, done for the northern alpine rivers in a survey (comp. MÜLLER 1991a) and for the Lech, in details (MÜLLER et al. 1992).

Following parameters should be part of the inventory:

- Discharge and bedload dynamics (river dynamics)
- River morphology
- Classification of water
- Land utilization in the area of the floodplains and the catchment area
- Biozooenoses of floodplains

Due to the fact that the pioneer vegetation of immature soil sites reacts extremely fast to impacts on the river system and determines the development of following communities in the course of floodplain succession, it can be used as bioindicator for the function of the braided river system. The same is true for the fauna of gravel bars (PLACHTER 1986, REICH 1991).

Therefore the organisms and the biozooenoses of pioneer sites deserve special attention in the inventory of the floodplain biozooenoses. Areas for which protection- and development conceptions are urgent, can be registered quickly by an inventory of the gravel bar biozooenoses.

Because of the fact, that in floodplains important correlations exist between different habitats (comp. e.g. REICHHOLF 1989) the registration of the whole floodplain is necessary. In disturbed river stretches important habitats can be found even in the fossile floodplains, which are often of great importance for nature conservation.

The first aim of natural conservation is to secure the last natural or only moderately disturbed braided river landscapes in the Alps.

For the remaining river stretches, in which the floodplain vegetation has already been disturbed more or less by impoundment and river regulation, restoration measures are urgent to stop a further decrease in species and biozooenoses typical for floodplains. Restoration measures will only be successful if the essential factors of river ecosystems are restored. That means that bedload will have to be added to the river and the discharge regime will have to be adapted to the original conditions.

Short-term measures which can at least stop the extinction of many species are also possible until extensive measures at the alpine rivers are put into practice. For example:

- Restoration of longitudinal and diagonal constructions make at least a minimum of dynamics possible.
- Bed ramps could stabilize the bottom of the river bed and raise the ground-water level.
- In floodplains separated by dyke buildings, old river channels could be watered and in this way improve the situation for moist forests and old river bends.
- By use of *Alnetum incanae* in a way similar to that of coppice woods, river dynamics can be simulated to a certain level.

In addition to this, measures are necessary which have the aim of re-establishing the continuum of the floodplains along the whole river and connecting the often isolated habitats. The linking of floodplain habitats will be especially difficult in areas where the continuum of floodplains is interrupted by reservoirs. At least biotop aid conceptions should be realized which reconnect the existing residual habitats, and through management measures simulate the lacking river dynamics. Restoration measures lead to unavoidable conflicts with the hydroelectric use of the river. A complete restoration will often be limited by settlements in former floodplains. Examples in the U. S. A. where dykes and dams at rivers have been dismantled for a number of years, show that a regeneration is basically possible (PALMER 1986).

To stop a further decrease in species and biozooenoses and to recreate essential functions of floodplains, nature conservation will have to develop new conceptions in which especially the natural dynamics of this ecosystem are taken into consideration. In view of the momentary situation the conservation of the whole spectrum of flora and vegetation in braided river landscapes will be difficult. The success of restoration will essentially depend on the question of how quick comprehensive conceptions, reaching from the catchment area to the estuaries of alpine rivers, can be put into action.

8. Summary

Since the late days of the Stone Age man has influenced the large European floodplains by clearings and agriculture in the catchment area. In contrast to this major intrusions into the water and bedload regime of alpine rivers have taken place only since the Middle Ages. Despite intensive civil engineering measures since the last century some few stretches of natural conditions still exist in the catchment areas.

Alpine floodplains are consequently very suitable for research on human impact on floodplain ecosystems.

Within the last natural river floodplains of the northern and southern Alps, the regularities of river dynamics and floodplain vegetation are being investigated. By comparing different river stretches before and after civil engineering measures it is possible to examine the human impact on river dynamics and floodplain vegetation. Important results are:

- Essential abiotic factors in floodplains are hydro-, morpho- and nutrition dynamics (river dynamics). Due to the natural hydro- and morphodynamics, the plant succession as well as the development of soil in the amphibious zone is constantly interrupted and set back to an earlier stage. An important feature of alpine floodplains is that their alluvions, in contrast to that of lowland river plains, are poor of nutrition.
- Natural alpine floodplains have a highly specialized flora which is adapted strongly to the special life conditions (river dynamics). Besides plants originating from other extreme habitats there are a number of braided river specialists which do not accept substitute habitats outside of floodplains. Regarding the types of strategists, the plants in the amphibious zone are mostly stress-strategists which are adapted to a lack of nutrition and to temporal water shortage.
- Natural alpine floodplains are an impressive example for the dynamics balance in ecosystems. Referring to a larger area they show, under natural conditions, a high constancy in flora and vegetation. Plant communities mainly influenced by morphodynamics – the so-called pioneer vegetation – exist only in this habitat (*Chondriletum chondrilloides*, *Calamagrostietum pseudo-phragmitis*, *Equiseto-Typhetum minimae*, *Salici-Myricarietum*, *Salicetum elaeagni*, *Salici-Hippophaetum rhamnoidis*). Communities of lowland river plains the so-called flooding vegetation (*Barbarea vulgaris*-community, *Rorippo-Agrostietum prorepentis*, *Phalaridetum arundinaceae*).

Phalarido-Petasitetum hybridi, *Dactylo-Festucetum arundinaceae*) cannot be found before the lower reaches where increasingly only hydrodynamics are at work.

One can distinguish between the following human impacts on floodplain ecosystems:

- Changes of landscape in the catchment area
- Direct nutrient input into the river system
- Civil engineering measures
- Loss of biogeographical barriers

Whereas the impact of the changes of landscape in the catchment area of alpine floodplains can be reconstructed only roughly, the impacts due to civil engineering measures and to the loss of biogeographic barriers can be proved directly.

Because of river regulations the river dynamics were reduced to the regulated river bed and because of the construction of barrage dams it was totally stopped. Therefore it is possible that in the remaining natural river stretches soil development and succession to more mature floodplain vegetation is able to continue undisrupted within large parts of former floodplains. The result is that the nutrition supply on gravel bars will increase. Stress-strategists are driven out by competition- and ruderal-strategists. The share of fossile and episodically inundated floodplain woods is increasing enormously, while the amphibious zone is getting smaller and smaller. Due to the better nutrient supply the communities of the pioneer vegetation are substituted by those of the flooding vegetation. In this way the latter were able to move from the lower reaches as far as to the upper reaches.

Massive changes took place in the silt-up vegetation of old river bends, too. Besides the loss of area due to dyke building and river bed erosion one has to mention the decrease of oligotropic communities due to the lack of river dynamics (*Caricetum davallianae*, *Primula-Schoenetum ferruginei*, *Bellidiastro-Saxifragetum mutatae*).

Periodically inundated floodplain woods were promoted temporally by civil engineering measures. In the course of floodplain succession especially the *Alnetum incanae* conquered the sites which had before civil engineering been dominated by gravel transport. But due to the fact that there is a lack of regular inundations nowadays, the *Alnetum incanae* have just as the *Salicetum albae* been replaced by more mature floodplain communities (*Quercu-Ulmetum*).

Connected with the retreat of highly specialized floodplain specialists is, especially in the area near the river, the spread of ruderal species. As to their origin, one can distinguish between local species (idiochorophytes) and immigrated species (agriophytes). The latter can, corresponding to the time when they arrived in Europe, be divided into older immigrants (archaeophytes) and new ones (neophytes).

Widely spread archaeophytes are *Capsella bursa-pastoris*, *Dactylis glomerata*, *Melilotus alba* and rather common neophytes *Conyza canadensis*, *Impatiens parviflora*, *Solidago gigantea*. Some of them build up dominant communities poor of different species (*Arrhenatherum elatius*, *Impatiens glandulifera*, *Solidago gigantea*).

Particularly rich in agriophytes is the flooding vegetation (*Barbarea vulgaris*-community) and the formerly periodically inundated floodplain woods (*Alnetum incanae*).

Summing up it becomes clear that especially the construction of hydroelectric power plants have led to a major change of flora and vegetation in river floodplains. This has led to a lasting change of the fundamental abiotic factors of floodplain ecosystems, especially in the morpho- and river dynamics. Therefore species and biozoenoses adapted on the special conditions of river ecosystems vanish even in natural stretches. Common communities of the central European rivers and communities characterized by man (ruderal communities) with euryoecious species increase in number and move as far as to the upper reaches.

The primary aim of nature conservation consequently has to be the protection of the last natural river floodplains. To secure their typical spectrum of species and biotopes in the long term, their habitats will have to be extended, because already now a number of species show critical sizes of population.

To prevent a further loss of floodplain habitats it is urgently necessary to start restoration measures. They will only be successful if the natural river dynamics are re-established. Restorations

are particularly worthwhile in areas where no impoundments have changed the river dynamics strongly and where the typical spectrum of the floodplain vegetation still exists.

Regarding the momentary situation the conservation of the whole spectrum of the flora and vegetation typical for floodplains will be difficult. This is also true for the Alps. The success of restoration measures will depend to a large extent on the speed in which comprehensive conceptions are prepared and put into action, beginning in the catchment areas and proceeding to the estuaries.

10. Zusammenfassung

Bereits seit der Jungsteinzeit hat der Mensch die großen europäischen Auen des Tieflandes durch Rodungstätigkeit und ackerbauliche Nutzung im Einzugsgebiet beeinflusst. Demgegenüber erfolgten größere Eingriffe in den Wasser- und Feststoffhaushalt der Alpenflüsse erst seit dem Mittelalter. Trotz intensiver wasserbaulicher Eingriffe seit dem letzten Jahrhundert existieren hier noch einige Abschnitte mit weitgehend natürlichen Verhältnissen.

Alpine Auen eignen sich darum in besonderen Maße, um den Auswirkungen des menschlichen Einflusses auf Auenökosysteme nachzugehen.

An den letzten naturnahen Flußauen der Nord- und Südalpen werden Gesetzmäßigkeiten der Flußdynamik und Auenvegetation untersucht. Durch den Vergleich von verschiedenen Flußstrecken vor und nach dem Ausbau werden die Auswirkungen des menschlichen Einflusses auf Flußdynamik und Auenvegetation überprüft. Wichtige Ergebnisse sind:

- Wesentliche abiotische Faktoren in Auen sind die Hydro- die Morpho- und Nährstoffdynamik (Flußdynamik). Durch die natürliche Hydro- und Morphodynamik wird die pflanzliche Sukzession und Bodenentwicklung im amphibischen Bereich immer wieder unterbrochen und in ein jüngeres Stadium zurückversetzt. Ein wesentliches Merkmal alpiner Auen gegenüber den Tieflandauen ist die Nährstoffarmut der Alluvionen.
- Naturnahe alpine Auen weisen eine hoch spezialisierte Flora auf, die eng an die spezifischen Lebensbedingungen (Flußdynamik) angepaßt ist. Neben Pflanzen aus anderen Extremlebensräumen treten eine Reihe von Wildflußspezialisten auf, die außerhalb von Auen keine Ersatzstandorte annehmen. Nach den Strategietypen handelt es sich im amphibischen Bereich vorwiegend um Streßstrategen, die an Nährstoffarmut und zeitweisen Wassermangel angepaßt sind.
- Naturnahe alpine Auen sind ein eindrucksvolles Beispiel für das dynamische Gleichgewicht in Ökosystemen. Bezogen auf einen größeren Raum weisen sie unter natürlichen Verhältnissen eine hohe Konstanz von Flora und Vegetation auf. Die Pflanzengesellschaften, die am stärksten von der Morphodynamik beeinflußt sind – die sog. Pioniervegetation –, treten nur in diesem Lebensraum auf (*Chondriletum chondrilloidis*, *Calamagrostietum pseudophragmitis*, *Equiseto-Typetum minimae*, *Salici-Myricarietum*, *Salicetum elaeagni*, *Salici-Hippophaetum rhamnoidis*).

Erst zum Unterlauf, wo zunehmend nur noch die Hydrodynamik wirkt, kommen Gesellschaften der Tieflandauen, die sog. Überflutungsvegetation, vor (*Barbarea vulgaris*-Gesellschaft, *Rorip-po-Agrostietum prorepentis*, *Phalaridetum arundinaceae*, *Phalarido-Petasetum hybridi*, *Dactylo-Festucetum arundinaceae*).

Unter den menschlichen Einflüssen, die in Auenökosystemen wirken, kann man unterscheiden:

- Landschaftsveränderungen im Einzugsgebiet
- Direkte Nährstoffeinträge ins Flußsystem
- Flußbaumaßnahmen
- Verlust biogeographischer Barrieren

Während die Auswirkungen der Landschaftsveränderungen im Einzugsgebiet der alpinen Auen nur mehr grob rekonstruierbar sind, sind die Auswirkungen von Flußbaumaßnahmen und durch den Verlust biogeographischer Barrieren direkt nachweisbar.

Durch Flußregulierungen wurde die Flußdynamik auf das regulierte Gerinne reduziert, durch den Bau von Staustufen wurde sie ganz unterbunden. Dadurch kann in den verbliebenen Fließstrek-

ken die Bodenentwicklung und Sukzession zu reiferen Auwaldgesellschaften auf einem Großteil der ehemaligen Auenflächen ungehindert fortschreiten. Die Folge ist, daß zunehmend bessere Nährstoffverhältnisse auf den Kiesbänken gegeben sind. Streßstrategen werden dadurch von Konkurrenz- und Ruderalstrategen verdrängt. Der Anteil an fossilen und episodisch überschwemmten Auwäldern erhöht sich stark, während die engere amphibische Zone stark verringert wird. Auf Grund der verbesserten Nährstoffverhältnisse werden die Gesellschaften der Pioniervegetation von Überflutungsgesellschaften ersetzt. Letztere konnten so von den Unterläufen bis in die Oberläufe vordringen.

Starke Veränderungen haben auch in der Verlandungsvegetation der Altwasser stattgefunden. Neben einem flächenmäßigen Verlust durch Ausdeichung und Sohlenerosion ist vor allem der Rückgang oligothraphenter Gesellschaften durch den Verlust der Flußdynamik zu nennen (*Caricetum davallianae*, *Primulo-Schoenetum ferruginei*, *Bellidiasstro-Saxifragetum mutatae*).

Periodisch überschwemmte Auwälder erfuhren durch den Flußausbau zeitweise eine starke Förderung. Im Zuge der Auensukzession eroberte vor allem das *Alnetum incanae* die Standorte, die vor den Flußbaumaßnahmen von der Umlagerung beherrscht wurden. Da jedoch regelmäßige Überschwemmungen heute fehlen, werden die Grauerlenwälder ebenso wie das *Salicetum albae* von reiferen Auwaldgesellschaften (*Quercu-Ulmetum*) ersetzt.

Mit dem Rückgang von hochspezialisierten Auenarten ist vor allem im flußnahen Bereich die Ausbreitung von Ruderalarten verbunden. Nach ihrer Herkunft kann man zwischen einheimischen Arten (Idiophyten) und eingebürgerten Arten (Agriophyten) unterscheiden. Letztere kann man nach der Einbürgerungszeit in die Flora Europas in Alteinwanderer (Archäophyten) und Neueinwanderer (Neophyten) unterteilen.

Weit verbreitete Archäophyten sind *Capsella bursa-pastoris*, *Dactylis glomerata*, *Melilotus alba* und häufige Neophyten *Conyza canadensis*, *Impatiens parviflora*, *Solidago gigantea*. Einige von ihnen bauen artenarme Dominanzgesellschaften auf (*Arrhenatherum elatius*, *Impatiens glandulifera*, *Solidago gigantea*).

Besonders reich an Agriophyten sind die Überflutungsvegetation (*Barbarea vulgaris*-Gesellschaft) und die ehemals periodisch überschwemmten Auwälder (*Alnetum incanae*).

Zusammenfassend wird deutlich, daß vor allem der Bau von Staustufen zu starken Veränderungen in Flora und Vegetation von Flußauen führt. Sie verändern nachhaltig die wesentlichen abiotischen Faktoren von Auenökosystemen, insbesondere die Morpho- und Gewässerdynamik. An die spezifischen Verhältnisse von Flußökosystemen angepaßte Arten und Biozönosen gehen dadurch auch an den verbliebenen Fließstrecken verloren. Häufige Gesellschaften der mitteleuropäischen Fließgewässer und vom Menschen geprägte Gesellschaften (Ruderalgesellschaften) mit euryöken Arten nehmen zu und dringen bis in die Oberläufe vor.

Oberstes Ziel des Naturschutzes muß deshalb der Schutz der letzten naturnahen Flußauen sein. Will man ihr typisches Arten- und Biotopspektrum langfristig sichern, muß ihr Lebensraum wieder vergrößert werden, da bereits heute eine Reihe von Arten kritische Populationsgrößen aufweisen. Um einen weiteren Rückgang auentypischer Lebensräume aufzufangen, ist es darüber hinaus zwingend notwendig, daß Renaturierungsmaßnahmen eingeleitet werden. Sie haben nur Aussicht auf Erfolg, wenn die natürliche Flußdynamik wieder hergestellt wird.

Rückbaumaßnahmen sind vor allem in den Bereichen lohnend, wo noch keine Staustufen die Flußdynamik entscheidend verändert haben und das typische Spektrum der Auenvegetation noch vorhanden ist.

Die Erhaltung des gesamten Spektrums der auentypischen Flora und Vegetation wird sich angesichts der derzeitigen Situation auch in den Alpen schwierig gestalten. Wesentlich wird der Erfolg von Renaturierungsmaßnahmen davon abhängen, wie rasch umfassende Konzepte von den Einzugs- bis zu den Mündungsgebieten vorbereitet und umgesetzt werden.

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