Wetlands

xxxxxxxxxx.

Fig. 2. Restoration (1999, 2000) of two formerly channelised streams in the middle of arable fields, Dolní Moravice, N Moravia. After removing the concrete tubes and filling the grooves, a shallow, varied streambed and several retention reservoirs were created with an excavator. Subsequently autochthonous trees were planted in the space between the reservoirs to create a local biocorridor. This operation was initiated, designed and realised by Ekoservis Jeseníky, Světlá hora and financed from Landscape management programmes. (L. Bureš)

Restoration of drained mires in the Šumava National Park

Ivana Bufková & František Stíbal

Location 	South-west Czech Republic, along the border with Germany and Austria; 48°59'–49°0' N, 13°47'–14°28' E; altitude 750–1200 m.
Protection status	Šumava NP, Šumava Peatlands Ramsar Site, SCI, UNESCO Biosphere Reserve.
Ecosystem types	Open raised bogs with dwarf shrub, lawn and hollow vegetation surrounded by *Pinus ×pseudopumilio* krummholz, bog pine (*Pinus rotundata*) forests on valley bogs, transitional mires, spruce mires, waterlogged spruce forests.
Restored area	Ca. 500 ha (19 sites), nearly 60 km of blocked ditches.
Financial support	Ministry of the Environment, Šumava NP and PLA Authority.
Costs	Ca. €510,000.

Initial conditions

Many mires in the Šumava National Park have been modified by various human activities like forestry, agriculture and peat extraction in the past (Schreiber 1924). Various interventions in the hydrology, mainly surface drainage, are generally the most harmful impacts on mires in the area. A current mire survey revealed that almost 70% of mires have been influenced at least once by drainage. However, disturbance intensity varies largely across the area depending on e.g. human population density and land use. Drainage ditches from the turn of 19th and 20th centuries are rather shallow and usually less damaging for mires. By contrast, deep channels made from the 1960s to the 1980 are less frequent but represent a much more serious problem (Fig. 1).

Drainage in the past has caused significant degradation, both in mire ecology and mire structure (Bufková et al. 2008), and has negatively influenced mire biodiversity including rare and relict species. In acknowledgement of these trends, a long-term project called "Šumava Mountain Mire Restoration Programme" has been carried out in the area from 1999. Since 1996, only the position of the water table and its basic chemistry (pH, conductivity) was monitored but since 2005, the restoration project has been coupled with detailed research and a monitoring programme.

Abiotic conditions

All restored sites monitored in detail were situated on the central mountain plateau (at an elevation of ca. 1000 m). The bedrock is nutrient poor and acid. It is formed mainly of paragneisses, with some granite in places. The mean annual temperature is 3.2 °C and annual precipitation 1200–1330 mm (Svobodová et al. 2002).

Fig. 1. Blocked ditches on an open raised bog four years after restoration, Březnické slatě.

Fig. 2. Heavily drained spruce mire before restoration, Ztracená slať.

Fig. 3. Volunteers helping with mire restoration at Vrchové slatě (2010).

Objectives

The main objectives of the mire restoration programme were: (i) restoration of natural (or near-natural) mire hydrology; (ii) enhancement of peat-forming vegetation and processes, (iii) conservation of natural mire biodiversity; and (iv) involvement of the public into local mire conservation.

Regarding hydrology, the aim of the restoration was to raise the water table to a natural (pre-drainage) level, decrease the fluctuations, and retain sufficient water in the mires especially during the driest periods. These measures were expected to halt or moderate degradation processes and to enhance peat-forming vegetation and spontaneous mire regeneration.

Restoration measures

The restoration of drained mires was based on the target water table concept. The target water table corresponds with the natural water table in undisturbed mires, and differs according to mire type. The main restoration technique was the blocking of ditches with a set of board dams (Fig. 2) followed by filling the dammed ditches with natural material. The target water table and slope of the ditches were the key parameters to establish the number of dams and their distribution along the ditch. In deep ditches, the water-filled segments between the dams were then partly filled with peat, fascines (brushwood bundles), branches, *Sphagnum* clusters, etc. to enhance their terrestrialisation. In shallow ditches, especially under good light conditions, spontaneous terrestrialisation usually proceeds very well without any support. Because of the high vulnerability of the restored habitats, all work was carried out manually.

All restoration measures were limited in time (usually carried out during 1–2 years) and focused on the re-establishment of natural or near-natural hydrological conditions, after which subsequent autogenic plant succession including peat-forming vegetation and self-regulating development of a particular mire type are expected to start.

Since 2005, under the mire restoration programme, mire sites in various stages of degradation have been studied. Permanent plots (97 in total) were established to study the microtopographical, vegetation and drainage patterns of the different mire sites. The water table height was measured manually in all boreholes at roughly fortnightly intervals. Automatic gauging (at 1 h intervals) with piezometers was used in 49 selected boreholes. Water samples from boreholes, ditches, runoff profiles from drained sites and control streams were taken monthly for a detailed hydrochemical analysis, including the main cations and anions (SO_4, NO_3, NH_4, PO_4, Ca, Mg, Al, Fe), pH, conductivity and dissolved organic carbon (DOC). Runoff from drained sites as well as precipitation were measured continually.

1994–1998	Survey of mires in the Šumava NP including human impacts (e.g. drainage) and rough assessment of degradation changes.
1999	Initiation of the mire restoration programme. Restoration of the Kamerální slať Mire pilot project.
1995–2011	Basic monitoring (water table, groundwater pH and conductivity) of two selected raised bogs, the first one being restored in 1999, the second one in 2004.
2003	Update of the mire restoration programme conception – target water table concept included.
2003–2010	Restoration of 18 sites.
2005–2007	Detailed monitoring – pre-restoration phase.
2008	Restoration of two sites monitored in detail.
2009–2011	Detailed monitoring – post-restoration phase.

Results

First results suggest that the restoration has had a positive effect on the hydrology at the moderately degraded site. The mean water table rose and its fluctuations were reduced, especially in the dwarf-shrub bog sites and wet forests (Fig. 3). The water table beneath *Trichophorum* lawns remained at almost the same level, but also here

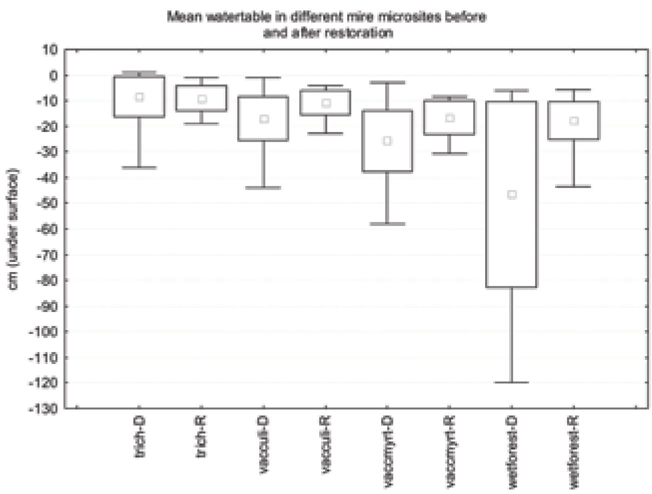

Fig. 4. Mean water table of moderately disturbed mire at Schachtenfilz, before and after restoration. D – before restoration; R – after restoration; trich – bog lawns dominated by *Trichophorum cespitosum*; vacculi – dwarf bog shrubs dominated by *Vaccinium uliginosum*; vaccmyrt – dwarf bog shrubs with both *Vaccinium uliginosum* and *V. myrtillus* (heavily drained); wet forest – waterlogged spruce forest.

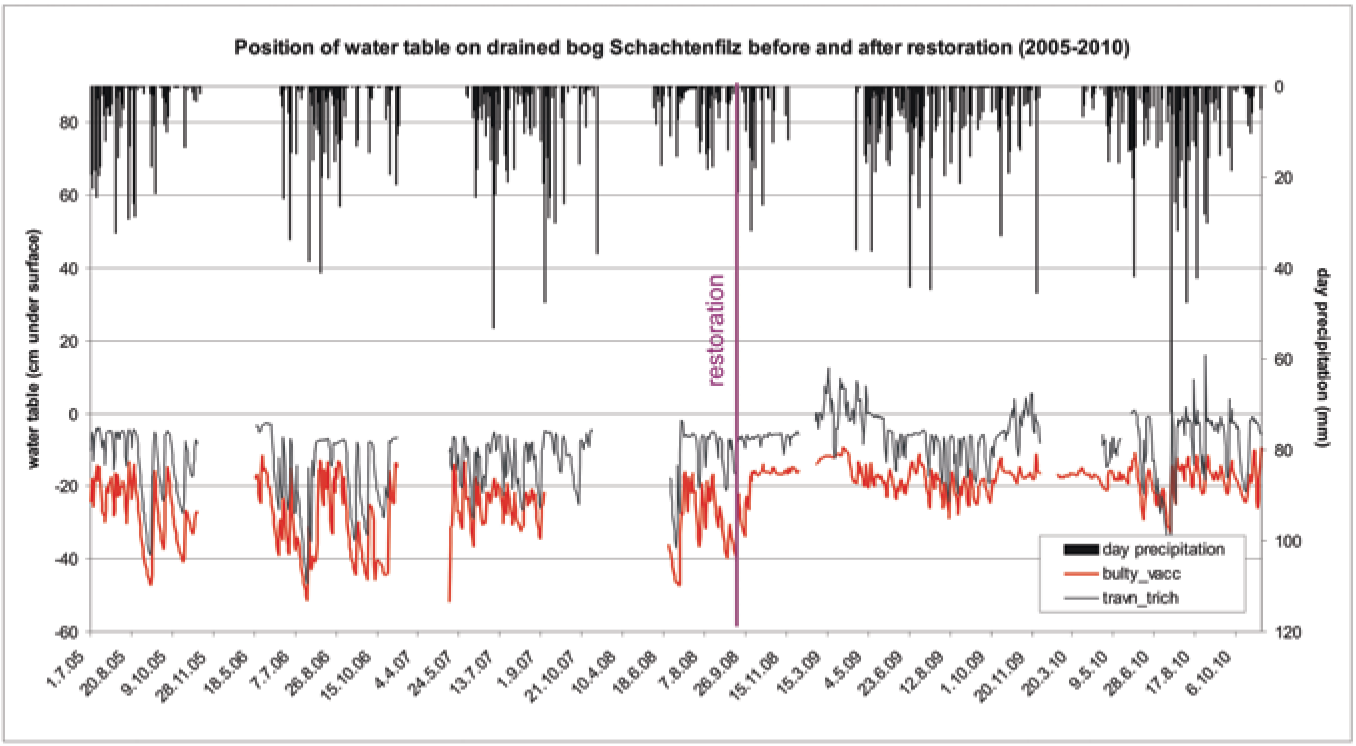

Fig. 5. Water table fluctuations before and after restoration in moderately disturbed raised bog at Schachtenfilz. Restoration time is indicated with a red vertical line; bulty_vacc – dwarf bog shrubs dominated by *Vaccinium* spp.; travn_trich – bog lawns dominated by *Trichophorum cespitosum*.

fluctuations were reduced (Bufková et al. 2010). The positive effect of the restoration on water table fluctuations can be seen in Fig. 4.

The various mire types differed in the hydrochemical response to the restoration. The results suggest that hydrochemical changes are more prominent in wet forests than in bogs. Electrical conductivity, PO_4, Al and Fe concentrations increased in wet forests but remained almost the same in bogs after the restoration. However, data two years after the restoration show only the short-term response of a mire to drain-blocking and may differ from the long-term response (Worrall et al. 2007). As a result, long-term monitoring will be necessary for a full understanding of the ecological processes and changes caused by restoration.

Other lessons learned and future perspectives

The target water table concept seems to be a useful tool in mire restoration especially in the case of bogs and various sloping mires. Long-term monitoring including a pre-restoration period of several years is necessary for evaluation of restoration success both in mires and adjacent habitats. The various proportions of restored minerotrophic mires and bogs should be taken into consideration when assessing hydrochemistry effects of restoration on the catchment level.

Public support

Involvement of the public into mire restoration and information on it are included into the aims of the project. Both visitors and local people regularly attend “Mire Days”, which have been organised in the Šumava NP since 2008. In the first half of such a mire day, people help with mire restoration after which they can visit undisturbed mires during the afternoon excursion. Similar “Mire Weeks” have also been organised in collaboration with NGOs for already 8 years. These “Mire Weeks” are attended mainly by young people and students. In this way several hundred people from the whole Czech Republic have taken part in mire restoration (Fig. 5).

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Restoration of the mined peatbog Soumarský Most

Petr Horn & Marek Bastl

Location	Šumava, southwest Czech Republic, near the border with Germany; 48°54'45" N, 13°49'33" E; altitude 745 m.
Protection status	NP, Šumavská peatlands Ramsar Site, SCI, UNESCO Biosphere Reserve.
Ecosystem types	Valley bog originally covered by bog pine (*Pinus rotundata*) forest and dwarf shrub vegetation dominated by *Vaccinium uliginosum*; degraded bog.
Restored area	53 ha.
Financial support	Ministry of the Environment – Landscape management programmes, Šumava NP and PLA Authority.
Costs	€3,193/ha.

Initial conditions

The Soumarský Most peatbog (total area ca. 80 ha) is part of a large mire complex developed in the basin of the Upper Vltava river. Initially, the peatbog was covered by typical bog pine (*Pinus rotundata*) forest (Schreiber 1924), but was partly damaged by manual peat digging on an area of approximately 15 ha at the beginning of 20th century. In 1959–1960 a detailed survey of the peatbog including peat profiles was carried out by the former Research Institute for Soils and Reclamation. Based on the results of this study peat mining was proposed on an area of 75 ha indicating a supply of 1,850,000 m^3 of peat (Anonymus 1960). Industrial peat milling was started shortly after the survey (in 1962) on large areas. Only a small remnant of the original bog remained in the southeast edge of the exploited area. Peat milling was stopped by the National Park Authority between 1998 and 2000.

Fig. 1. Redeveloped *Sphagnum* carpet between *Eriophorum vaginatum* tussocks on former bare peat (2011).

Abiotic conditions

After peat mining had ceased, the peatbog consisted of large areas of abandoned bare peat strongly drained by system of open ditches (Fig. 1). Several large ditches (both central and peripheral) were connected with a large number of small lateral ditches and in many places even piped (Fig. 2). The residual peat layer was up to 3 m thick, but the prevailing peat layer thickness was only 0.5 m and average peat thickness about 0.8 m. The bare peat surface was characterised by a harsh microclimate – especially high temperature extremes near the peat surface and a strong fluctuation of the water table and peat moisture, causing extreme desiccation in some places. Colonising plants and spontaneous revegetation were strongly limited by these conditions. The mean annual temperature in the area is 6.2 °C, the total annual precipitation is ca. 760 mm (Svobodová et al. 2002), but the whole valley is under strong influence of temperature inversion and a high amount of horizontal precipitation from frequent fogs.

Objectives

Restoration of a raised bog almost completely destroyed by industrial peat mining. Establishment of wetland communities and peat-forming vegetation with possible return of relict peatbog species in parts with a high water table and low nutrient contents.

Restoration measures

1995–1996	The first negotiations about further use and the future of Soumarský Most peatbog started with the former owner (Rašelina Soběslav, a private company).
1999	Ownership of the peatbog was changed from private to state (Šumava NP and Protected Landscape Area Authority).
1998–1999	Shallow surface depressions were created in collaboration with Rašelina Soběslav using their machinery.
1999	Peat milling was definitely finished.
2000	Project documentation was elaborated.
2000	The peatbog came in the hands of the town of Volary. Negotiations on the future of the bog took place.
2000–2004	Implementation of the restoration project.
2000–2011	Hydrology and vegetation monitoring.

The restoration measures were based on the concept of directed succession. First of all a few shallow depressions were made in the bare peat surface and consequently the highly fluctuating water regime was stabilised by blocking drainage ditches with boards (Fig. 3).

Fig. 2. Bare peat immediately after peat milling was finished in 2001.

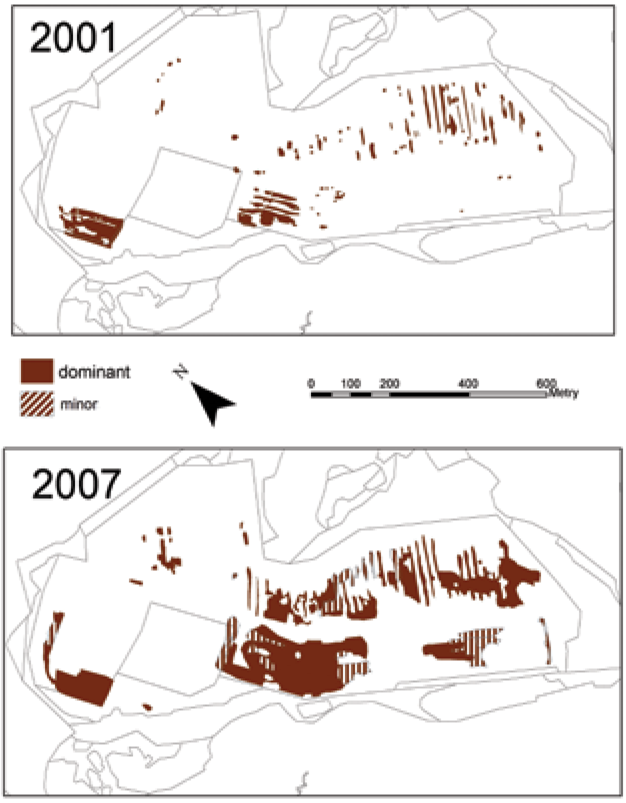

Fig. 3. The area covered by dominant *Eriophorum vaginatum* (brown patches) has grown tenfold between 2000 and 2007.

This improved the water regime in a large area and some parts of the bog were even shallowly but permanently flooded (Fig. 2 or 5). Sphagnum mosses – fundamental in peat-forming communities – were reintroduced, especially into these shallow basins (Fig. 6). The bare peat surface was covered with mulch from adjacent minerotrophic sedge mires to accelerate colonisation by appropriate vascular plant species. In dry areas selected groups of trees mostly including *Betula pubescens* and *Pinus sylvestris* were felled to reduce water loss through transpiration.

Assessment

The initial vegetation on the peat bog immediately after peat mining finished was dominated by wetland species growing mostly on the wet bases of the draining ditches, e.g. *Eriophorum angustifolium*, *E. vaginatum*, *Carex rostrata*, *Molinia caerulea*, and *Juncus effusus* (Zýval et al. 2000). These species were also later the main colonisers of bare peat areas, and the different proportions of them at the sites were probably determined by moisture and nutrients. The colonisation process was later strongly accelerated by experimental planting of *Carex rostrata* and *Eriophorum angustifolium* during restoration (Fig. 4). The main factor facilitating successful regeneration of peatbog vegetation was the restoration of the water regime. The main factors influencing the vegetation of flooded areas are water table height, depth of the remaining peat and successional age. The vegetation of flooded areas did not significantly respond to relatively small differences in water chemistry.

Initially Common Cottongrass (*Eriophorum angustifolium*) spread very successfully over both wet and dry areas. This species formed ring polycormons in drier parts which facilitated the establishment of other plants in their centre (Lanta et al. 2008). Therefore the increasing abundance of *E. angustifolium* in drier parts was only temporal and occurred in the first 5 years after the restoration measures had been carried out.

The main process observed during the vegetation development after 2006 was the rapid colonisation of bare peat by Hare's-Tail Cottongrass (*Eriophorum vaginatum*) tussocks (Fig. 7) (Horn 2009). Considerable changes in the total cover of this species after restoration (in 2000–2007) are shown in Fig. 8. It is very probable that *Eriophorum vaginatum* will also be reduced and facilitate establishment of other species in the future.

	bare	CalaEpig	Carx.spp	ErioAngu	ErioVagi	flooded	JuncEffu	MoliCaer	PhalArun
bare	0,7088	0,0147	0,0159	0,0452	0,1081	0,0000	0,0601	0,0473	0,0000
CalaEpig	0,1528	0,3426	0,0463	0,0417	0,0000	0,1042	0,2836	0,0289	0,0000
Carx.spp	0,1760	0,0035	0,1851	0,0871	0,2441	0,1347	0,0782	0,0912	0,0000
ErioAngu	0,2073	0,0000	0,0462	0,4608	0,1847	0,0418	0,0496	0,0096	0,0000
ErioVagi	0,1489	0,0014	0,0349	0,0973	0,6016	0,0183	0,0088	0,0888	0,0000
flooded	0,0000	0,0009	0,1159	0,0910	0,2344	0,4053	0,0751	0,0773	0,0000
JuncEffu	0,2108	0,0309	0,0419	0,0153	0,1062	0,0498	0,4358	0,1093	0,0000
MoliCaer	0,2176	0,0000	0,0452	0,0304	0,1813	0,2155	0,0897	0,2203	0,0000
PhalArun	0,0000	0,0000	0,7500	0,0000	0,0000	0,0000	0,2222	0,0278	0,0000

Tab. 1. Transition matrix of vascular species interaction between years 2000 (rows) and 2007 (columns). Bare – bare peat; flooded – permanently flooded areas without vegetation; yellow cells show the probability of an unchanged status, red cells show for each species in 2000 the highest probability of replacement with another species in 2007.

Fig. 4. Shallow waterlogged basins at the end of the restoration (2004), bare peat partly covered with vegetation can be seen in the background.

Fig. 6. Example of experimental planting plots with *Carex rostrata* and *Eriophorum angustifolium* (2001).

Margins of flooded areas and shallow basins were colonised by reintroduced *Sphagnum* species, especially *Sphagnum fallax* and *S. cuspidatum*. These sites have the best potential for establishment of peat-forming processes and communities (Fig. 6). The total area of *Sphagnum* carpets considerably increased in the restored peatbog. In 2002, the estimated *Sphagnum* cover was only about 1–2% of the total peatbog area, but in 2007 it was already about 8% (P. Horn, unpubl.).

Dry parts of the site were mostly colonised by trees such as *Betula pubescens* and *Pinus sylvestris* (Lanta & Hazuková 2005). At flooded sites, however, their proportion was significantly reduced by death. The interaction between vascular plant species recorded after restoration in 2000– and 2007 can be read from the transition matrix in Table 1. The matrix clearly shows that the most expansive species in 2000–2007 was *Eriophorum vaginatum*, which has the highest success not only in the colonisation of bare peat, but also in replacing other vascular plants (e.g. *Carex* spp., *Eriophorum angustifolium*). The second most successful plant was *Juncus effusus*, which colonised rather thin remaining layers of probably strongly mineralised bare peat.

Public support

Some restoration measures at the site were carried with the help of volunteers, mainly students. The site is also used as a tourist information point with connection to the nearby Vltava river floodplain. The nature trail with observation tower is under construction at the moment.

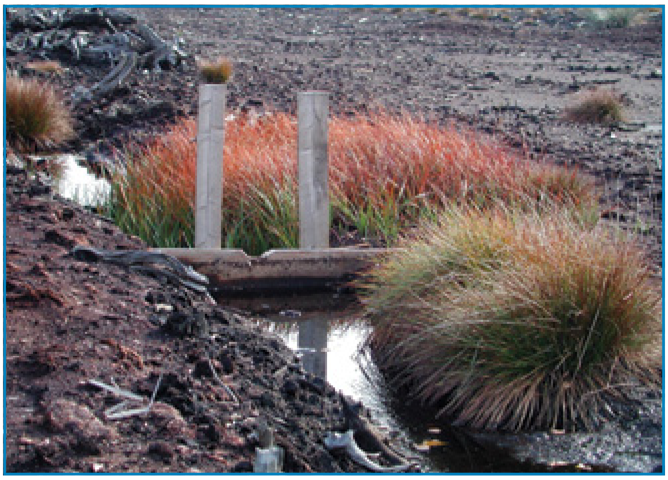

Fig. 5. Simple board dam used for blocking small open ditches (2001).

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Revitalising effects of near-natural bypass at a migration barrier on the Blanice River

Petr Hartvich & Petr Dvořák

Location 	Bypass at a weir on the Blanice River at Bavorov near Vodňany, South Bohemia; 49°12'23" N, 14°09'08" E; altitude 420 m.
Protection status	Important landscape element, riverine biocorridor, species protection.
Ecosystem types	Alluvial river ecosystem.
Restored area	Six kilometres of the Blanice River (between km signs 34.8 and 40.8).
Financial support	Landscape management programmes.
Costs	€19,920.

Initial conditions

The Blanice River springs at 972 m above sea level in the Šumava Mountains and joins the Otava River at an elevation of 362 m, where it is characterised as a lowland river with remaining oxbows. The gradient of the 93.3 km long river is 5.15% and the average flow is 4.23 $m^3.s^{-1}$ at its lower end.

Many damming-up devices have been built for water mills, hammer mills and sawmills, increasing the need for water. The river was fragmented into parts with still water and parts where the flow was regulated. The character of the river ecosystem has changed, affecting the natural development of fish populations (Hartvich et al. 2004).

A high dam works as a migration barrier. It cannot be overcome by fish moving upstream and so the long-term loss of upstream migration negatively influences the exchange of genetic information during reproduction. Separated fish populations become smaller as well as less resilient. Fish which are flushed downstream by the flow cannot get back to their habitat (Peter 1998, Lucas & Baras 2001).

Therefore fish passes are built where damming-up devices (weirs etc.) are located. They allow fish and other aquatic animals to pass the barriers and move freely along the river. Fish passes transfer the backwater to the stream below the barrier and are either a part of the migration barrier or placed on the grounds next to the barrier. In this case the fish pass functions as the bypass of a barrier. These fish passes are built in such a way that their character, structure and stream flow are similar to the conditions of natural rivers (Kubečka et al. 1997, Cowx & Welcomme 1998, Gebler 2009, Lusk et al. 2011).

In total 17 fixed or mobile barriers (weirs, dams) are placed across the Blanice River. These barriers are not migration-permeable, with one exception. The river continuity is disrupted mainly by the Husinec Dam-lake (area 61 ha, backwater 3.5 km long, maximum 25.5 m deep). Below the dam, the river has a weir impassable for migrating aquatic animals. On the right bank a ground overgrown with deciduous trees and a part of a former oxbow connected to the river below the weir were available. Because of these conditions, a near-natural bypass was proposed as the most convenient solution.

Objectives

Restoring and preserving healthy populations and diversity of the original fish species in Blanice River by means of building a bypass.

Restoration measures

In 2002, a 35 m long bypass was built at the weir to allow upstream migration. It runs from the upper weir through natural terrain around the body of the weir and joins the river 20 metres downstream of the weir. The average gradient is 5%. Fig. 3 shows the placement of this near-natural bypass. At a medium flow rate (Q180), up to 250 $l.s^{-1}$ flows through the bypass. The 2.5 m wide upper part of the bypass is a torrent fish pass with an inlet device placed upstream of the weir. The construction includes 9 stone sills for the necessary backwater, in which 7 to 16 cm wide gaps between the stones (boulders) enable fish to swim through either at the bottom or below the water surface. Gravel and smaller stones on the bottom decrease the flow in the lower water layers. The sills differ no more than 15 cm in height and their depth ranges from 0.3 to 0.5 m (Fig. 1).

The lower part of the bypass is formed by the oxbow (which was first cleaned) with slowly flowing water (Fig. 2). The width of the low-

Fig. 1. Upper torrent segment of the bypass. (V. Šámal)

Fig. 2. Torrent and lower, fluvial part of the bypass. (P. Dvořák)

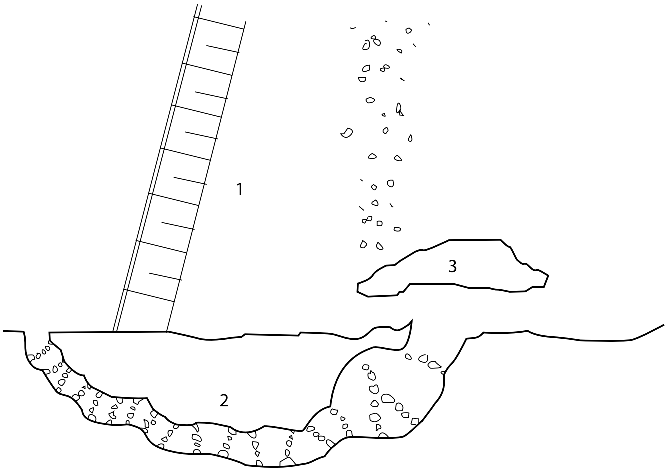

Fig. 3. Placement of the near-natural bypass at the migration barrier. 1 – migration barrier (weir body); 2 – bypass with stone sills; 3 – gravel island in baffle platform.

er part ranges from 3 to 5 m and the gradient is only 2%, but a few stone sills form up to 1 m deep pools. In places over sand and gravel banks shoals have been formed by high-water flows.

Management measures

— Bypass maintenance after floods, in spring and autumn.
— Removal of sediments to keep the bypass clear.
— Seasonal monitoring of local fish fauna diversity in the bypass passable for migration.

Conclusions

The presence of fish in the bypass was monitored once a month during the year 2002 (except during ice cover in winter and high-water) to assess species diversity (Hartvich et al. 2004). This was done by damming up the inlet profile with a board to stop the stream, so that the fish present could be collected and the remaining ones caught with electric current. A small net was placed in the lower part to prevent the fish from escaping. The fish were measured using common ichthyologic methods and returned immediately.

The critically endangered Brook Lamprey (*Lampetra planeri*) and 13 species of six families were detected during the first monitoring period (Tab. 1). According to ecological preference rheophilous (living in fast streams) species (8) were the most abundant, followed by eurytopic (5) and one limnophilous (living in standing water) species, namely Doctor-fish (*Tinca tinca*). The total fish fauna counted 610 individuals weighing 8,939 g in total. The most abundant species were *Pseudorasbora parva*, *Leuciscus leuciscus*, and *Perca perca*. In the lower part of the bypass, a few individuals of the critically endangered European Crayfish (*Astacus astacus*) were found. In the following period (January to November 2003), the number of species grew to 18, including the newcomers *Alburnus alburnus*, *Barbus barbus*, *Scardinius erythrophthalmus* and *Anguilla anguilla* (Hartvich et al. 2004). The annual fish fauna abundance was 993 individuals and their biomass 7,876 g. The detected species assemblage corresponds, except for *Cottus gobio*, to the results given by Krupauer (1984) for the Blanice River upstream of the Husinec Dam-lake, and later mentioned by Křížek et al. (2004) for the upper and central part of the Blanice River.

Fig. 4. The bypass under construction. Depositing of boulders on the banks and into the sill across the stream. (V. Šámal)

Other lessons learned and new perspectives

1. Grassland and self-seeded trees (willows and aspen) permanently reinforce and protect the banks of the bypass against erosion. The open inlet device passes water level fluctuations into the bypass. High-water flows do not endanger the bypass construction. Loosely placed stones on the bypass banks slow down the flow, prevent lateral erosion and create shelter for fish. Coarse gravel on the bottom is an appropriate substrate for the settling of benthos.
2. Monitoring results show that fish not only migrate through the bypass but also settle there for a certain period of time. The 18 species of fish and lamprey detected in the bypass correspond to the composition found in ichthyologic research conducted in the upper and central part of the Blanice River. Fish migration in the bypass takes place during the whole year, except when there is ice cover.
3. Monitoring of bypass passability not only provides ichthyologists, nature conservationists, water authorities, and designers and builders of fish passes with a lot of new information, but it also shows the real state of the fish fauna in river districts, especially in the case of functional passes such as the one at Bavorov.

Public support

The bypass on the Blanice River was co-supported by the town council of Bavorov and by the Bavorov branch of the Czech Fishing Association. The bypass is open to everybody who is interested in it.

Fig. 5. Bypass under construction. Depositing of coarse gravel on the stream bottom between the stone sills. (V. Šámal)

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