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Managed flooding as a tool for supporting natural fish reproduction in man-made lentic water bodies

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Abstract In 2001, fish diversity and abundance were investigated in six man-made borrow pits in the flood plain of the River Dyje (Danube basin). All borrow pits had uniform habitats without shelter, and with limited spawning and nursery areas. Spawning and nursery habitat conditions in three borrow pits were experimentally improved by managed flooding during spring and summer, while the other three borrow pits were not flooded. Adult (>1 year) fish were surveyed in spring and autumn by beach seining and 0+ fish were monitored monthly by dipnetting and fry beach seine nets. Flooded borrow pits had slightly higher adult species richness, considerably higher adult fish abundance and considerably higher 0+ fish species richness and abundance. The seasonal decline in 0+ fish abundance varied between flooded and non-flooded borrow pits, with a faster decline in 0+ abundance at non-flooded sites. Management implications for floodplain lentic water bodies are discussed.

KEYWORDS: 0+ fish, flood, floodplain, oxbow lakes, recruitment, river management, spawning.

Introduction

During floodplain inundation, many fishes migrate from the main channel and permanent lentic water bodies to the flooded areas (Galat, Fredrickson, Humburg & Bataille 1998). The presence of large numbers of juvenile fishes shows that many species utilise the flood plain for spawning and as nursery areas (Guillory 1979; Ross & Baker 1983; Sheaffer & Nickum 1986; Turner, Trexler, Miller & Toyer 1994). The timing of flooding and water temperature are important for the success of reproduction in phytophilous and phytolithophilous fishes (e.g. Balon 1966; Welcomme 1979; Bartošová & Jurajda 2001).

The channelisation and dyking of floodplain rivers have decreased the physical diversity of these river systems, with much of the surrounding flood plain and lentic waters (e.g. oxbows and pools) separated from the main river channel and its flood events (Holland & Huston 1985; Scott & Nielsen 1989; Neumann, Seidenberg-Busse, Petermeier, Staas, Mools & Rutschke 1996; Cowx & Welcomme 1998).

Several studies investigated the utilisation by larval and juvenile fishes of backwaters (Holland & Huston 1985; Sheaffer & Nickum 1986; Scott & Nielsen 1989) and artificial gravel-pits connected with the main river channel (Staas & Neumann 1994) as nursery habitats. However, few studies (Copp 1989; Grift, Buijse, van Densen & Klein Breteler 2001) have addressed 0+ fish fauna of floodplain oxbow lakes that are separated from the main river. These permanent static water bodies in the flood plain may play a crucial role for 0+ fish survival after the flood has receded (Halyk & Balon 1983; Sabo & Kelso 1991). Floodplain borrow

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pits excavated during dyke construction could serve as convenient substitute biotopes, performing the same ecological role as natural backwaters and oxbows, lost as a result of river regulation (Sabo & Kelso 1991).

In this study the structure of fish assemblages and success of reproduction in a series of differently managed borrow pits were assessed. Three borrow pits were annually flooded (May to June) while the other three were not flooded. The effects of flooding regimes and flood duration on the structure of the 0+ fish community in each borrow pit were evaluated.

Study area, material and methods

Work was conducted in the flood plain of the River Dyje, the right tributary of the River Morava (Danube basin) and one of the largest rivers in the Czech Republic (length of 305 km) with a drainage area of 13 418 km^2. The average annual discharge at the study site was 44 m^3 s^{-1} (Vlček, Kestřánek, Kříž, Novotný & Píše 1984).

Most backwaters available to fishes as nursery areas were lost after channelisation of the River Dyje during the 1970s. Natural flooding in the study area was eliminated because of river regulation and the construction of the Nové Mlýny reservoirs 45 km upstream of the study sites during the 1980s. In the last decade, spring floods (with a discharge > 80 m^3 s^{-1}) were recorded only in 1996 and 1997. This investigation was conducted in the lowest section of the River Dyje flood plain (0.0–10.0 river km). Study sites were situated along the left bank of the river (Fig. 1) in the area of floodplain meadows.

All six localities were created between 1983 and 1985, when the flood protection dykes were built from excavated material. No further dredging of these localities was carried out since their construction, corresponding to the term borrow pits according to Cowx & Welcomme (1998). All localities had a regular shape (square, rectangular or round), steep banks and a sand-gravel bottom with a thin layer of silt. Aquatic vegetation was absent, with the exception of the rare occurrence of *Ceratophyllum* sp. in borrow pit 6. At the highest water level reached during non-flood situation, water may extend to the base of bankside vegetation. The size of borrow pits varied from 0.2 to 1.4 ha with an average depth of 2 m. Three borrow pits (sites 1–3) situated in the upper part of the study area (Fig. 1) were not influenced by managed flooding. Hereafter these sites will be referred to as non-flooded borrow pits. The other three borrow pits (4–6) were situated in the lower part of study area and were affected by the managed flooding (Fig. 1). They are referred to as flooded borrow pits. The three flooded borrow pits were relatively close to each other and became connected during flooding. However, no connection with the river occurred during managed flooding. Borrow pit surroundings were inundated by raising the ground water level. The water level fluctuation in all borrow pits was measured throughout the study period. Zero value corresponded to a bankfull water level. Positive water level values indicated the extent

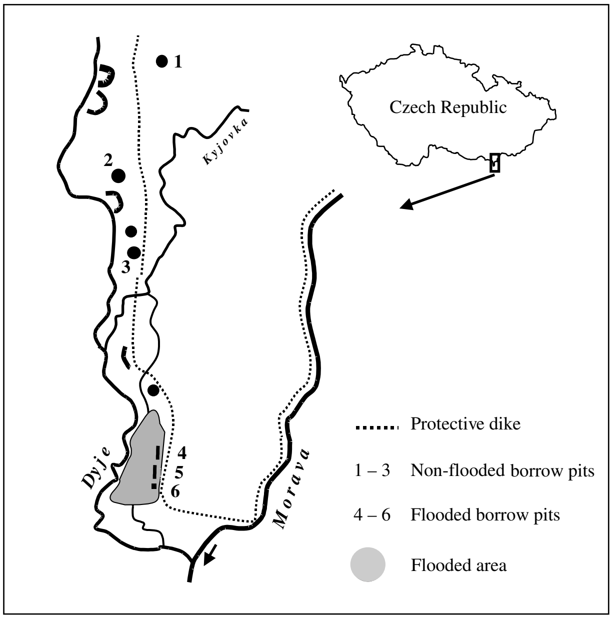

Figure 1. Map of the lower course of the River Dyje under study in 2001, with six study sites indicated.

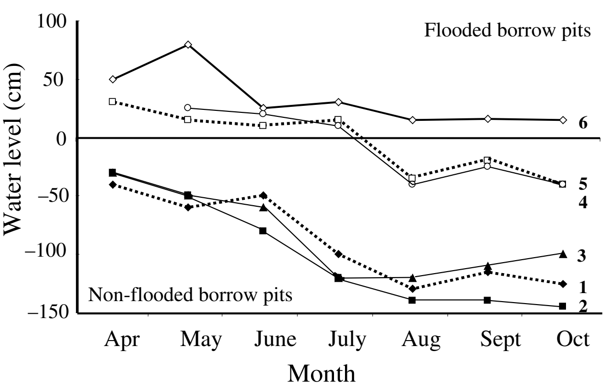

Figure 2. Seasonal dynamics of water level fluctuation in the six borrow pits in 2001. Positive values indicate flooding, negative values indicate a fall in water level below a bankfull.

Table 1. Physical characteristics and sampling effort in the borrow pits of the River Dyje surveyed in 2001

	Non-flooded			Flooded		
Parameter (unit)	1	2	3	4	5	6
Area (ha)	1.2	1.4	1.2	0.7	0.8	0.2
Maximal depth (m)	3	3	2.7	2.3	3.2	2.8
Length of shoreline (m)	370	500	470	670	1100	400
Water temperature in May (°C)	20.0	21.3	22.0	22.5	21.0	20.5
Water temperature in June (°C)	18.0	19.0	18.2	19.0	19.0	20.0
Water temperature in July (°C)	24.8	25.0	25.0	24.0	25.0	29.0
Conductivity (μS)	473	436	535	523	528	536
Number of seining hauls (adults)	7	10	8	6	8	2
Number of dipnet hauls (0+)	20	20	20	20	20	20
Number of seining hauls (0+)	12	12	12	12	12	4

of flooding and negative values indicated the extent of water level below bankfull (Fig. 2).

Adult fish (1 year and older) were sampled at two to 12 locations in each borrow pit in spring and autumn 2001 using a beach seine (40 m length, 10 mm mesh size) (Table 1). The 0+ fish were sampled monthly from May to October. In May and June, dipnetting using a point abundance strategy was used for semi-quantitative sampling (20 points per site). After June, a beach seine (5 m long, 2 mm mesh size) was used for 8–12 nettings at each site (Table 1).

In May, the meadows around the three flooded borrow pits (sites 4–6) were artificially inundated by the Forestry Authority from the River Kyjovka (a tributary of the River Dyje) for 3–4 weeks (Fig. 2). Natural flooding occurred in July because of high discharge levels in the River Dyje, thereby prolonging the inundation of flooded borrow pits until late summer (Fig. 2).

Over the study period, the physicochemical parameters of water of each borrow pit did not differ markedly between study sites (Table 1). Data for semi-quantitative comparisons (number of specimens per seining) were calculated from seine sampling and treated as catch-per-unit-effort (CPUE). Data from dipnetting were used only for comparisons of species richness.

All fishes 1+ and older were identified, measured, weighed and released. The 0+ juvenile fish were preserved in 4% formaldehyde and identified in the laboratory. Large 0+ specimens [e.g. perch, *Perca fluviatilis* L., pikeperch, *Sander lucioperca* (L.)] were identified and measured at the study site and released. Fishes were classified according to reproductive guilds after Balon (1975).

Results

Species richness

A total of 7847 adult fish (1 year and older) belonging to 22 species (Table 2) were collected. In non-flooded borrow pits (sites 1–3) the mean number of species was slightly lower than in flooded borrow pits (mean = 11.0, SE = 0.58 and mean = 14.7, SE = 0.33).

A total of 4423 0+ fish belonging to 18 species were captured. The 0+ fish assemblages in the non-flooded borrow pits comprised 13 species compared with 15 species in flooded borrow pits. Species richness in non-flooded borrow pits decreased from seven species in May and eight in July to three and two species in August and October respectively (Table 3). In flooded borrow pits, species richness increased from 11 species in May to 15 species in July and August and then decreased slightly to 13 species in October (Table 3).

Assemblage structure

In the adult fish samples phytophils and phytolithophils dominated in both flooded and non-flooded borrow pits (Table 1). In non-flooded borrow pits, perch and roach, *Rutilus rutilus* (L.), were the most abundant species at sites 1–2 (together 67 and 75%, respectively). In borrow pit 3 (also non-flooded), silver bream, *Abramis bjoerkna* (L.), Prussian carp, *Carassius auratus gibelio* (L.), and ruffe, *Gymnocephalus cernuus* (L.) dominated (Table 1). In the flooded borrow pits, roach, silver bream, common bream, *Abramis brama* (L.), and rudd, *Scardinius erythrophthalmus* (L.), were the dominant species.

Table 2. Relative abundance (in %) of adult fish in three non-flooded and three flooded borrow pits of the River Dyje surveyed in 2001

			Non-flooded			Flooded		
Scientific name	Common name	Reproduction guild	1	2	3	4	5	6
Esox lucius L.	Pike	Phytophil	0.7	2.6	1.1	0.5	1.6	18.9
Rutilus rutilus	Roach	Phytolithophil	36.4	4.0	42.9	29.3	39.1	41.0
Leuciscus idus (L.)	Ide	Phytolithophil				0.1		0.4
Scardinius erythrophthalmus	Rudd	Phytophil	4.5	0.2	9.2	5.7	7.1	14.4
Ctenopharyngodon idella (Val.)	Grass carp	Pelagophil					0.2	1.3
Aspius aspius (L.)	Asp	Litophil				0.1	0.6	0.4
Tinca tinca (L.)	Tench	Phytophil						1.4
Pseudorasbora parva (Schlegel)		Phytolithophil						0.3
Alburnus alburnus (L.)	Bleak	Phytolithophil	0.6	4.0	7.4	2.6	3.5	
Abramis bjoerkna	Silver bream	Phytophil	13.2	24.4	5.2	42.9	25.3	
Abramis brama	Common bream	Phytolithophil		15.1	7.4	14.3	15.3	1.8
Abramis ballerus (L.)	Blue bream	Litophil				0.1	0.1	
Rhodeus sericeus (Pallas)	Bitterling	Ostracophil			0.5	0.4	0.4	5.6
Carassius auratus gibelio	Prussian carp	Phytophil	0.1	23.8	0.4	3.1	3.4	8.8
Cyprinus carpio L.	Common carp	Phytophil	0.4				0.0	0.1
Misgurnus fossilis (L.)	Weather fish	Phytophil					0.2	
Silurus glanis L.	Wels catfish	Phytophil			0.2			
Perca fluviatilis	Perch	Phytolithophil	38.8	5.4	24.4	0.5	1.7	5.5
Sander lucioperca	Zander	Phytophil	0.5	2.2		0.1		
Gymnocephalus cernuus	Ruffe	Phytolithophil	4.7	15.7	1.1	0.1	0.2	0.1
Proterorhinus marmoratus	Tubenose goby	Speleophil		0.7	0.3			0.1
	hybrid			2.0		0.2	1.1	
Number of species			10	11	12	14	15	15

Table 3. Seasonal dynamics of 0+ fish community structure (species relative abundance in %) in flooded (F) and non-flooded (NF) borrow pits

Month	May		June		July		August		October	
Species/borrow pits	F	NF	F	NF	F	NF	F	NF	F	NF
Esox lucius				4.1	0.3	0.4	0.2		0.3	
Rutilus rutilus	46.3	37.8	25.5		11.0	0.9	29.4	29.1	28.2	
Leuciscus idus	0.3	0.5	1.2		0.0		0.2		0.0	
Aspius aspius					0.1		0.2		0.1	
Leucaspius delineatus (Heckel)	0.3		1.8		1.0		1.0		1.7	
Scardinius erythrophthalmus	9.1	2.4	7.8	61.6	18.5	16.4	54.6		26.1	
Tinca tinca					0.1		0.2			
Pseudorasbora parva			1.2		0.1		0.1		0.1	
Alburnus alburnus	0.1	16.2	1.8	1.4	1.2	1.3	0.3		0.5	
Abramis bjoerkna	13.3		20.7		58.0	1.3	8.6		40.2	
Abramis brama	20.2		8.1	1.4	3.9		0.2		0.9	
Rhodeus sericeus	2.0	1.1	2.7		3.7		3.8		1.0	
Carassius auratus	6.0	26.8	20.1		0.7		0.4		0.1	
Perca fluviatilis	2.2	15.1	8.7		1.0	61.9	0.3	21.8	0.2	68.0
Sander lucioperca				27.4		16.8		49.1		32.0
Proterorhinus marmoratus			0.3	4.1	0.1		0.0		0.0	
hybrid	0.2				0.2	0.9	0.4		0.5	
Species richness	11	7	12	6	15	8	15	3	13	2

In May and June, the 0+ fish assemblages in non-flooded borrow pits comprised mainly roach, rudd and Prussian carp, but predatory perch and zander dominated from July to October. In flooded borrow pits rudd, silver bream and roach dominated throughout the entire study season (Table 3).

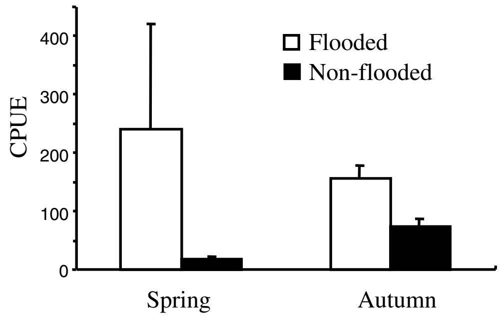

Figure 3. Catch-per-unit-effort (CPUE) of adult fish (mean, SE) caught in the flooded and non-flooded borrow pits in the floodplain of the River Dyje in spring and autumn 2001 (note different scales).

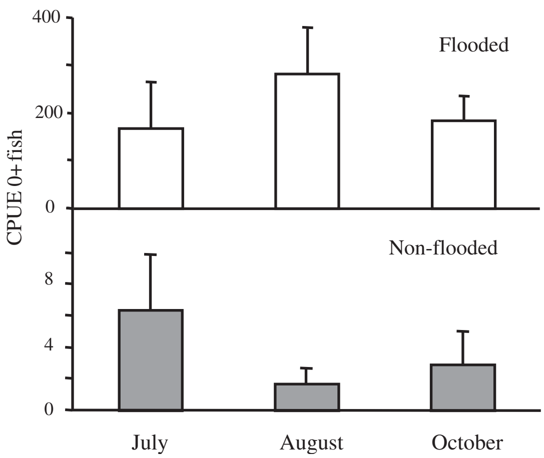

Figure 4. Catch-per-unit-effort (CPUE) of 0+ fish (mean, SE) caught in the flooded and non-flooded borrow pits in the floodplain of the River Dyje in July, August and October 2001.

Fish abundance

The relative abundance (CPUE) of adult fish was 3 and 14 times higher (autumn and spring estimates, respectively) in flooded than in non-flooded borrow pits (Fig. 3). CPUE of 0+ juvenile fish was approximately two orders of magnitude higher in flooded than in non-flooded borrow pits throughout the study period (Fig. 4).

Discussion

A series of small floodplain borrow pits that differed in their artificial flooding management were surveyed to understand their importance for fish reproduction, especially as nursery areas during the first year growing season. Species richness of adult fish (1+ and older) assemblages at flooded and non-flooded sites did not differ considerably, but the abundance of adult fish was up to 14 times higher at flooded sites. This difference was affected mainly by abundance of young age classes (1–3 year old fish), that reflected good recruitment in previous years and lower mortality of older juveniles (1+).

In non-flooded borrow pits, spawning and early development of many fish species were successful in early spring. Fish spawned on a narrow strip of flooded terrestrial vegetation along the inundated base of the borrow pit margin. However, water level quickly declined and the absence of shelters caused a considerable decrease in the abundance of 0+ juvenile fishes, possibly because of predation by abundant 0+ perch and pikeperch. In October, the abundance of 0+ fish was almost 100 times lower at non-flooded sites than flooded sites.

On the contrary, flooded areas surrounding the flooded borrow pits represented valuable spawning and nursery habitats for phytophilous and phytolithophilous species in the floodplain. Long-term flooding increased the species richness and especially the abundance of fishes in flooded borrow pits. Flooded vegetation affects fish abundance by creating structurally complex habitats that provide more food and shelter (Dewey & Jennings 1992). High food availability and higher temperatures in flooded areas support the rapid growth of many juvenile fishes and henceforth increase their survival (Halyk & Balon 1983).

The flooded meadows adjacent to the flooded borrow pits also supported a high density of aquatic gastropods and waterfowl. These species are a vector and definitive host of the digenean parasite *Posthodiplostomum cuticola*, that could eventually negatively affect the condition of 0+ juvenile fish, and, over the longer period, may have the potential to decrease the abundance of some fish species (Bartošová, Jurajda & Ondračková 1999). The significance of this parasite infection and the interaction between flooding and parasite abundance are subject of ongoing research. In spite of significantly higher parasite prevalence, 0+ fish abundance at the end of the first growing season is still much higher at the flooded than at non-flooded sites.

The results showed that the capacity of borrow pits with a uniform habitat to act as nursery areas was limited by the absence of vegetation and other shelters in non-flooded borrow pits. Absence of shelters led to high mortalities from predation, evident as a strong decline in the abundance of 0+ fishes. Managed flooding of borrow pits could improve conditions for spawning and 0+ fish survival during the first few months and enhance fish reproduction in these man-made habitats. Nevertheless, further research to identify the optimal timing, duration and magnitude of the flooding regime is required to put the results into management practice. The benefit of successful reproduction in borrow pits to entire river ecosystem depends on a connectivity between the borrow pits and the main channel. At the study sites, juvenile fish could reach the main channel only during the discharge in excess of that achieved during the managed flooding, which rarely occurs. Consequently, fish production in borrow pits cannot support fish assemblages throughout the river system at present because of lack of connectivity between habitats. Thus, construction of dispersal routes seems a crucial next step in further management plans.

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