Structure of 0+ juvenile fish assemblages in the modified upper stretch of the River Elbe, Czech Republic

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ABSTRACT: In August 2007, the 0+ juvenile fish assemblage of the upper River Elbe was surveyed using electrofishing. Thirty-six localities were sampled along a 177 km long section between the towns of Verdek and Brandýs nad Labem (river km (RKM) 136–313). Four localities with natural riverbeds, 14 channelized stretches, nine beaches, and nine backwaters were sampled. Altogether, 4521 0+ juvenile fishes were caught, belonging to 26 species. A decrease in species richness and abundance was evident near Hradec Králové, while decreased species abundance was noted along the navigated stretch below Přelouč. The highest catch-per-unit-effort (CPUE), species richness, and Shannon index values were observed at beach habitats, the lowest in channelized habitats, and intermediate values in backwaters. Generally, rare beach habitats had significantly more rheophilic species than other habitats, while backwaters had significantly more eurytopic species and higher CPUE for limnophilic species. Backwaters and channel habitats, however, did not differ in any other 0+ fish assemblage parameter studied. The study demonstrated the importance of beaches for fish assemblages along navigable channels. Surprisingly, however, backwaters were not confirmed as important nursery habitats.

Keywords: YOY fish; fish reproduction; regulation; channelization

Many European floodplain rivers have been heavily modified and adapted to the needs of human society over recent centuries (Nilsson et al., 2005) and, in many cases, regulation and channelization have led to a significant reduction in river habitat diversity. Such rivers often lack off-channel habitats, have banks that are artificially stabilized using boulders, and have flow conditions adapted to riverine traffic. As a consequence, the rivers lack shallow zones, which represent important spawning and nursery habitats for fluvial fishes, their banks offer very low habitat diversity for fluvial fishes and fish fry, and longitudinal profiles are blocked by weirs and locks that disturb or prevent fish migration. These modifications have usually resulted in changes to fish species diversity and abundance, manifested through extinction, an increase in the number of endangered species, and shifts in species composition from habitat specialists to eurytopic forms (Wolter et al., 2000; Wolter, 2001a; Arlinghaus et al., 2003).

The River Elbe lies within the boundaries of two countries – the Czech Republic and Germany, and is one of the most extensive aquatic catchments in Central Europe. The upper part of the river flows through the Czech Republic, with the first 370 km channelized and regulated with two reservoirs, 24 locks, and 67 weirs. Despite the channelization, a number of off-channel habitats (connected backwaters, the remains of original meanders) remain more-or-less connected.

Over recent decades, the Elbe has become one of the worst polluted major rivers in Europe (Zimmer et al., 2011). For this reason, the Elbe has been the subject of interest for many scientific surveys primarily focused on water pollution and risk to humans associated with consumption of contaminated fish (e.g. Havelková et al., 2008; Baborowski

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et al., 2011; Chalupová et al., 2012). Few studies, however, have monitored fish populations in the Elbe from an ecological point of view, and most of these have taken place along either the German stretch (Fladung et al., 2003; Oesmann, 2003) or in the Elbe estuary (Thiel et al., 1995, 2003). Indeed, few studies are available on the fish community in general, despite the Elbe being one of the most important rivers in the Czech Republic. Some information is available on adult fish species richness from the IKSE-MKOL (1996, 2008) international monitoring project and from Project Elbe (Fuksa, 2002). In addition, Jurajda et al. (2010a) and Kubečka et al. (2000) have examined the adult fish community of the Elbe, though the former study focused on the short, highly polluted stretch near Pardubice only and the latter, while monitoring both the Czech and part of the German stretch, used horizontal sonar. As regards young-of-the-year (YOY) fish, which have been monitored in the Czech Republic for many years, only one study on natural fish reproduction has been published from the Czech stretch of the Elbe (Horký et al., 2013).

Heavy stocking in the Elbe makes it impossible to determine the extent to which adult fish assemblages result from natural reproduction. Monitoring of YOY fish, on the other hand, can be a reliable indicator of reproduction success and recruitment between years (Jurajda et al., 2010b). YOY fish have specific habitat requirements and are sensitive to habitat change (Jurajda et al., 2010b), hence YOY fish class strength can also reflect adult fish assemblage "quality", as well as availability of suitable spawning and nursery habitats.

The aim of this study, therefore, was (1) to survey 0+ juvenile fish assemblages along a large, rarely explored section of the Elbe stretching on the Czech territory, and thus establish baseline knowledge of natural fish reproduction here and (2) to evaluate the importance of particular habitat types, including non-channel habitats, for fish recruitment along this stretch.

MATERIAL AND METHODS

The River Elbe is 1154 km long and has a drainage basin of 144 055 km^2. The upper part of the river flows through the Czech Republic (Figure 1). The stretch from the German border upstream to Pardubice (RKM 241) has been modified for navigation, though the upper 24 km (from Přelouč to Pardubice) are isolated by riffles and only used for recreational and pleasure boating.

Continual electrofishing (220–240 V, 1.5–2 A, 100 Hz) was used to sample 0+ juvenile fish (Janáč and Jurajda, 2007) along a 177 km stretch of the River Elbe between the towns of Verdek and Brandýs nad Labem (RKM 313–136) (Figure 1). Verdek was chosen as it represented the end of the unmodified trout zone of the Elbe, allowing comparison of similar species under similar condi-

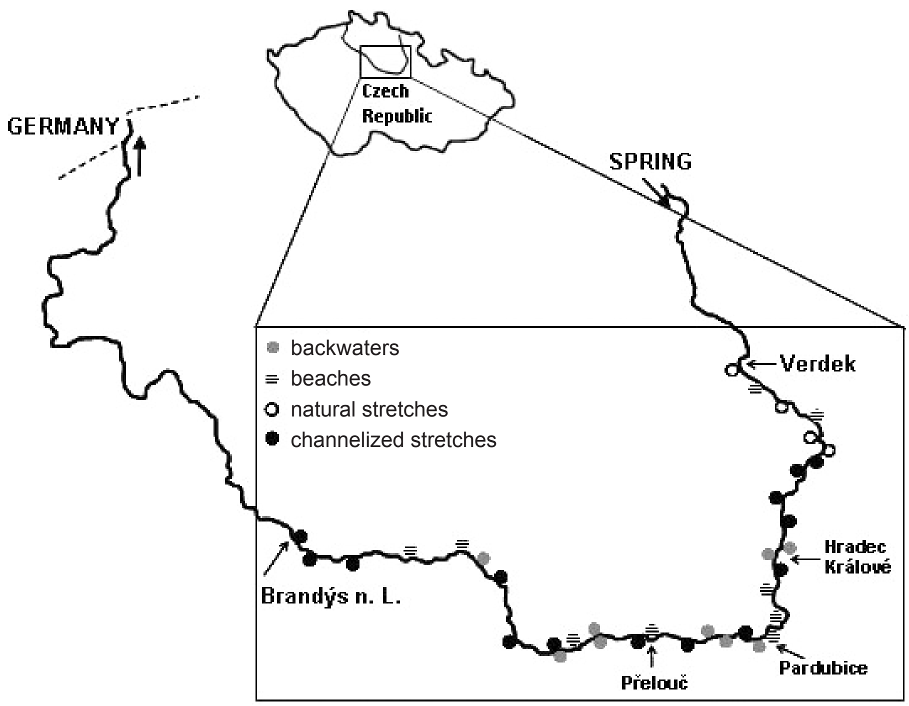

Figure 1. Map indicating sampling sites along the River Elbe

tions. In total, 36 sites were sampled, including four natural localities, nine beaches, nine backwaters, and 14 channelized sites. All sites were situated along the shoreline and comprise stretches of approximately 85 m (SD = 6.0 m) with the same representative habitat type.

Three habitat types were surveyed: (1) "Natural" localities, with riffle-pool sections and coarse substrate typical of the barbel zone (*sensu* Huet, 1959). These occur in the upper part of the study stretch only. The shorelines are shallow with gentle slope and the river bottom and banks are not stabilized. (2) Channelized stretches, representing most of the main channel shoreline along the study stretch, are dominated by homogeneous, straight, and steep shorelines stabilized by riprap. At lower sites with shipping, a stable high water level is maintained by weirs and both submerged and floating vegetation occurs. (3) Beach localities, which occur sporadically all along the study stretch; all were sampled for this study. In the non-navigable upper stretch, natural shallow gently-sloping pebble beaches are formed on the inside of meanders. Along the navigable stretch, beach localities, which were situated mainly below weirs only, were primarily formed of fine-grained sands and gravels eroded from upstream and had moderate to strong water velocities. Woody debris and vegetation occurred rarely.

As a result of historical river straightening, many oxbows and backwaters are found along the Czech banks of the Elbe. In this study, we surveyed nine backwaters with a direct connection to the main channel. These non-flowing backwaters had a substrate consisting mainly of deep mud or sandy-mud and often had dense vegetation (*Nuphar luteum*) growth in open water. Woody debris and roots were common and the shorelines were covered with dense vegetation, especially reed (e.g. *Phragmites australis*).

0+ juvenile fish captured at each site were identified to species, measured (standard length (SL) to nearest mm), and categorized into ecological guilds according to Schiemer and Waidbacher (1992).

Data analysis. Species abundance was calculated as catch-per-unit-effort (CPUE, number of individuals (ind) per 100 m) at all sites, while diversity was assessed using the Shannon diversity index. Note that further statistical analysis was only undertaken on beaches, backwaters, and channelized sites as too few natural localities were sampled.

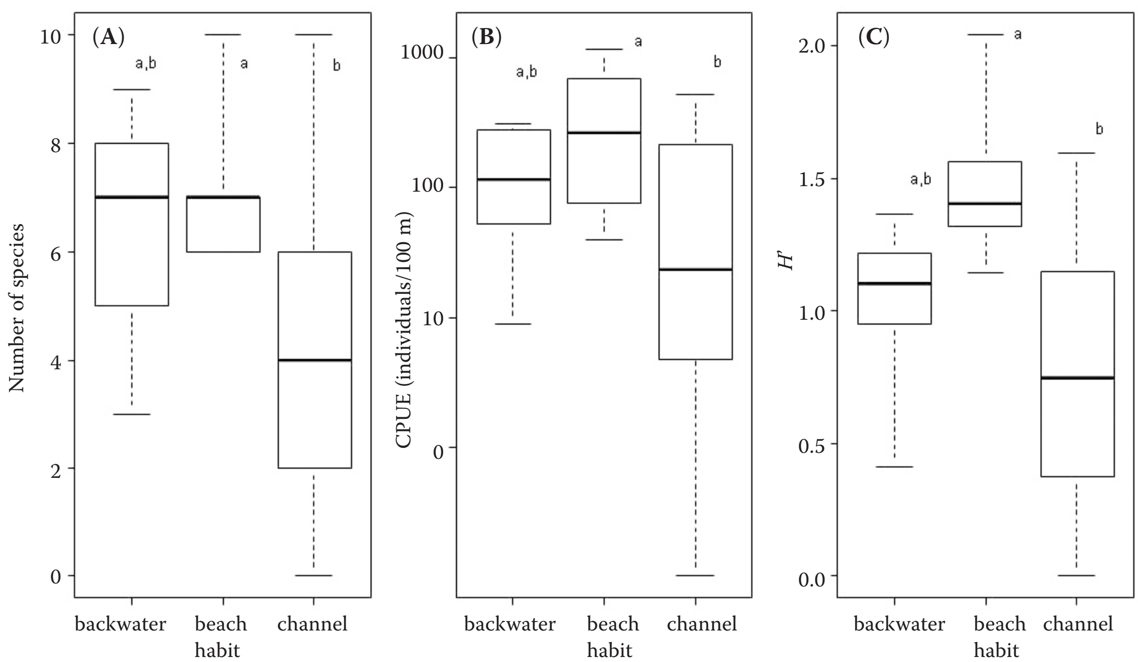

Figure 2. Species richness (**A**), catch-per-unit-effort (CPUE) (**B**), and Shannon diversity index *H'* (**C**) for 0+ fish at three habitat types along the River Elbe in 2007

centre line = median, box = quartile range, whiskers = range

different letters at the bars indicate significant differences according to multiple post-hoc comparisons (significant at $P < 0.016$)

Table 1. Species abundance (CPUE) and frequency (%) at four habitat types along the River Elbe (Czech part)

Species		CPUE					Frequency			
		CODE	NAT	B	BW	CHAN	NAT	B	BW	CHAN
Brown trout	*Salmo trutta* m. *fario*	ST	0.68	–	–	–	25	–	–	–
Pike	*Esox lucius*	EL	0.34	–	–	–	25	–	–	–
Roach	*Rutilus rutilus*	RR	5.08	16.98	6.72	8.09	75	78	67	36
Dace	*Leusicsus leuciscus*	LL	3.05	29.05	–	0.08	75	78	–	7
Chub	*Squalius cephalus*	LC	79.66	67.14	2.28	11.89	75	100	67	79
Ide	*Leuciscus idus*	LI	–	2.54	–	–	–	33	–	–
Minnow	*Phoxinus phoxinus*	PP	7.46	23.33	–	0.08	75	22	–	7
Rudd	*Scardinius erythrophthalmus*	SE	–	1.11	5.13	1.94	–	11	56	36
Asp	*Aspius aspius*	AU	–	0.48	0.23	0.32	–	33	22	21
Nase	*Chondrostoma nasus*	CN	0.34	13.49	–	0.24	25	67	–	14
Gudgeon	*Gobio gobio*	GG	64.44	57.78	8.66	1.13	25	100	56	21
Stone moroko	*Pseudorasbora parva*	PR	–	0.32	0.34	0.08	–	11	22	7
Barbel	*Barbus barbus*	BB	2.71	18.57	–	0.16	25	56	–	7
Bleak	*Alburnus alburnus*	AA	1.02	6.51	44.19	20.23	25	33	78	43
White bream	*Abramis bjoerkna*	BJ	–	2.86	3.19	4.05	–	11	67	29
Common bream	*Abramis brama*	AB	–	–	0.91	0.08	–	–	22	7
Vimba	*Vimba vimba*	VV	–	0,79	5.13	0.97	–	22	22	14
Bitterling	*Rhodeus amarus*	RS	–	4.92	56.38	51.62	–	44	78	36
Prussian carp	*Carassius auratus*	CA	–	–	0.23	0.16	–	–	11	14
Stone loach	*Barbatula barbatula*	NB	–	0.16	–	–	–	11	–	–
Wells	*Silurus glanis*	SG	–	–	–	0.16	–	–	–	14
Brown bullhead	*Ictalurus nebulosus*	IN	–	–	0.11	1.70	–	–	11	14
Perch	*Perca fluviatilis*	PF	–	–	0.68	0.65	–	–	33	14
Pumpkinseed	*Lepomis gibbosus*	LG	–		2.73	–	–	–	11	–
Stickleback	*Gasterosteus aculeatus*	GA	–	–	–	0.08	–	–	–	7
Bullhead	*Cottus gobio*	CG	0.34	–	–	–	25	–	–	–
No. of species			11	16	15	20				
Total CPUE			165.56	437.05	159.42	125.60				

CPUE = catch-per-unit-effort (number of individuals/100 m), NAT = natural stretches, B = beaches, BW = backwaters, CHAN = channelized stretches

CPUE (log-transformed) and the Shannon index were compared between the different habitat types using the Analysis of Variance (ANOVA), while differences in species richness were tested using Generalized Linear Models (GLM) because species richness is a count variable and therefore it has Poisson distribution. In cases where ANOVA or GLM indicated a predictor (habitat type) having a significant effect, multiple post-hoc comparisons (MPC) were conducted to reveal pair-wise differences between separate habitats (Bonferroni correction of α applied, thus MPCs were significant at $P < 0.017$).

Separate analyses were conducted for (a) the whole fish assemblage, and (b) eurytopic, (c) limnophilic, and (d) rheophilic species. Differences in assemblage composition between the three habitats were visualized using non-metric multidimensional scaling, with the Bray-Curtis index as a distance measure.

All statistical analyses were conducted using R Statistical package (Version 2.14.2, 2008).

RESULTS

Species richness and abundance. A total of 4521 0+ juvenile fishes, comprising 26 species, were caught along the study stretch (Table 1). Eleven species were recorded at natural stretches, 15 in backwaters, 16 along beaches, and 20 species in channelized stretches.

On average, 437.05 ± 102.91 (mean ± SE) individuals were recorded per 100 m of beach shoreline, 165.56 ± 135.78 ind/100 m at natural localities,

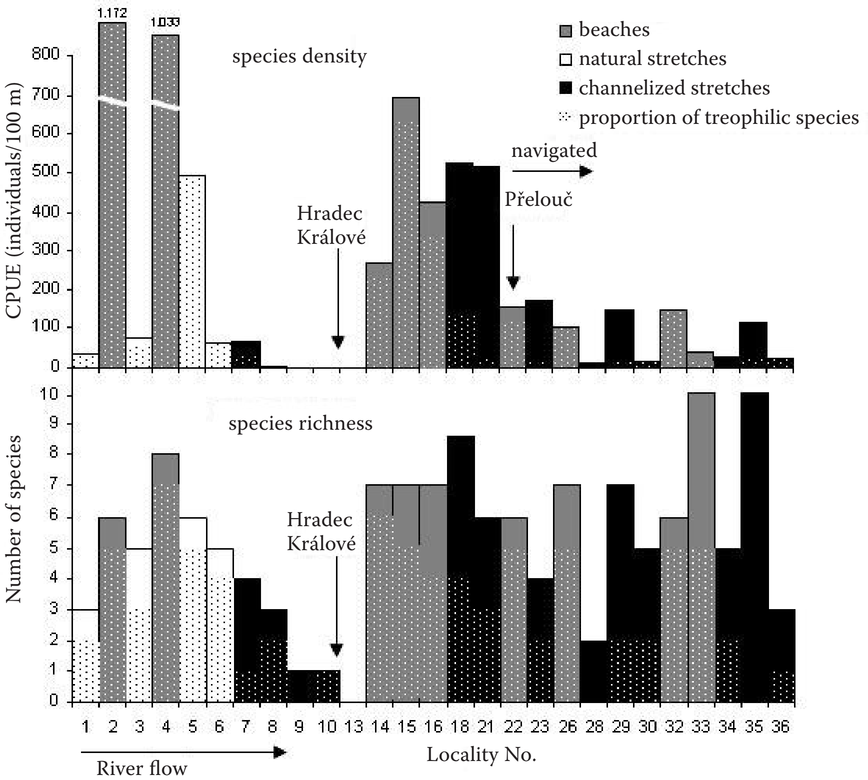

Figure 3. Abundance and species richness along the main channel of the River Elbe study stretch (not including backwaters)

159.42 ± 39.03 individuals/100 m in backwaters, and 125.60 ± 47.58 individuals/100 m along channelized stretches.

Significant differences were noted in species richness, CPUE and Shannon index between habitat types (ANOVA and GLM, all df = 2.29 and $P < 0.05$), with higher CPUE, species richness, and Shannon index observed at beach habitats, intermediate values in backwaters, and lower values in channels (Figure 2).

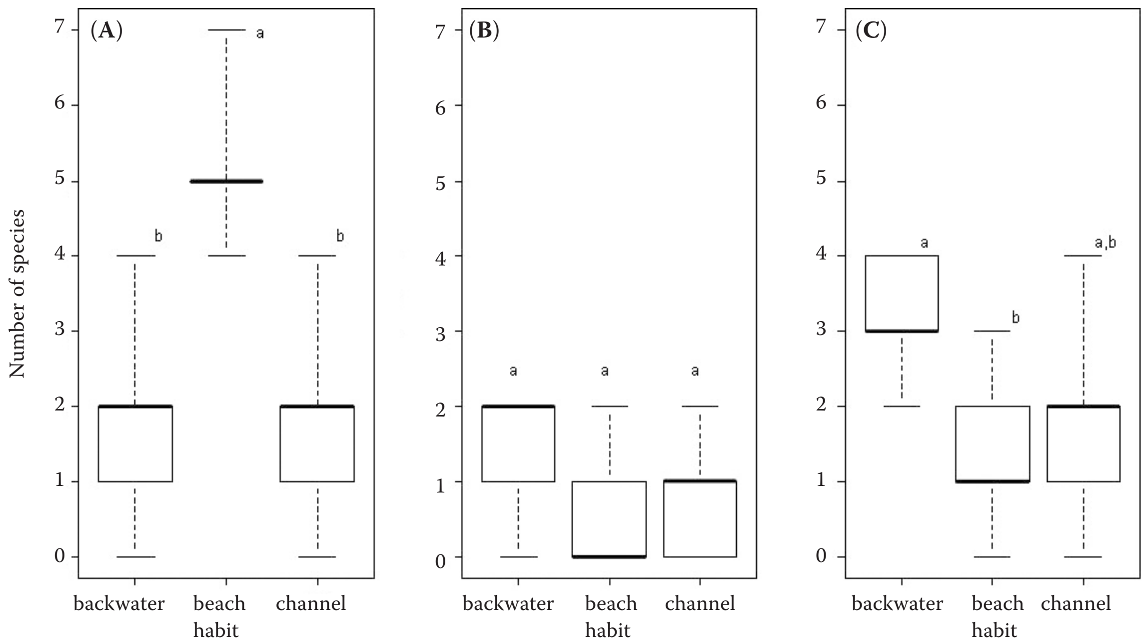

Figure 4. Species richness of (**A**) rheophilic, (**B**) limnophilic, and (**C**) eurytopic 0+ fish at three habitat types along the River Elbe in 2007

centre line = median, box = quartile range, whiskers = range

different letters at the bars indicate significant differences according to multiple post-hoc comparisons (significant at $P < 0.016$)

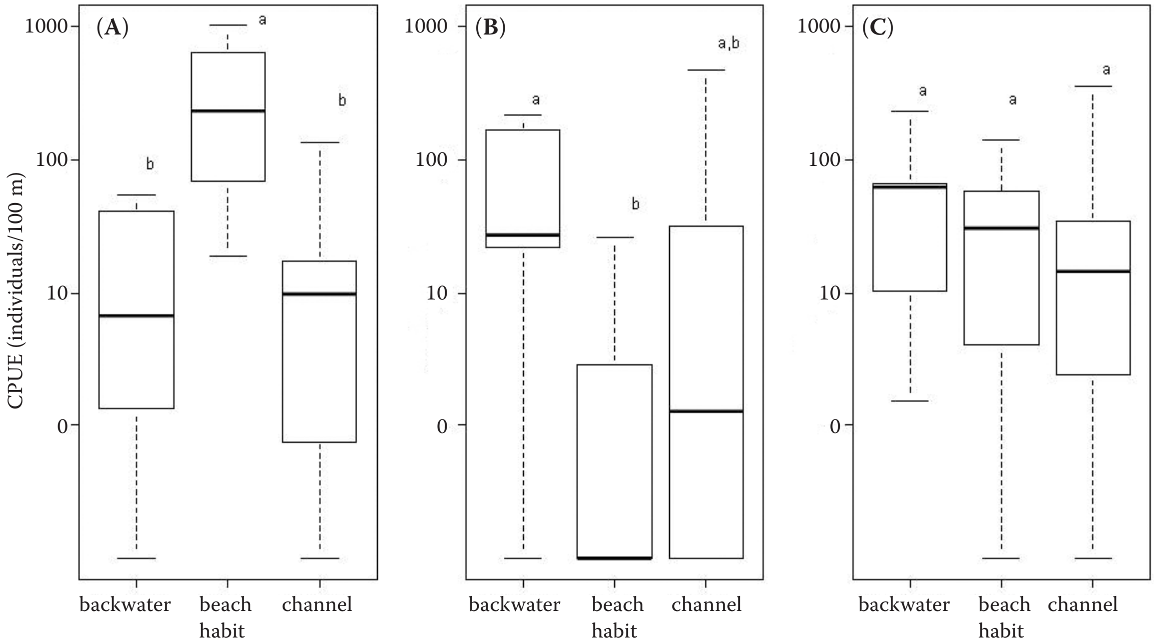

Figure 5. Catch-per-unit-effort (CPUE) of (**A**) rheophilic, (**B**) limnophilic, and (**C**) eurytopic 0+ fish at three habitat types along the River Elbe in 2007

centre line = median, box = quartile range, whiskers = range

different letters at the bars indicate significant differences according to multiple post-hoc comparisons (significant at $P < 0.016$)

Longitudinal profile. A considerable decrease in species richness and abundance was recorded near the town of Hradec Králové, with only one specimen caught at localities 9 and 10, and no fish at locality 13 (Figure 3). Species abundance also decreased in the lower (navigated) part of the study stretch, from locality 22 at Přelouč onward (Figure 3).

Ecological guilds. Beaches were significantly richer in rheophilic species (in terms of both CPUE and species diversity) compared to both channel and backwaters (ANOVA and GLM, both df = 2.29 and $P < 0.05$; MPC, $P < 0.017$) (Figures 4 and 5). Beaches were, however, significantly poorer than backwaters in numbers of eurytopic species (ANOVA, df = 2.29, $P < 0.05$; MPC, $P < 0.017$) and in CPUE of limnophilic species (GLM, df = 2.29, $P < 0.05$; MPC, $P < 0.017$). Neither of these two parameters differed between channels and backwaters (MPC, $P > 0.017$). No difference was observed between habitats in number of limnophilic species or in CPUE of eurytopic species (GLM and ANOVA, df = 2.29, $P > 0.05$) (Figures 4 and 5).

Similarity of habitat types. In general, all beach sites possessed assemblages that were similar to each other and differed from backwaters and the main channel (Figure 6). Barbel, nase, and dace

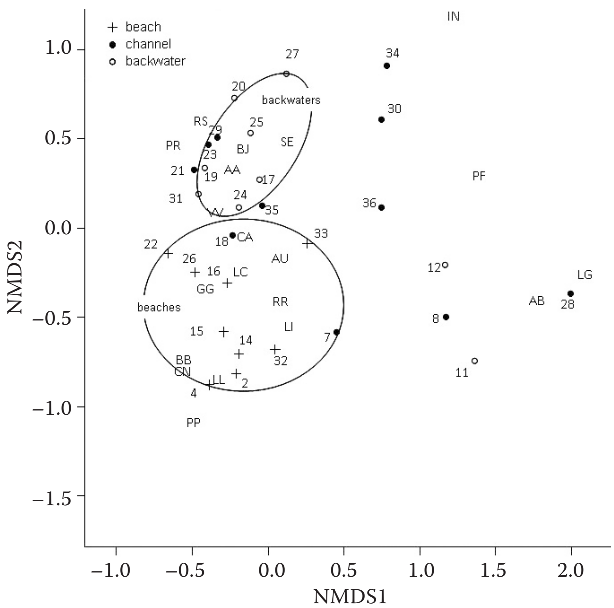

Figure 6. Ordination (non-metric multidimensional scaling – NMDS) of sites along the River Elbe according to similarity (Bray-Curtis index) in 0+ fish assemblages in 2007

only species with a total abundance > 5 individuals/100 m are shown; sites 9, 10, and 13 (channel habitat) are not shown as only one species was captured at sites 9 and 10 (Prussian carp and chub, respectively), and no fish were captured at site 13 (for species codes see Table 1) were typical for beaches, while roach, gudgeon, and chub were common in both beach and channel habitats. There was a large overlap between main channel assemblages and those in backwaters (Figure 6), with bleak, bitterling, and white bream being the most common species in both habitats. Fish assemblages from backwater localities were similar to each other, except for two neighbouring backwaters near Hradec Králové (sites 11 and 12), which were the only two backwaters where common bream and pumpkinseed occurred (Figure 6).

DISCUSSION

Despite the River Elbe being one of the most important rivers in the Czech Republic, only limited information is available on its adult fish community. The IKSE-MKOL Project (1996, 2008), for example, produced presence-absence data for the complete longitudinal profile, while seven sites along the length of the river were examined as part of the River Project Elbe (Fuksa, 2002) in 1999. Kubečka et al. (2000), who undertook a hydroacoustic survey, were unable to provide specific species determination and presented abundance data (number per ha or kg per ha) only. Finally, between 2005 and 2006, Jurajda et al. (2010a) studied 12 sites near Pardubice, an important pollution source on the Elbe. While the number of fish species detected in these studies differed, a combined total of 39 adult fish species was found. Our 0+ data confirmed successful natural reproduction for at least 26 species, representing around 67% of the total adult fish species documented in the above mentioned studies.

Juvenile fish species richness on the Elbe was relatively similar to that from other Central European rivers. Bischoff and Wolter (2001), for example, noted 28 species on the lower Oder, while Staas and Neumann (1996) also recorded 28 species on the lower Rhine. Valová et al. (2006) recorded 27 species from the lower stretch of the non-navigable River Morava and, most importantly, Oesmann and Scholten (2002) reported 30 juvenile fish species from the German part of the Elbe.

Comparison of YOY abundance data is often made difficult by differences in the sampling strategy employed (Staas and Neumann 1996; Bischoff and Wolter, 2001). In our case, however, we are able to compare our results with data collected by the same authors using the same methods as part of a routine national monitoring programme of comparable lower river reaches (of the Rivers Morava, Dyje, and Oder). Within 2006–2011, this programme indicated YOY abundance in beach habitats ranging between 220–772 individuals/100 m (mean 468 ind/100 m). The 437 individuals/100 m observed at Elbe beach habitats, therefore, is well within this range and close to the mean. YOY abundance along channelized stretches (125.60 individuals/100 m), however, was noticeably lower in the Elbe compared to similar rip-rap habitats along the Morava, Dyje, and Oder (range 150–414 individuals/100 m, mean 313 individuals/100 m). The main difference between the two rip-rap habitats would appear to be the minimal or negligible current speed along the regulated Elbe.

Although a relatively high number of species were captured at channelized localities, the 0+ fish assemblage was not well-balanced. Few species (bitterling, bleak, chub) were classified as dominant (> 10%) and most of those with specific habitat requirements were registered at a very low abundance. Dominant species (chub and bleak) are characterized by wide ecological valence. Bleak is a typical eurytopic species living in both lotic and lentic waters, while chub is often connected with degraded habitats, despite being a rheophilic species (Arlinghaus and Wolter, 2003), and was even common along the larger part of the main channel. Thanks to a low channel gradient and a slow flow, the limnophilic bitterling occurred at very high abundance, not only in the backwaters but also in the navigable main channel. Similar results have been found by other authors, who have linked this to a recent increase in population density and an expansion in distribution of this fish species throughout Europe (Kottelat and Freyhof, 2007; Konečná et al., 2009).

The studies of Wolter et al. (2000) and Wolter (2001a, b) suggest that a high abundance of eurytopic perch, roach, and common bream should be found in the main channel, as an increase in the number of generalists and a concurrent decrease in specialists is a typical phenomenon of fish communities in biotopes modified by river regulation and reconstruction of waterways (e.g. Wolter, 2001a; Sindilariu et al., 2006). Surprisingly, however, these species occurred at lower abundances than expected all along the channelized stretch in this study. In intensively navigated rivers, juvenile population structure (species richness and abundance) and development are negatively affected by navigation-induced physical changes, which can have a significant subsequent effect on adult assemblage composition (Wolter and Arlinghaus, 2003; Kucera-Hirzinger et al., 2009). This was confirmed in this study, with a decline in species abundance along the more intensively navigated stretch downstream of Přelouč. On the Elbe, however, navigation intensity and wave action appear to have less effect on juvenile fish assemblages than on similar large rivers, such as the Danube or the Rhine. Instead, habitat modification appears to be the most important factor affecting fish communities along the main channel, with steep stabilized river banks, increased depth, and negligible flow providing limited nursery habitat for juvenile fish.

The decrease in fish species richness and abundance observed near Hradec Králové (sites 9, 10, and 13), as well as the different fish assemblages noted at two of the backwater sites along the same stretch, were rather unexpected. Absence of 0+ fish along the Hradec Králové stretch was also confirmed during a later monitoring program that took place in 2010 (Jurajda, unpublished data). A possible explanation for this could be the switchover from an upper trout zone to non-trout zone in this area, as well as strong river channel modification in the town itself. Identification of specific reasons for this bottleneck will require further detailed study.

Connected off-channel water bodies serve both as major nurseries for fish and as areas for survival of young fish and overall recruitment (Niles and Hartman, 2011). Indeed, the regular distribution of fish between main channel and off-channel habitats is generally taken to underline well-developed ecotone connectivity and complexity of water systems (Sindilariu et al., 2006). According to some studies (e.g. IKSE-MKOL, 1994; Fladung et al., 2003), phytophilic and phyto-lithophilic fish species spawn preferentially in off-channel water bodies (i.e. backwaters) and fish species such as roach, perch, white bream, and common bream use these areas for spawning and recruitment development. Staas and Neumann (1996) have also confirmed the enormous potential of gravel-pit lakes connected to the Rhine as spawning and nursery areas. Scheaffer and Nickum (1986), meanwhile, have stated that backwater areas are responsible for 90% of the juveniles in the River Mississippi (USA). Our study, however, demonstrated that off-channel habitats along the River Elbe did not fully meet such predictions as they provided nursery areas for just a few species, only bleak and bitterling using the habitat to any large extent. Occurrence of other limnophilic species was limited, with only rudd and pumpkinseed found in very low frequencies. What is more, phytophilic species such as pike and tench, which commonly occur in such habitats, were absent in this study. The partial ecological dysfunction of backwaters on the Czech Elbe was probably caused by disturbance to the ecomorphological habitat conditions. However, no visible disturbance, such as silting resulting in insufficient depth or lack of connection with the main channel, was observed during this study. Further studies at the microhabitat scale are needed to assess the specific characteristics of the backwaters studied and understand the causes of dysfunction.

As expected, 0+ juvenile assemblages along beaches consisted of typical rheophilic species such as chub, nase, barbel, gudgeon, and dace. Presence of rheophilic fish species, which have been determined as the group most at risk from river modification (Galat and Zweimüller, 2001; Buijse et al., 2002), is probably supported by the presence of beaches in the main channel. In many large European regulated rivers, stable high water levels and slow flow are maintained for navigation and rheophils are forced to live in the channelized main stream under less-than-ideal conditions. Our study documented intensive utilization of beaches (Figure 3) and this habitat type was probably of more importance to presence of rheophilic species in the main channel than longitudinal connectivity. Beach habitats, which are typically formed by water fluctuation and decrease in flow, are typically rare in regulated river systems. This study demonstrates that beaches, though limited to weir pools, can be extremely important for increasing the density of more specialized rheophilic populations in regulated rivers (Figure 3).

CONCLUSION

Overall, the Czech stretch of the Elbe displayed relatively high species diversity, due to the presence of a variety of habitat types, but low fish abundance, caused by a relatively low number of beaches and non-functional backwater habitats. In particular, this study demonstrates the critical importance of main channel beaches for 0+ fish diversity. Degraded fish assemblages typical for navigable canals were confirmed in the channelized stretch. Surprisingly, backwaters were not acting as major nursery habitats. Further long-term monitoring of 0+ juvenile fish in all three habitat types along a shorter study stretch may provide more specific information on habitat conditions in the Czech part of the Elbe, and provide further impetus for future habitat restoration and management strategies.

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