Shoreline configuration determines species-specific fish larvae drift in the man-made River Danube

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Introduction

Navigation, flood protection and hydroelectric power generation as well as the disconnection of tributaries resulted in riverine habitat degradation and fragmentation. Numerous studies have pinpointed the ecological deterioration for certain faunal associations at the Danube and one of the important groups affected are riverine fish assemblages. Fish communities are good indicators for habitat structure as well as for the ecological integrity of river systems due to their complex habitat requirements at different stages of their life cycles. Especially functional spawning grounds and nursery habitats are considered to be limiting factors for riverine fish populations in the Danube nowadays.

Centuries of channelization, followed not least with regard to the Water Framework Directive by single restauration measures, resulted in a nearly complete man-made shoreline for the upper sections of the Danube. The present article summarises the results for the early life stages of fish deriving from the latest monitoring campaigns in Austria (2013-2015), where species-specific fish larval dispersal of three different constructed shoreline configurations (gravel bar, riparian side arms and riprap) and a near natural bypass system were investigated. The results of fish larval dispersal give an indication for the quality and acceptance of these artificial habitats as spawning grounds. More detailed results can be found in Waidbacher et al. (2016), Meulenbroek et al. (2017a), Meulenbroek et al. (2017b) and Waidbacher et al. (in press).

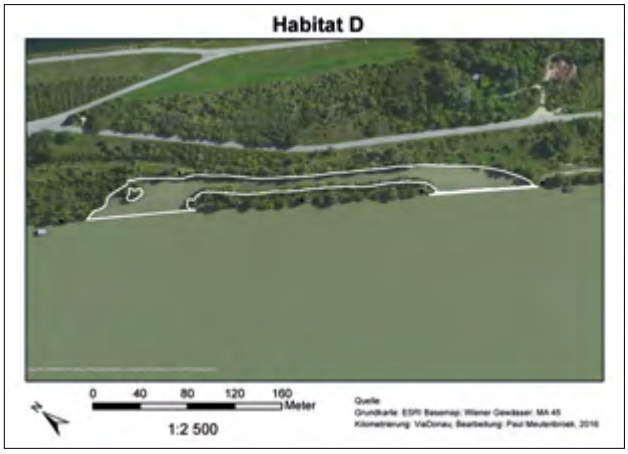

Figure 1. *One of the man-made side arms (Waidbacher et al. (2016))*

Figure 2. *Gravel-bank inshore structure under construction with two ripraps. Nowadays, after filling of the impoundment, only parts of the upper riprap are visible (Waidbacher).*

Methods and study site

The studies were conducted in Vienna between the hydropower plant (hpp) Freudenau and the hpp Greifenstein. In total, 12 sites were sampled. These include four riprap sections, as they are found at most of the Danubian shoreline nowadays and various mitigation measures, which were implemented 20 years ago at the impoundment of the newest hpp Freudenau/Vienna to counteract and minimize the impacts. The latter include three gravel bars, two artificially built side arms and three sites within a near natural fish bypass system. All sites are anthropogenically built or initiated.

The two sampled side arms *(Figure 1)* are man-made inshore structures at an orographic left-side bar of the Danube on the so called “Danube Island” in Vienna, with a length of 1.1 km (Habitat C) and 0.4 km (Habitat D).

All three gravel bars are also completely technically constructed. The riparian shoreline is fixed with a riprap, while another underwater riprap prevents the gravel bar from major dislocation into the main channel *(Figure 2)*. The uppermost gravel bar was initiated by setting up of a groin field.

The fish migration bypass system *(Figure 3)* has been constructed with two major components; a near natural bypass channel and a near natural pool pass. The bypass channel with a mean discharge of 1.6 m³/s and an average slope of 0.7 % is situated in a riverbed of seven meters width and a corresponding average current speed of around 0.6 m/s. It consists of a delta system in the tail water, a straightened section, followed by a 300 meters meandering section and a branched situation in the middle. The uppermost part of the system is built as a near natural pool pass with 19 pools.

Figure 3. Near natural fish bypass system Freudenau (Waidbacher)

Two of the studied riprap sections *(Figure 4)* are located in the central impoundment upstream of the side arms; another two in the uppermost part of the impoundment in a nearly free flowing section.

Early life stages of fish were sampled continuously from April to July 2013–2015 with drift nets. Subsequently a subsample of the trapped fish larvae was analyzed with mtDNA barcoding to species level (Meulenbroek et al. 2017a).

Results and Discussion

We collected more than 20.000 fish larvae, representing 31 species out of eight families. These include 13 species that are considered as endangered *(Aspius aspius, Ballerus sapa, Cottus gobio, Barbus barbus, Chondrostoma nasus, Esox lucius, Proterorhinus marmoratus, Rhodeus amarus, Leuciscus sp.)* and further three species *(Cyprinus carpio, Rutilus virgo, Zingel streber)* as in danger of extinction for the Austrian Danube. On a European scale, seven species *(Aspius aspius, Cottus gobio, Rhodeus amarus, Romanogobio vladykovi, Rutilus virgo, Gymnocephalus schraetser, Zingel streber)* are listed in Annex II of the Flora-Fauna-Habitat Directive. Table 1 shows the calculated relative distribution of all caught species and families separated for all sampling sites.

Figure 4. Riprap as it is found at most of the Danubian shoreline

Species of the Gobiidae family invasive in the upper Danube made up nearly half of the catches – and here most frequently Round Goby *(Neogobius melanostomus:* 32 %) and Bighead Goby *(Ponticola kessleri:* 12 %). Furthermore, the native Bullhead *(Cottus gobio:* 16 %) was frequently caught, followed by Asp *(Aspius aspius)*, Nase *(Chondrostoma nasus)* and Barbel *(Barbus barbus)* (all ~5.5%). Within the Percidae, Perch *(Perca fluviatilis)* and Pike Perch *(Sander lucioperca)* were most abundant. All other species were rare, with less than 3 %.

Regarding the spatial distribution and family/species composition, the results present a clear picture *(Figure 5):* Sites downstream of gravel bars are dominated by Cyprinidae (61–65 %) and equal shares of Percidae (13–18 %), Gobiidae (11–17 %) and Cottidae (8–13 %). Early life stages of fish caught in the side arms display a similar family distribution. By comparing on species level or functional spawning guilds the differences become apparent. While gravel banks provide spawning habitats for lithophilic species like *Chondrostoma nasus* or *Barbus barbus,* the side arm provides high proportions of organic material and macrophytes available for phytophilic species such as *Perca fluviatilis* or *Rutilus rutilus.*

In contrast, at riprap sections the majority of the caught larvae consist of speleophilic Gobiidae (47–53 %) and Cottidae (23–29 %). Cyprinidae (13–20 %) and Percidae (7–13 %) are less frequent in catches. The dominance of this shoreline configuration at the Danube accelerated the expansion of neobiota like Gobiidae by providing spawning grounds and suitable habitats. These results are in line with former studies, which conclude that near-natural shores provide substantially more suitable larval habitats for the native fish fauna than stabilized ones. Therefore, a measure to reduce the abundances of the invasive Gobiidae is to remove riprap where it is possible. Furthermore, these structural alterations affect the hydraulics of the inshore areas, which may have dramatic effects on the dispersal and viability of native fish populations (Meulenbroek et al. 2017a).

	Rip rap	Gravel bank	Side arm	Fish bypass
Cottidae	**24.43**	**8.47**	**1.06**	
Cottus gobio	24.43	8.47	1.06	
Cyprinidae	**17.31**	**64.05**	**70.95**	**25.90**
Abramis brama	0.10	3.84	6.20	
Alburnus alburnus		1.19	1.06	0.85
Aspius aspius	5.50	10.43	7.43	1.85
Ballerus sapa				0.03
Barbus barbus	1.78	15.45	1.06	11.47
Blicca bjoerkna		1.04		
Chondrostoma nasus	4.53	20.80	1.06	5.28
Cyprinus carpio		1.04	12.40	
Leuciscus idus	1.46	2.38		0.37
Leuciscius leuciscius				0.17
Pseudorasbora parva		1.19		
Rhodeus amarus	0.17			0.69
Romanogobio vladykovi				0.13
Rutilus rutilus	3.26	6.69	38.54	1.36
Rutilus virgo	0.33		2.12	0.05
Squalius cephalus	0.17		1.06	3.66
Esocidae			**0.58**	
Esox lucius			0.58	
Gasterosteidae	**0.14**		**1.06**	
Gasterosteus aculeatus	0.14		1.06	
Gobiidae	**50.66**	**13.37**	**6.98**	**53.72**
Babka gymnotrachelus	5.68			0.91
Neogobius melanostomus	33.76	11.51		37.74
Ponticola kessleri	11.22	1.86	6.98	14.85
Proterorhinus marmoratus				0.22
Percidae	**7.11**	**14.11**	**19.37**	**4.33**
Gymnocephalus cernua	0.02			0.99
Gymnocephalus schraetser	0.02			
Perca fluviatilis	1.49	2.82	4.77	0.78
Sander lucioperca	4.51	6.37	14.60	1.52
Sander volgensis	0.30			
Zingel streber	0.16	0.93		
Zingel zingel	0.62	3.99		1.04
Salmonidae	**0.34**			
Coregonus sp	0.34			
Siluridae				**16.04**
Silurus glanis				16.04

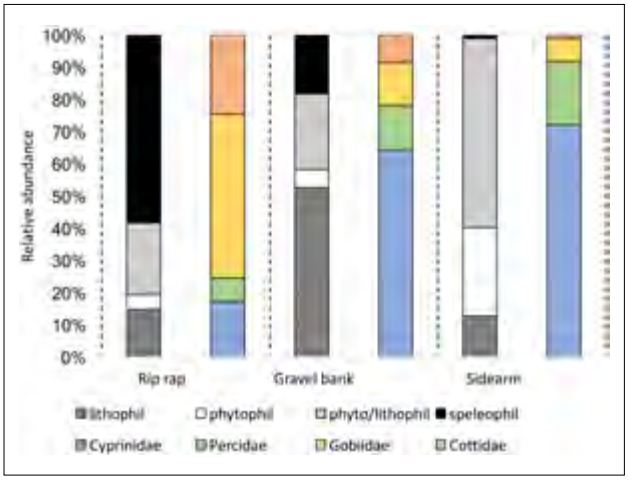

Figure 5. Mean relative abundance of major spawning guilds and families separated for riprap, gravel bank and side arm (after Meulenbroek et al. (2017a))

The study results of the bypass system also demonstrated the use of this man-made river for the reproduction of several species. At the upstream end a mixed set of fish larvae drifted into the system deriving from the Danube; the subadjacent sampling point downstream at the end of the pool pass is dominated by speleophilic (75–85 %) (particularly *Neogobius melanostomus)* and equal shares of lithophilic and phytophilic species. We hypothesise that especially the boulders at the thresholds between the pools are massively used by Gobiidae for spawning. In contrast, at the stream section the majority of the caught larvae consisted of lithophilic (55–66 %) species, foremost by *Chondrostoma nasus, Barbus barbus* and *Squalius cephalus.* In total, 22 fish larvae species were found in the bypass. The repeated capture of Rhodeus amarus larvae also reveals the occurrence of mussels, which are a prerequisite for the reproduction of this ostracophilic species. The study proves that many species have accepted the surroundings as a habitat for different life stages. The reproduction evidence of this species composition corresponds to a natural side arm or tributary of the Danube system. Therefore, it serves as an important refuge and key habitat for the conservation of a variety of endangered species. It is one of the key principles in ecology that habitat heterogeneity increases biodiversity. This is also shown at the bypass. The different sections provide conditions for different ecological guilds and therefore consequently increase species richness. Up to now, the focus for the implementation of fish bypasses is mostly driven to provide migration corridors. With the background knowledge that the Danube was originally a braided river with highly diverse habitats and in order to achieve the requirements formulated in the EU-WFD, a systematic approach for the creation and connection of habitats will be necessary to improve the ecological situation at large rivers like the Danube. Especially the provision of functioning spawning and juvenile habitats is one of the most essential tasks to strengthen the remaining fish stocks and should be considered when planning and implementing fish passes or other artificial waterbodies. However, such systems also need to be managed continuously for a sustainable functioning (beaver dams and log- or driftwood jams, deepening of the riverbed etc.) (Meulenbroek et al. 2017b).

◀ *Table 1 . Calculated relative distribution (%) of all caught species and families separated for all sampling sites. n=21.126 (adapted after Meulenbroek et al. 2017a, Meulenbroek et al. 2017b)*

Conclusion

The results of fish larvae drift at different shoreline configurations of the Viennese Danube and at the bypass system demonstrate several important aspects:

All the artificial shoreline areas and the bypass are used as spawning grounds by riverine fish species.

- The effect of monotonous riprap shorelines on the spatial distribution and massive spreading of the invasive Gobiidae is clearly documented.
- The relevance of the studied mitigation measures (gravel bank and riparian sidearm) becomes apparent by the reproduction of numerous typical riverine fish species as well as several protected and endangered species.
- The natural-like solution of a bypass system serves in contrast to a hard technical construction – additionally to its migration function – as a key habitat for reproduction.

In summary, the fish-ecological conditions at the investigation area of the impoundment of Vienna/Freudenau have suffered just as much as in other Danubian impoundments (reduction of biodiversity and abundances of the typical riverine fish species). However, the mitigation measures work as a last refuge for these species.

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