Chapter 24
Danube Under Pressure: Hydropower Rules the Fish

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24.1 Introduction

Major studies, conducted recently at some Danube hydropower impoundments and along the river itself, have pinpointed certain challenging ecological situations for certain faunal associations (Schiemer 2000; Jungwirth 1984; Waidbacher 1989; Herzig 1987; Bretschko1992). One of the important groups affected are riverine fish assemblages. Fish communities are good indicators of habitat structure as well as of the ecological integrity of river systems due to their complex habitat requirements at different stages of their life cycles (Schmutz et al. 2014; Schiemer 2000; Schmutz and Jungwirth 1999). The construction of impoundments changes river systems ecologically by disrupting the connection between the river and the lateral backwaters, by changing the shoreline, and by stabilizing previously dynamic water levels as well as other impacts (Schiemer and Waidbacher 1992).

Impoundments confront fish with new situations that present a challenging difference with the sets of parameters they have adapted to in unmodified river habitats. Due to reduced flow, increased depth, low water temperatures, short retention times, silty to muddy sediments resulting from increased sedimentation, and higher benthic biomass in the sediment depositions, these impoundments conform more to the habitat needs of lacustrine fish species. However, the relatively low average annual temperature of the river, the lack of shoreline structures, and low plankton density inhibit better development of such "backwater" fish associations. The original dominant riverine fish species can mainly be found only in free-flowing sections, except for a few individuals in the uppermost part of the impoundments (Waidbacher 1989).

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In light of these results, strategies have been developed to counteract and minimize negative impacts caused by the construction of new hydropower dams. A more ecologically sustainable solution has been implemented during the construction of a low head dam (8.6 m height) for the impoundment at “Freudenau” in Vienna in 1998. A special attempt has been made here to maintain the ecological integrity of the river system by introducing a large number of mitigating measures. These include creating large gravel areas, improving the lateral integration between the river and the backwaters, and increasing the diversity of the inshore riverbed structures to improve the quality of spawning substrates and nurseries for fish (Waidbacher et al. 1996).

The results of the latest monitoring 2013–2015 are presented here and can be seen as a first indication of the response of the fish association to the innovative large-scale measures of “Freudenau” impoundment.

24.2 Historic Development of the Austrian Danube and Its Faunal Elements

The upper part of river Danube extends from the river’s source in Germany to the Austrian/Slovakian border and is topographically well defined by its high slope (0.43‰ in Austria) and high bedload transport. Large tributaries from the Alps considerably increase river discharge, which reached a mean value of approx. 2000 m^3/s eastward from Vienna prior to river engineering (Liepolt 1967). The pristine morphological condition of the river alternated between canyons with narrow riparian zones to braided reaches with large alluvial areas, especially in the plains of Eastern Austria. A variety of river arms offered a rich diversity of ecological structures with gradients of flow velocity, substrate, and riparian vegetation. This provided ideal conditions for a typical Austrian Danube fish community (Hohensinner et al. 2005).

During the last 100 years, these ecological conditions have been considerably changed by river regulation and damming (Hohensinner et al. 2004). The main regulation started in the second half of the nineteenth century and resulted in substantial changes due to straightening and enforcement of most of the river’s flow into one channel and an abandonment of side arms. This had major effects on:

(a) The ecological conditions of the river habitats (e.g., increase of flow velocity, bedload erosion, and deepening of the riverbed)
(b) The interactive dynamics between river and riparian zone
(c) The relative proportion of alluvial habitat types

The construction of large run-of-the-river hydropower plants started in the 1920s with the ultimate goal of forming a continuous chain of impoundments along the German/Austrian Danube section (Rathkolb et al. 2012). These developments resulted in severe ecological degradation due to an almost complete disconnection between river and lateral backwaters, mostly monotonous shoreline constructions and a stabilized water level over long distances. The characteristic limnological features of these impoundments are:

(a) Short retention times
(b) Low water temperatures
(c) Sedimentation of fine particles in the central impoundment
(d) Reduction of littoral gravel banks to the uppermost sections of the impoundments
(e) Low plankton density
(f) Higher densities of benthic invertebrates in the fine sediment deposits

24.3 Basic Scheme of Impacts of Danube Hydropower Impoundments on Native Fish Associations

Fish communities are good indicators of ecological integrity of river systems because of their complex habitat requirements that shift in the course of their life cycles. The changes in population structures and abundances induced by damming can be elucidated by comparing the fish fauna in free-flowing sections with that of impounded areas. The first such investigations were done in river Danube as part of an interdisciplinary study of the impoundment of "Altenwörth" (50 km upstream of Vienna) in the mid-1980s (Hary and Nachtnebel 1989; Waidbacher 1989; Schiemer and Waidbacher 1992). The fauna in the free-flowing river is characterized by a dominance of rheophilic species (i.e., their life cycle is bound to rapid-flowing water conditions). Species such as barbel (*Barbus barbus*) and nase (*Chondrostoma nasus*) occur in high abundances in the free-flowing section of the "Wachau," followed by a distinct predominance of eurytopic species [e.g., roach (*Rutilus rutilus*) and bleak (*Alburnus alburnus*)] in the impounded section. Data are based on electro-boat fishing along the shoreline (system Coffelt, attracting efficiency approximately 6 m width and 2.5 m depth) and additionally long-line fishing at the river bottom. The difference in the species composition between the uppermost part of the impounded river, with high flow velocity and coarse-grained sediments, and the central part of the impoundment, with reduced flow, fine substrates, and monotonous shoreline structures, is relatively low (Table 24.1). However, the population density of the characteristic riverine species, nase and barbel, declines noticeably in the main impoundment (Fig. 24.1).

Table 24.1 Number of adult and juvenile species in the different sections of the impoundment in the main channel of the Danube at "Altenwörth" and "Freudenau"

	Altenwörth		Freudenau	
	Adult	Juvenile	Adult	Juvenile
Free-flowing	32	21	24	21
Head of impoundment	35	18	23	17
Central impoundment	36	18	21	12

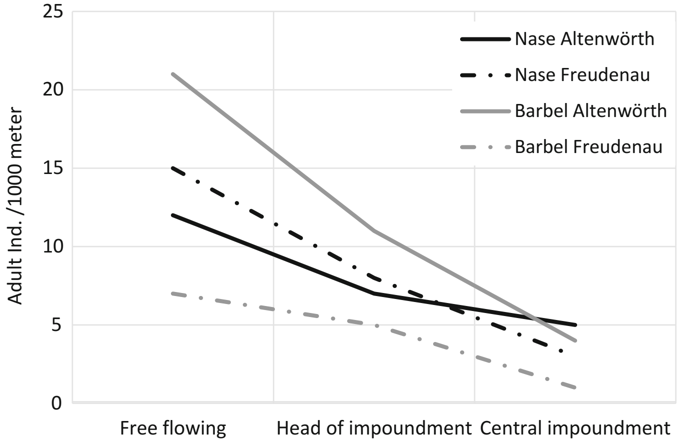

Fig. 24.1 Example for the distribution of two originally dominant fish species in the monotonous constructed Danube impoundment of "Altenwörth," 50 km westward of Vienna, and the latest constructed impoundment of "Freudenau"; adult nase and barbel individuals per 1000 m electrofishing in the riparian zones (own data, late spring/summer situation)

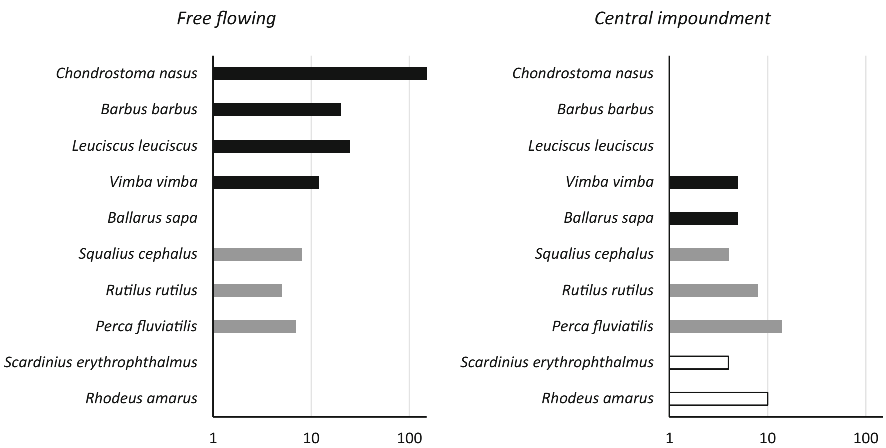

Fig. 24.2 Mean numerical composition of juvenile fish in three shore seine catches; free-flowing area is located in "Wachau"; central impoundment in the impoundment of "Altenwörth"; black, rheophilic; gray, eurytopic; white, limnophilic species (own data)

An analysis of the size structure of the characteristic riverine species shows that in the vicinity of the dam, only old age classes are represented, supported by abundant food supplies in the rich benthic deposits (Waidbacher 1989). Surveys of fish juveniles, as seen in Fig. 24.2, show that the overall density is low, and riverine species are rarely represented or are completely missing in the main impoundment zone. Flow velocity and the nature of littoral substrates (mainly riprap) are not adequate to function as spawning sites and rearing areas for riverine species.

24.4 Implementation of Mitigation Measures in the Latest Constructed Hydropower Dam and Impoundment of Vienna/Freudenau

Based on the results of research at the “Altenwörth” impoundment in the mid-1980s, strategies have been developed to improve the ecological conditions of affected areas. Ecological improvements were designed to counteract and reduce negative impacts caused by the hydropower dams over periods long enough to make such improvements sustainable.

As an example, the objectives for habitat improvements for characteristic Danube fish populations contain the creation of:

(a) Dynamic gravel banks
(b) Dynamic sand habitats
(c) Shelters in times of flood events
(d) Possibility for upstream migration
(e) Lateral connections of water bodies
(f) Riparian bays and channel systems

Various “ecologically sustainable” solutions have been implemented during the construction of the low head dam for the impoundment at “Freudenau” in Vienna. In this case, for the first time, a whole suite of mitigating measures has been introduced to maintain the ecological integrity of the Danube and especially to support the development of self-reproducing fish communities. Figure 24.3 gives a rough overview of the location of implemented measures in four sections, which are described in more detail below.

Section 1

Along riparian floodplains, the connection of lateral water bodies to the main river channel favors the migration of fish, especially lacustrine backwater fish species, and offers rearing and feeding areas (Fig. 24.4). Migration into riparian side arms is extremely important for different life stages of some endangered fish species, such as white-eye bream (*Ballerus sapa*) and zope (*Ballerus ballerus*).

Section 2

The original, dominant, rheophilic fish fauna is represented in Danube impoundments by adult individuals only. To mitigate these effects, gravel bank spawning grounds have been constructed in extended areas in the uppermost part of the “Freudenau” impoundment to support the reproduction of original faunal elements of the river (Fig. 24.5). This was done by the construction of an underwater riprap, which prevents the gravel bar from major erosion into the main channel.

Section 3

An extensive riparian channel and bay system in the central impoundment serves mainly as a spawning ground and rearing area for eurytopic species and as a feeding area for all fish associations. During flood events these zones act as refuges (Fig. 24.6).

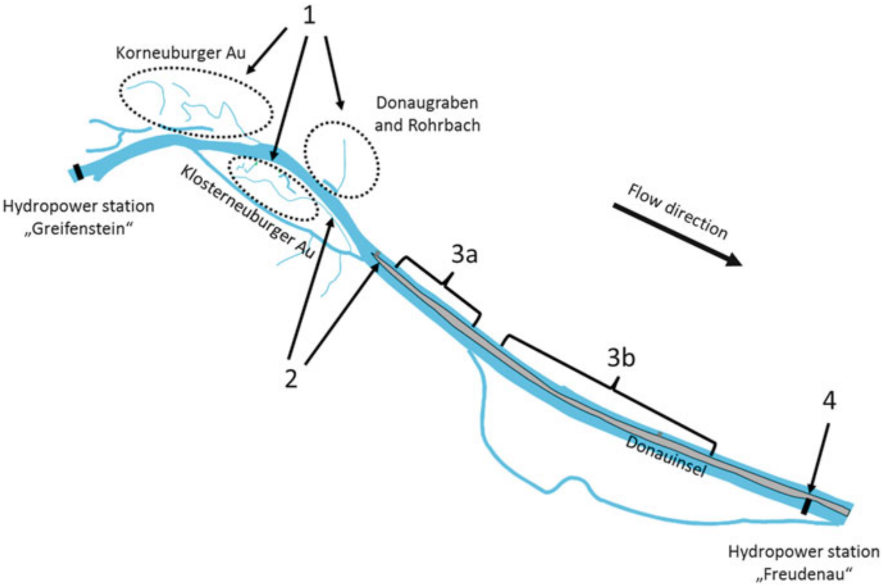

Fig. 24.3 Location of different ecologically sustainable solutions in four sections of the impoundment "Freudenau" (1. lateral connections; 2. gravel banks with riprap stabilization; 3. riparian channel and bay systems; 4. fish migration bypass)

Fig. 24.4 Lateral connection of Korneuburger Au with the main channel of the Danube via a fish bypass system (courtesy of Verbund AG)

Fig. 24.5 Extended underwater gravel bank inshore structure under construction; red arrows indicate "double riprap"; blue line indicates the water level nowadays after construction (Section 2)

Fig. 24.6 Constructed riparian channel and bay system in the central impoundment (Section 3)

Section 4
Fish migration in a bypass channel system supports genetic exchange (Fig. 24.7).

Fig. 24.7 Bypass channel system for fish migration at the power station "Freudenau" (Section 4) (courtesy of Verbund AG)

24.5 Ecological Response and Sustainability of the Constructed Habitat Improvements at "Freudenau"

A second round of research was conducted to monitor constructed habitat improvements some 18 years after construction. Without the influence of constructed measures, the fish assemblages in the main channel of Freudenau responded in the same pattern as already seen in "Altenwörth," namely:

- Decrease or lack of juvenile fish in the central impoundment
- Low number of species in the riparian part of the impounded area
- Low abundance of riverine assemblages in the central part of the impoundment

Considering the ecological improvements indicated by research some 18 years after construction, a clear positive sign for fish assemblages becomes visible:

In Section 1, a better connection has been constructed between the channel and the riparian floodplain waters of "Klosterneuburger Au" (right bank of the Danube). A pool pass allows fish migration at two different water levels of the backwater (summer and winter) and has been accepted by 29 fish species in the direction to the backwater and by 38 species in the direction to the main river channel. In addition to the movement pattern expected in times of spawning activities, the results (fish trap in the pool pass) from 2006 show a remarkably fast response of riverine fish, which were washed into the backwater system during a flood event, in finding again the migration pass for leaving the backwaters in the direction of the main Danube channel. Eighty-five percent of the composition of the sampled migrating rheophilic fish, which showed locomotion after the flood event, belongs to the species assemblage of nase, ide (*Leuciscus idus*), vimba (*Vimba vimba*), asp (*Leuciscus aspius*), and schrätzer (*Gymnocephalus schraetser*)—a classic river fish assemblage (Fig. 24.8).

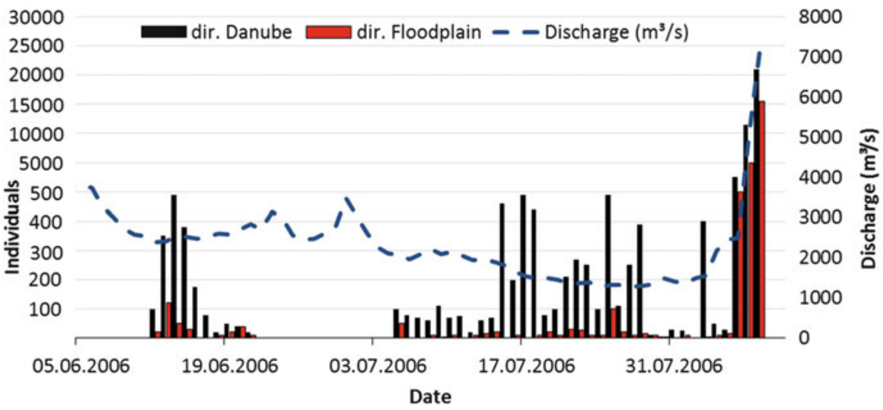

Fig. 24.8 Left axis: Number of migrating individuals into the floodplain system (dir. Floodplain) and vice versa in the direction of the main channel of the Danube (dir. Danube). Right axis: Discharge of the Danube (adapted after Schinninger 2008)

Expected peaks in fish migration are visible in the period of late spring, pinpointing migration activities for spawning and after reproduction (Schinninger 2008).

Investigation via a pool pass system of migration activities to the “Korneuburger Au”—situated on the left bank of the Danube—has shown similar results (Jungwirth and Schmutz 1988). In total, 32 species migrated in both directions. Bleak, roach, white bream, bream (*Abramis brama*), barbel, nase, and zope were the most frequently observed species in this study.

Where connection to the main channel is limited, i.e., lack of a pool pass or other migration facilities, fish communities in backwaters can show a high specialization and often are inhabited by rare species. Some species, such as the weatherfish (*Misgurnus fossilis*) recorded in this study, occur exclusively in disconnected floodplain waters. The design concept implemented for ecological improvement at “Freudenau” supports such species by leaving small floodplain habitats disconnected in years without natural flood events (e.g., “Rohrbach” habitat).

In Section 2, a large amount of gravel material was excavated from the riverbed and newly located in the riparian area to construct gravel bank spawning grounds. Extended shallow areas of several hectares have been artificially established and secured against abrasion by a massive underwater riprap structure (Fig. 24.5). Despite several flood events (up to a 200-year-flood event) over 18 years, no massive changes in the constructions are visible, and the gravel banks are still functioning as spawning grounds. Figure 24.9 shows results from 2013 where larval stages of fish

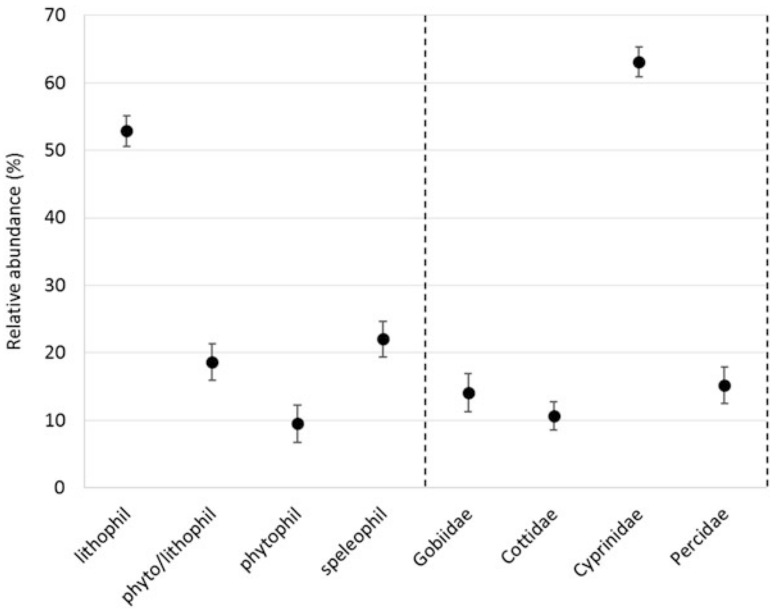

Fig. 24.9 Mean and confidence limits of relative abundance of drifted fish larvae for spawning guilds and families at an artificially built gravel bank, $n = 171$ (adapted after Meulenbroek et al. 2017a)

have been sampled downstream of a large artificial gravel bank situated at the upper most part of the "Viennese Donauinsel." The fish larvae have been identified via barcoding and displayed high shares of lithophilic riverine cyprinids in their abundances (Meulenbroek et al. 2017a). Although spawning activities of adult individuals could not be observed in turbid waters, the drifting of fish larvae in the presumed time period provides indications of successful reproduction activities at the artificially constructed gravel bank.

Section 3 is divided in two parts where one part (3a) is self-cleaning from fine sediments along the shoreline after flood events, while the other one (3b) is not.

In Section 3a, flow velocity is high enough at mean discharge (1 m/s) to wash out fine sediments, which are deposited during flood events in the riparian structures. Inside of the constructed riparian arms, a riverine fish assemblage has developed and persists even after 18 years (Table 24.2).

In Section 3b, the fine sediment deposition along the shoreline is not cleared at mean discharge. The constructed riparian bays are hotspots of biodiversity in the depauperated, i.e., species impoverished, central impoundment of "Freudenau." Their quick colonization by fish and benthic invertebrates just after their construction was documented by Chovanec et al. (2002) and Straif et al. (2003). The importance of such measures was highlighted in 2013–2015, by the high diversity, e.g., total 38 fish species, and high abundances of juvenile riverine species found in these areas (Fig. 24.10).

Recent findings of early life stage abundances suggest several colonization patterns for such riparian habitats. The most unlikely pattern is colonization only from the main channel via unidirectional drift. But there are three different drift patterns visible as described by Meulenbroek et al. (2017a):

(1) Larvae drift into the side arm over longer time periods with different densities and the use of the habitats as nursery grounds.
(2) There are spawning activities at different densities within these side systems.
(3) There is additional drifting of larvae in the direction of the main channel.

These factors identify the multiple functions of these habitats in providing suitable nursery and spawning grounds for an essential variety of Danube fish species.

Furthermore, the high abundance of juveniles in these riparian flat habitats with high sedimentation is additionally sustained by low predating pressure from fish-eating birds. Such water bodies are too shallow for cormorants or goosanders to hunt for prey, and it is most likely that a few herons, stepping, picking, and taking fish,

Table 24.2 Comparison of the number of species within the most upstream riparian side arm for each habitat guild between years 1999/2000 and 2014/2015

	1999/2000	2014/2015
Eurytopic	8	8
Limnophilic	1	1
Rheophilic A	5	4
Rheophilic B	2	3
Total	16	16

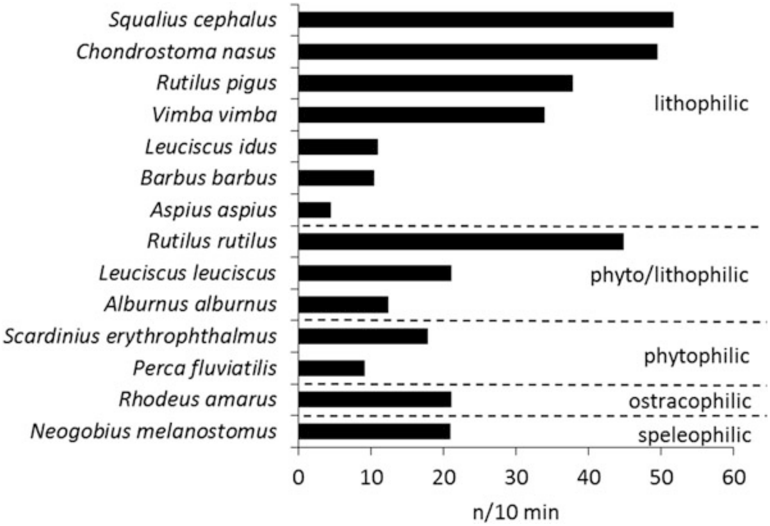

Fig. 24.10 Mean density (per 10-min electrofishing) of the 14 most abundant fish species for different reproductive guilds of one of the riparian side arms in 2014 (Section 3)

can be surely sustained by the system. The repeated validation over 18 years indicates that these mitigation measures are sustainable, even though some vegetation and sediment management needs to be established in the near future.

Results of the latest surveys, 18 years after construction, show that the fish assemblage in the impoundment of “Freudenau” follows the same pattern as in other Austrian Danube impoundments if the riparian mitigation measures are not taken under consideration (compare Figs. 24.2 and 24.11).

However, the mitigation measures show satisfactory improvements in the habitat conditions and support the functions of lost habitats essential for riverine fish. Fish association of juveniles found in a riparian side arm in the central impoundment in 2015 shows that nase and barbel as well as rudd (*Scardinius erythrophthalmus*) and bitterling (*Rhodeus amarus*) are part of the young-of-the-year assemblage and ready for building up new adult stocks.

Additionally, a new development became visible. It’s the first time in major scientific Danube investigations that alien species are visible in extraordinarily high densities. Beside the racer goby (*Babka gymnotrachelus*) and the bighead goby (*Ponticola kessleri*), the round goby (*Neogobius melanostomus*) dominates the bottom fish fauna at least in the impounded area. The bottom of main channel and the bottom of side arms, especially close to ripraps, are completely “infected” with enormous ecological effects on food webs and the native fauna caused by competition (Ahnelt et al. 1998; Wiesner 2005; Ebm 2016).

In Section 4, a fish migration bypass system has been constructed with three major components that robustly complement each other in a sustainable way. It starts with a bay system in the tail water (Fig. 24.7) with calm, shallow waters over some 200 m.

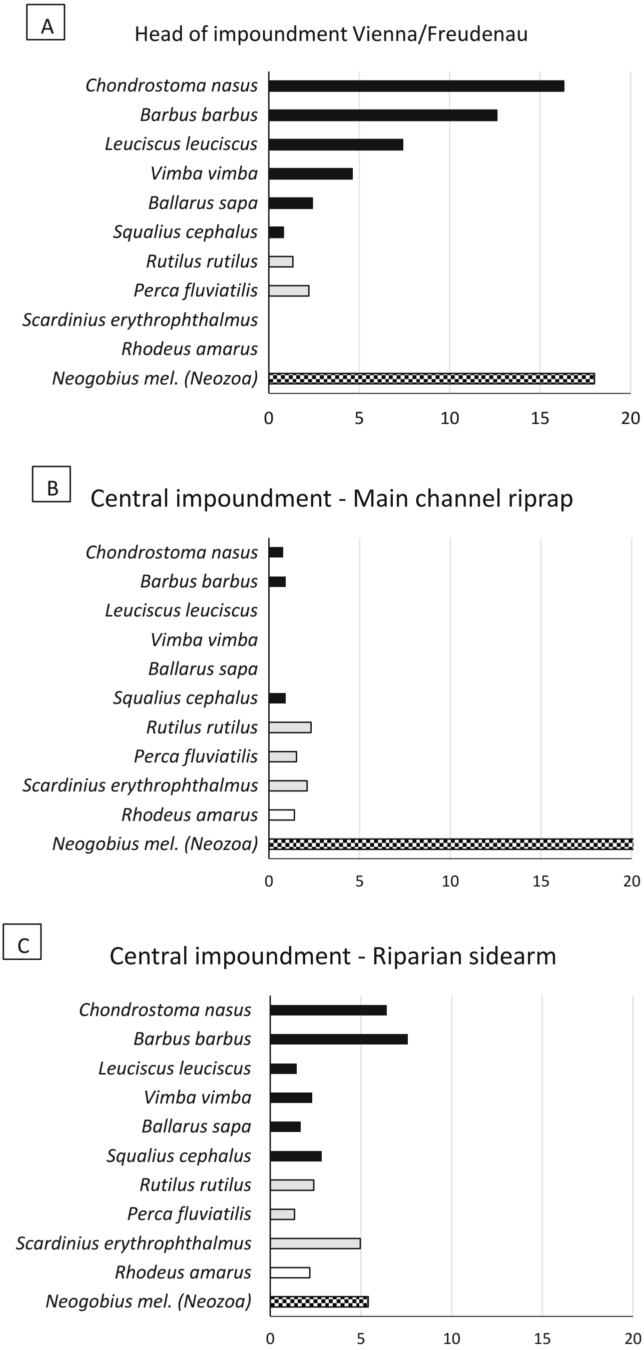

Fig. 24.11 Species composition of juvenile fish in the impoundment of "Freudenau"; black are rheophilic, gray are eurytopic, and white are limnophilic species; n = individuals/10-min electrofishing

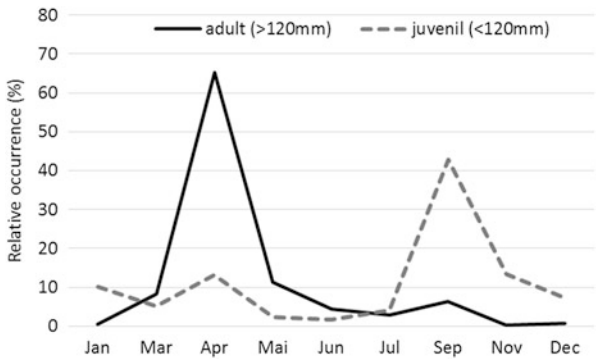

Fig. 24.12 Relative occurrence of juvenile and adult nase within the fish bypass system of "Freudenau" (adapted after Meulenbroek et al. 2017b)

The subsequent, seminatural bypass channel with a mean discharge of 1.6 m^3/s and an average slope of 0.7% is situated in a riverbed of 7 m width and a corresponding average current speed of 0.6 m/s. The discharge is not constant but follows the mean discharge of the Danube, reaching a maximum of 3.6 m^3/s. The length of this free-flowing section is approximately 900 m. The uppermost part of the system is built as a pool pass of 19 pools with a minimum of 70 m^2 per pool and a water level difference of 11 cm from pool to pool.

Beside the systems function as migratory facility, shown in 2000 by Eberstaller and Pinka (2001), the bypass system also provides a spawning ground for all the guilds of Danube fish and therefore makes an important contribution to the maintenance of several endangered species. In a monitoring survey, conducted throughout 2013 and 2014, seasonal changes in abundances, species diversity, and spawning events were observed. A total of 41 species colonize the bypass with temporary and spatial fluctuations. In early spring, the indicator species of the free-flowing Danube, nase and barbel, migrated into the fish pass in very high quantities. After spawning in April and May, most of the adults left the system. Shortly afterward a massive drift of early life stages of riverine fish species was observed, followed a few months later by thousands of juvenile fish (Fig. 24.12) (Meulenbroek et al. 2017b).

Present studies at the bypass system of "Freudenau" show that, in contrast to a pure technical construction, the seminatural bypass system provides a migration function and performs like a Danube tributary. However, geodetic research showed a deepening of the riverbed caused by continuous erosion due to lack of gravel input from upstream. This demonstrates the absolute need of management actions from time to time (after 15–20 years) to secure the positive ecological values for fish and other riverine faunal elements (Meulenbroek et al. 2017b).

24.6 Conclusion

In the Austrian stretch of river Danube (approx. 350 km), ten hydropower stations/ impoundments have been implemented within the last 70 years. All of them massively affect the fish fauna. The most threatened fish are those of the rheophilic guild, which was dominant during pristine conditions. Straightening the river channel at larger scales started in the 1850s. Their further development favored lacustrine as well as eurytopic species at the same time that it decreased abundances and occurrences of riverine species by shortening free-flowing habitats and cutting off side arms.

Impoundments deny rheophilic fish a number of structures found in free-flowing river stretches: suitable gravel spawning grounds, small- and large-scale inshore structures for nursery and juvenile development, and shelters in times of flood events and winter situation as well as proper food security. As a consequence, fish ecological research shows an extreme decrease of riverine adults in the central impoundments, and successful reproduction is only possible in small, restricted areas of running waters with gravel habitats in the tail water of the dams.

However, in impoundments stronger development of eurytopic and lacustrine fish species is hampered by comparatively low water temperatures, low plankton density needed as starter feed for their larvae, a lack of macrophytes as spawning habitats, and a lack of structured refuge and nursery habitats.

Based on these abiotic and biotic conditions, a Danube impoundment does not serve the development of a proper life cycle for riverine fish or for lacustrine communities. Eurytopic species are most likely to accept suboptimal conditions, and therefore in most impoundments a very limited number of eurytopic species dominate the fish fauna.

Planning and constructing of the latest Danube hydropower plant at "Freudenau" (operation started 1998) considered a variety of ecological measures to improve the biotic integrity of the affected river section. Large-scale habitat constructions—based on the lessons learned at other impoundments—include double-riprap secured gravel banks, creation of massive inshore riverbed structures, a bypass system for fish migration, and creation/connection/integration to riparian backwaters and side arms. Results from the fish assemblages as seen in Fig. 24.11 pinpoint the positive ecological development of the central impounded area only when riparian side arms and structures are situated.

Because of "aging" of the constructed riparian elements, succession happens in the riparian vegetation as well as in the habitat morphology, and hence continuous human management and maintenance are vital to sustain the habitat's functioning. Given the scale that humans use the river's flow to satisfy such needs as electricity, in response habitat management has to secure the functioning of ecological improvements to guarantee future fish stocks for next generations. Hydropower rules the fish!

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