# The importance of instream reservoir structures for the biodiversity of the benthic macroinvertebrate fauna in the Viennese Danube

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## Abstract

Dam-created reservoirs adversely affect riverine biotic communities, such as macroinvertebrates. To mitigate these negative effects, multiple mitigation measures have been proposed, including the creation of lateral widenings and gravel bars and islands as instream structures in the reservoir section. Here, we examined the potential of eight such shoreline habitats for the biodiversity of benthic macroinvertebrate fauna in the impounded Viennese Danube (hydropower station Freudenau). We found 79 different taxa present in the shoreline habitats, therefrom 43 taxa were unique to these habitats as they did not occur in the main channel. Both, the non-metric multidimensional scaling and the cluster analysis grouped the eight shoreline habitats and showed that they differed from sampling sites in the main channel (reservoir and free-flowing section). Hence, our results demonstrate the importance of such instream structures to the overall biodiversity of benthic macroinvertebrate fauna in impounded rivers, such as the Danube River.

## Introduction

Dams have been built for millennia, but especially since the mid-20th century, dam construction rates boosted due to economic development (Schmutz & Moog 2018). However, dam development is still ongoing. From 2007 to 2016, about 8,000 new large dams were built globally, resulting in a total of >58,000 dams with a height greater than 15 meters (Liro 2019). Unsurprisingly, 48 % of all rivers worldwide (expressed as river volume) are moderately to severely affected by flow regulation and/or river fragmentation, and 25–30 % of pre-disturbance sediment flux is stored in reservoirs (Schmutz & Moog 2018). Whereas most research has focused on studying impacts and mitigation measures downstream of dams, comparably little attention has been paid to upstream river sections (Liro 2019).

Dams create reservoirs (impoundments) which turn a free-flowing river into an entirely new ecosystem which is neither river nor lake. Such reservoirs usually exhibit a longitudinal gradient from the dam (lentic zone) to the upstream reaches (riverine zone). Between the two, a transition zone often develops which shows both, lentic and lotic features (Schmutz & Moog 2018). These changes significantly impact riverine biota, in particular, aquatic communities associated with the hyporheic interstitial, such as benthic macroinvertebrates. For example, when fine sediments are deposited in the reservoir, the river bottom becomes clogged, which causes a reduction of benthic biodiversity as most taxa disappear while few taxa, such as chironomids, become dominant. In general, river type-specific rheophilous organisms are replaced by fine-sediment dwellers of standing water-bodies. Hence, the ecological status of the macroinvertebrate community in reservoirs is mostly classified as “poor” or “bad” according to the EU Water Framework Directive (Ofenböck et al. 2011).

To mitigate these adverse ecological effects caused by reservoirs, multiple mitigation measures have been proposed (Jungwirth et al. 2005). Measures in the head sections (riverine zone) include lateral widenings and the creation of gravel bars and islands as instream structures. In the lentic reservoir zone, the construction of artificial stabilized sand/silt islands along the embankments may provide suitable habitat for aquatic organisms. In this study, we examined the potential of eight shoreline habitats to enhance the biodiversity of benthic macroinvertebrate fauna in the impounded Viennese Danube.

## Study sites and methods

The run-of-the-river hydropower station Freudenau, located in Vienna, is the last hydropower station situated along the Austrian Danube. After a six-year construction phase from 1992–1998, it was put into operation in 1999,


*Figure 1. Overview of the eight sampled shoreline habitats (i.e., bays or side channels/islands as instream structures) created along the left bank of the Viennese Danube (habitat G and H were not sampled). “KW Freudenau” indicates the hydropower dam (Source: Stadt Wien - data.wien.gv.at, modified by P. Leithner).*

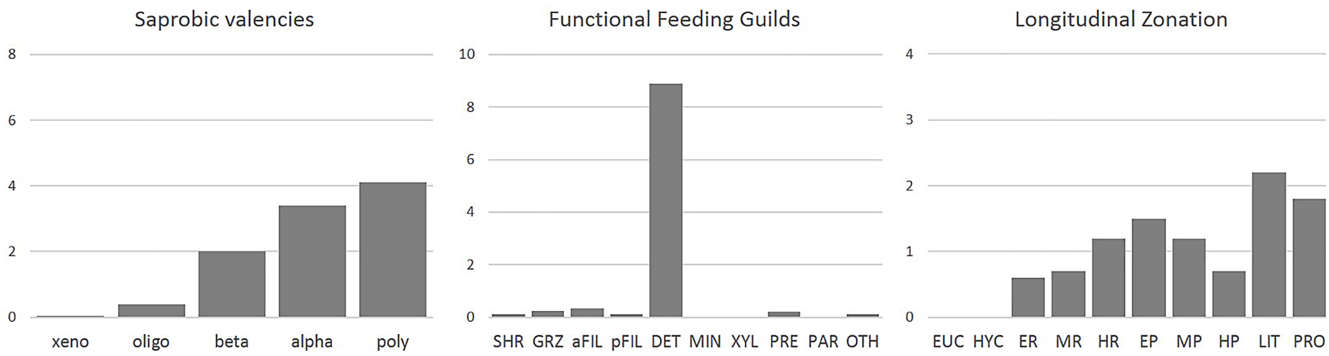


*Figure 2. Saprobic valencies (xeno = xenosaprobic, oligo = oligosaprobic, beta = beta-mesosaprobic, alpha = alpha-mesosaprobic, poly = polysaprobic), distribution of functional feeding types (SHR = shredders, GRZ = grazers, aFIL = active filter feeders, pFIL = passive filter feeders, DET = detritus feeders, MIN = miners, XYL = xylophagous, PRE = predators, PAR = parasites, OTH = other feeding types), and longitudinal zonation (EUC = eucrenal, HYC = hypocrenal, EP = epirhithral, MR = metarhithral, HR = hyporhithral, EP = epipotamal, MP = metapotamal, HP = hypopotamal, LIT = littoral, PRO = profundal) of the benthic community.*

resulting in the damming-up of around 28 river kilometers. As one of the mitigation measures for damming the river, eight shoreline habitats (i.e., small- to medium-sized bays or side channels/islands as instream structures, connected either directly to the main channel and/or through pipe culverts) were created along the left river bank (rkm 1922.7–1936.0) – four in the main reservoir section (lentic zone), and four in the transition zone *(fig. 1).*

Fifteen years after the start of the hydropower operations, we sampled the benthic macroinvertebrate fauna of these eight shoreline habitats and compared the results to those of both, the reservoir and free-flowing section, which were investigated between 21 and 24 July 2014 by twelve airlift samples each. On 5 May 2014, we collected macroinvertebrates in the shoreline habitats with 25×25 cm hand nets through a multi-habitat sampling (MHS) approach to form [separate] substrate-type groups. Hence, depending on substrate diversity, we sampled two to five substrate groups per habitat.

All data were processed with the Ecoprof Software version 4.0 (Moog et al. 2013). To understand the importance of these shoreline habitats to the overall macroinvertebrate biodiversity of the Freudenau impoundment, we conducted non-metric multidimensional scaling (NMS) analysis, as well as cluster analysis using flexible beta linkages (-0.25) and the Sørensen (Bray-Curtis) distance measure of similarity. Both analyses were done with the software PCOrd 6.19 (McCune & Mefford 2011).

## Results

The assessment of habitat B (fig. 2) – as one representative shore-line habitat – regarding saprobic valencies revealed high alpha-mesosaprobic and polysabrobic shares, which is typical for stagnant areas such as littoral zones. Concerning feeding types, we found almost exclusively detrivorous taxa. Regarding river regions, the highest values were detected for the littoral and profundal zones. Worms (Oligochaeta) and non-biting midges (Chironomidae) combined accounted for 95% of the total abundance in the sediment core.

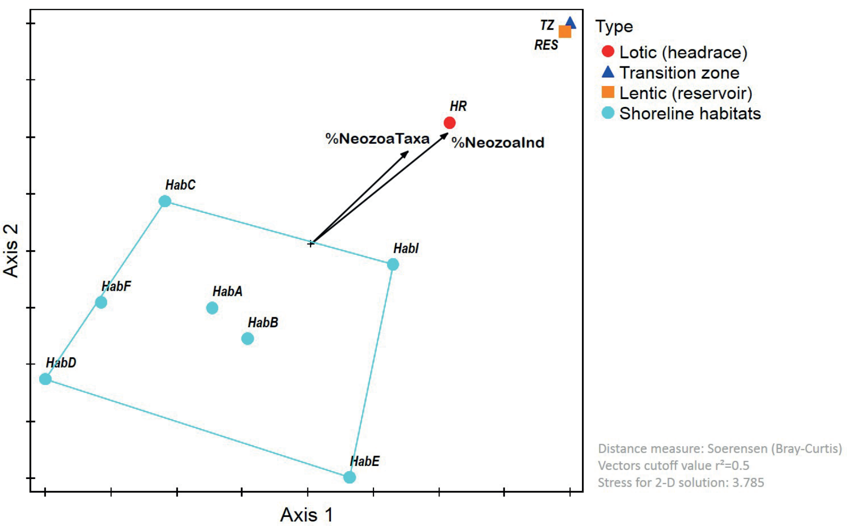


*Figure 3. Non-metric multidimensional scaling (NMS) analysis regarding macroinvertebrate abundance per habitat reach. Abundance was log-transformed (n+1). HabA–HabI = shoreline habitats, HR = lotic habitat close to the headrace, TZ = transition zone, RES = lentic reservoir zone, %NeozoaTaxa = share of neozoa taxa (taxa count), %NeozoaInd = share of neozoa taxa (individuals).*

In total, we discovered 79 taxa in the shoreline habitats through the MHS scheme. Comparing this taxa number to those found in airlift samples conducted in the main channel (reservoir and free-flowing section), it became evident that 43 taxa are unique to the shoreline habitats in the reservoir (Graf et al. 2016). The number of "exclusive" taxa per shoreline habitat ranged from 0–28 (mean = 11.1). The lowest number of taxa solely present in the shoreline habitats were found in the

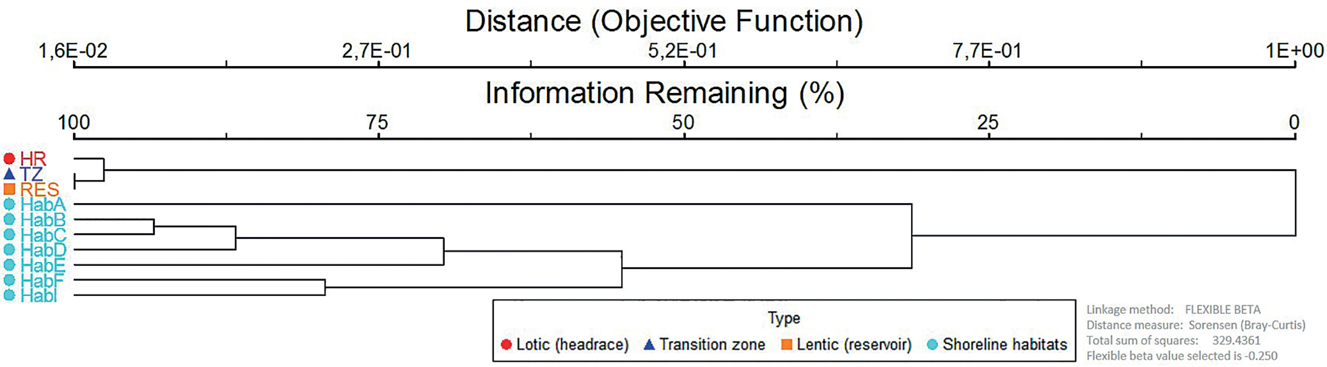


*Figure 4. Cluster analysis: single samples are grouped per habitat reach. Abundance was log-transformed (n+1). For habitat codes see Figure 3.*

four upstream sites situated in the transition zone of the impoundment (4, 0, 4, and 7 unique taxa, respectively). In contrast, the highest numbers of taxa only present in the shoreline habitats were discovered in four habitats located in the lentic zone of the reservoir. For example, in habitats B, C, and D, we found 14, 28, and 19 exclusive taxa, respectively. Interestingly, the 13 unique taxa which occurred in habitat A resulted from two substrate groups only.

The non-metric multidimensional scaling (NMS) analysis translates (dis)similarities between sampling sites into a special proximity. The results in figure 3 show that all eight shoreline habitats are separated from the sampling sites in the main channel. Hence, this result indicates that particularly the studied shoreline habitats are of high importance for the overall biodiversity of macroinvertebrate fauna in the heavily-modified Viennese Danube.

The cluster analysis *(fig. 4)* revealed that the biocenosis of the free-flowing and impounded sections within the main channel is rather similar to each other. The benthic community in the riverine impoundment zone shows greater similarity to the one in the lentic impoundment zone than that on the near-by gravel bar areas. Furthermore, all of the eight man-made shoreline habitats are clearly distinguished from the other habitat samples.

Analysis of species composition revealed that most organisms are primarily associated with palaeopotamon habitats which, in a natural floodplain river, would be located far off from the main channel. Hence, the presence of such species underlines that these shoreline habitats, as well as other stagnant waterbodies along the artificially constructed Viennese "Danube island" (Donauinsel), are important surrogate habitats in a cultivated landscape. Furthermore, these habitats constitute a vital contribution to overall biodiversity and are crucial stepping stone biotopes which connect floodplain elements of the Danube River.

The share of non-native macroinvertebrates within the eight shoreline habitats ranged from 4.5–65.0 %. However, each of the five most downstream habitats contained ≤10 % neozoa. Only the two most upstream sites, where the Danube current flows through, showed high shares of non-natives, with 50 % and 65 %, respectively. There, the macroinvertebrate community resembles the overall assemblage of the flowing sections of the Austrian Danube near Vienna.

## Conclusions

15 years after inundation of the Freudenau reservoir, we sampled the macroinvertebrate fauna in eight shoreline habitats created as compensation measure. We found a high number of taxa in these shoreline habitats that we did not detect in the adjacent main channel. Further analysis revealed that all shoreline habitats were distinct from main-channel sites as the composition of benthic invertebrates was typical for floodplain habitats far away from the main channel. Hence, our results demonstrate that such instream structures are important to enhance the overall biodiversity of benthic macroinvertebrate fauna in impounded rivers, such as the Danube River.

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