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# Ecohydraulic Assessment of Cooling Water Mixing in a Large River

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## Abstract

Aquatic ecosystems are affected by anthropogenic influence in many aspects. One among those is thermal pollution, which may be caused by discharging used cooling water of nuclear power plants back to the recipient water body. Research targeting this effect tends to focus more on coastal areas and small rivers, while less is known about the impact on large rivers. This paper focuses on the thermal effect on hydromorphology and fish assemblages of a once-through wet cooling nuclear power plant, situated on the right bank of River Danube in Hungary. After usage, the heated water is returned to the river, creating a locally variable aquatic environment. We aimed to investigate the abiotic and biotic (on fish assemblages) effects of the heat tail through seasonally repeated (spring, summer, autumn) field surveys. A clear effect was observed on the water temperatures, causing a 3-4°C temperature increment on the right-hand side of the river, downstream of the outfall of the warmwater channel. This difference decreased slowly and remained at least 1-2°C on the investigated 15 km reach, without complete mixing. Nearly 16400 individuals of 36 fish species were captured altogether during the survey campaign. The highest offshore fish abundance, regardless of season, was observed near the confluence of a side branch and the main channel, at ca. 3 km distance downstream from the warm outfall. Overall, the occurrence of specimens showed great variability within the reach, in which the heat tail did not seem to be dominant.

**Keywords:** Electrified benthic trawl; Fish assemblages; Hydromorphology; Nuclear power plant; Thermal pollution

## 1. INTRODUCTION

Aquatic ecosystems are exposed to a variety of threats through anthropogenic alterations of hydromorphology (Reid et al. 2019, Bukola et al. 2015, Vörösmarty et al. 2010, Dudgeon et al. 2006). The effects of modified water temperatures shall receive high attention in respect to climate change and its already apparent biological influence, pointed out by Daufresne et al. (2003). A wide variety of human impacts may induce such changes, as listed by Hester and Doyle (2011), including effluent discharges. A typical example of these is used and returned cooling water of thermal or nuclear power plants (Roy et al. 2021, Raptis et al. 2016, Madden et al. 2013).

Research on the effects of warm effluents of power plants on aquatic biodiversity in particular yield controversial results. Xu et al. (2021) found that the phytoplankton community of a reservoir adapted efficiently to an incoming thermal discharge. In contrast, brown macroalgae assemblages of coastal marine environment were reported to decline due to the warm effluent of nearby power plants (Széchy et al. 2017, Schiel et al. 2004). Worthington et al. (2015) found apparent changes in some parts of a riverine macroinvertebrate community, while other parts seemed unaffected by the thermal discharge of an adjacent power station. Shifts in water temperatures, even without effluent discharges, have been reported to cause changes in fish behavior (Goniea et al. 2006, Ebersole et al. 2001). Jan et al. (2001) studied coral reef fish communities nearby a nuclear power plant in Taiwan and found no considerable changes in the original assemblage. Teixeira et al. (2009) found that thermal pollution alters benthic coverage and decreases fish richness, however, this effect is mitigated on sites with complex habitat structure, as shown also by Teixeira et al. (2012). As Hester and Doyle (2011) pointed out, the occasional effect of a thermal discharge also depends on 1) how sensitive the thermal performance curves of the investigated species are to temperature change, and on 2) how the ambient temperature relates to the thermal optimum of the species. All these studies show that biotic response on thermal variability is the product of many factors. Nevertheless, further analyses of different cases are needed to universally understand this phenomenon.

Apart from gradients in temperature, a confluence of two flows in itself forms a highly diverse local environment (Baranya et al. 2015, Boyer et al. 2006, Benda et al. 2004), which may also affect the biota (Jones and Schmidt, 2016, Rice et al. 2006). However, these effects are assumed to be attenuated to some extent in our case, due to the magnitude difference between the flow discharges (a large river vs. the thermal discharge of a power plant) and to the lack of sediment in the thermal discharge.

This study focuses on the effects of a warm effluent on hydromorphology and fish assemblages in the recipient large river, the Danube River in Hungary. The thermal discharge is the used and returned cooling water of a once-through wet cooling nuclear power plant of Paks. The developed heat tail mixes slowly with the Danube water; Szolnoky and Raum (1991) reported that in a low flow regime its effect ranges to a 60-80 km distance downstream of the outfall. We aim to reveal 1) the extent to what the warm effluent affects the Danube's hydromorphological features (specifically water depth, flow velocities, bed material composition and water temperature) and 2) the induced changes in fish assemblages. This paper presents a qualitative assessment as an essential intermediate phase of the ongoing research.

## 2. MATERIALS AND METHODS

### 2.1 Study site

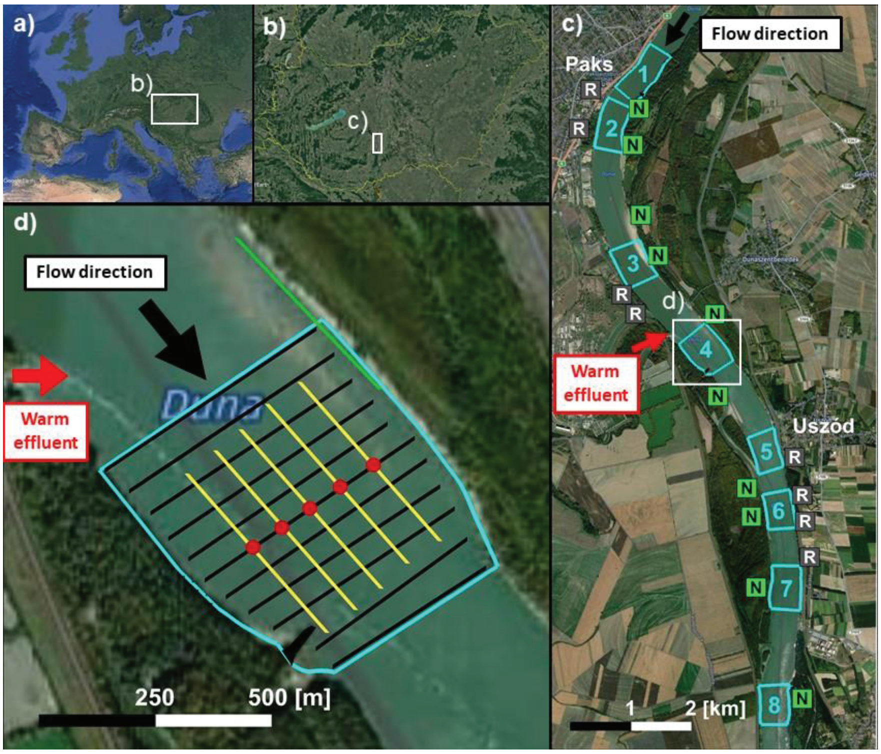


**Figure 1.** The location of the study site within Europe (a) and Hungary (b). (c) The study site near Paks, Hungary. Cyan edges with numbers: subreaches of the offshore sampling. White capital 'R's in grey boxes: rip-rap shoreline sections; black capital 'N's in green boxes: natural shoreline sections. (d) The survey design of the subreaches is presented on subreach No 4. Black spanwise lines: transects of bathymetry, velocimetry and surface thermometry; red dots: bed material sampling and vertical temperature profiles. Yellow streamwise lines: offshore benthic trawling electric fishing paths; green streamwise line: shoreline electric fishing path.

Our study site is a 15 km long reach of the Danube River next to the Paks Nuclear Power Plant (NPP) in Hungary (Figure 1c). The river is meandering slightly here with a few side-arms, its width varies between 400-500 m, while the floodplain is 1000-2000 m wide. The mean depth is 4 m at a mean flow regime, while the mean flow velocity is around 0.6 m $s^{-1}$. The mean flow discharge of the Danube here is 2300 $m^3$ $s^{-1}$, whereas the NPP's cooling water is returned with 100 $m^3 s^{-1}$. The riverbanks are natural, with sections of rip-rap embankment as erosion protection on the outer side of bends. Several groins are present to improve navigation conditions.

## 2.2 Data collection

The survey campaign consisted of three seasonally repeated field measurements in spring, summer, and autumn of 2020. Eight 500 m long subreaches were appointed within the whole reach, on which then the hydromorphologic survey and offshore benthic trawling were performed. Subreach No. 1 and 4 each included a groin on the left and the right shore, respectively. Three of these subreaches were located upstream of the mouth of the warmwater channel, while the remaining five were located downstream of it. The upper end of the closest subreach (No. 4) was at a 200 m distance from the channel. This subreach includes the reference cross-section (500 m distance from the outfall), in which authority regulations limit the maximum water temperature at 30°C (Szolnoky and Raum, 1991). Further shoreline sections (17 in spring and 18 in summer and autumn) were selected along the eight subreaches for shoreline electric fishing, in which the natural to rip-rap ratio represented the whole reach. Regarding the spatial distribution of these sections, nine of them were upstream of the warmwater channel; and four of them were located on the right shoreline downstream of the warm outfall; whereas the rest were appointed on the left side of the downstream reach (see in Figure 1c).

### *2.2.1 Hydromorphologic survey*

An Acoustic Doppler Current Profiler (ADCP) with a Real Time Kinematic (RTK) GPS mounted on a survey vessel was used for bathymetry and velocimetry. The water depth and vertical distribution of flow velocities were recorded in every 1.3 seconds while navigating along equidistant transects shown in Figure 1d (data processing then transformed velocity distribution into depth-averaged velocities). Every subreach was covered by 11 such transects.

The bed material was sampled in spring, at five points along the central transect of each subreach (Figure 1d). Altogether, 40 bulk samples were collected using a metal bucket from the survey vessel. The samples were then dried to constant mass on 104°C, and sieved by a Retsch AS 450 Basic vibratory sieve shaker. The grain size distribution was determined for each sampling point.

Water temperature was measured along the transects (near the surface) and also depth-wise (Figure 1d). A Teledyne Digibar S sound velocity profiler was used for measuring water temperatures in the vertical, while the total depth was provided by the ADCP. The Digibar records data in every 1 second, thus allows a good vertical resolution of temperature data. This was performed at the same five points in each subreach, where bed material sampling was carried out.

### *2.2.2 Fish collection*

Fish sampling was performed by offshore benthic trawling in the eight subreaches in daytime, and shoreline electric fishing on the 17 (spring) and 18 (summer, autumn) shoreline sections at night. The benthic sampling utilized a Hans-Grassl EL65 IIGI electrofishing device, electrifying a metal frame with a net as an anode and a copper cable floating in front of it as a cathode, see Szalóky et al. (2014) for details. The frame was lowered underwater from a boat and was trawled downstream on the riverbed, maintaining a speed just over the mean flow velocity. The sampling was done in five 500 m streamwise trawl paths along each subreach (see in Figure 1d). At the end of a path, the sampled fish were identified, measured, and returned into the water. The shoreline method was performed also from the boat, while rowing the boat downstream. The anode was the ring of a handheld landing net electrified by a Hans-Grassl Gmbh EL64 II GI, DC, 7.5 KW device, while the cathode was a copper cable floated at the rear of the boat. After each section, the collected fish were identified, counted, and released back to the river.

## 3. RESULTS AND DISCUSSION

## 3.1 Hydromorphology

Danube flow discharges for the three surveys were derived from the ADCP data and validated by up-to-date data published by the authority.

- Spring: 1700 $m^3 s^{-1}$;
- Summer: 2800 $m^3 s^{-1}$;
- Autumn: 1800 $m^3 s^{-1}$;
- Warmwater channel in every season: 100 $m^3 s^{-1}$.

The measured water depths revealed bed forms typical to a meandering river reach. Asymmetric cross-sections characterized the bends and the inflexion reach between them showed more complex morphology. Morphologic features induced by groins (local scouring and sand deposits) are also present. Water depths reflected the seasonal changes in flow discharges. The mean depth varied between 4-6 m, whereas the largest water depths were around 10-12 m in the three surveys. There was no apparent effect of the warm effluent on the water depths, i.e., on the bed morphology. We note, however, that even the closest subreach was at quite a distance from the outfall, while typical morphologic features of confluences (i.e., scour holes) develop more locally, in a 20-50 m distance (e.g., Baranya et al. 2015, Boyer et al. 2006).

The depth-averaged flow velocities resembled the depth data, as zones with higher velocities tend to erode, while lower velocities allow sediment to be deposited. The trace of the highest velocities defined the mainstream. The diverting and shielding effect of the groins were apparent. The maximum flow velocities varied between 1.45-1.60 m $s^{-1}$ throughout the surveys. Only a weak effect of the warm effluent could be detected due to the narrowed streamline in subreach No. 4, however, the subsequent groin might also account for this.

The bed material of the reach was dominated by sand with small portions of gravels and pebbles. Only a little amount of bulk sample was retrieved at the right shore of subreach No. 1 and 2, despite additional attempts. The base rock likely reached the riverbed surface there, with no mobile layer of bed material. Some samples, mostly from points affected by the heat tail, contained a significant number of mussels' shells. This observation is supported by Bódis et al. (2011), who showed that a distinct species composition is present near Paks, consisting of invasive species (with probably higher thermal tolerance as well). No other effect of the warm effluent could be shown. The thermal discharge does not carry bedload, which could alter the ambient bed material composition. With no severe flood in the time frame (flow discharge under 4500 $m^3$ $s^{-1}$ throughout the campaign), we assumed no significant change in bed material composition, thus performed no follow-up sampling after the spring survey event.

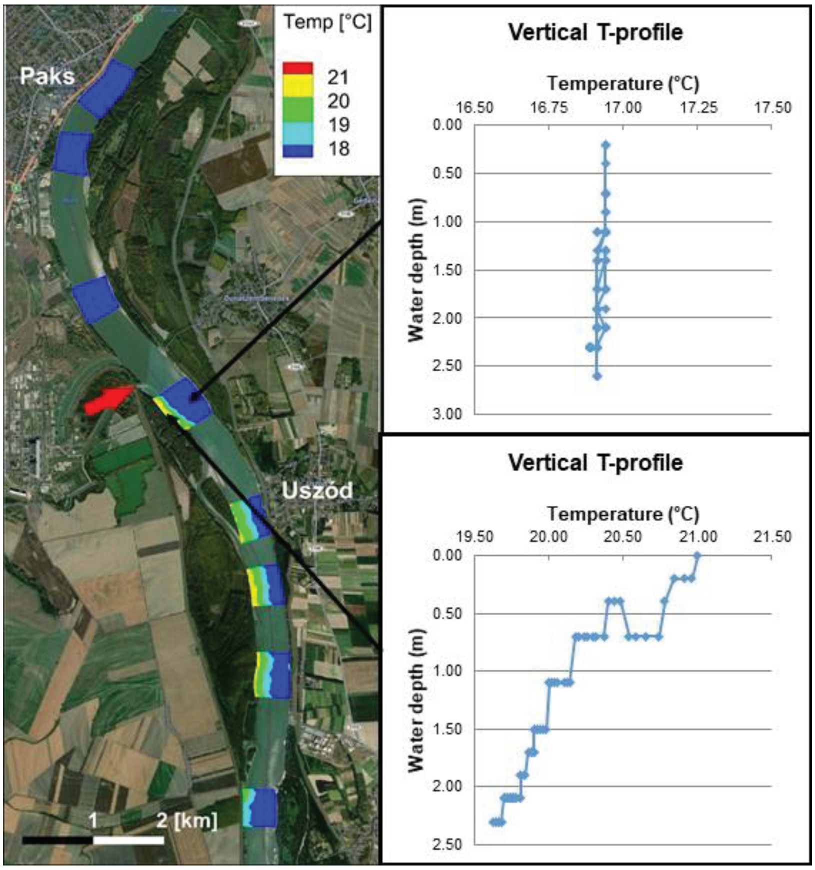


**Figure 2.** The spring results of thermometry linearly interpolated onto the subreaches. Two characteristic vertical temperature profiles are shown, recorded outside (upper) and inside (lower) the heat tail. (We note that the surface and the vertical temperatures were measured on the same day, though not at the same time.) Red arrow: warm outfall.

Obviously, the water temperatures were clearly affected by the NPP's warm effluent, as seen in Figure 2, which shows a linear spatial interpolation of the temperature data measured in spring. The temperatures in the unaffected upstream subreaches and along the left shoreline of the downstream subreaches were homogeneous in all survey events. The heat tail developed at the confluence, then propagated on the right-hand side of the Danube, without reaching the left shoreline. The temperature increment observed in the closest subreach to the confluence (No. 4) varied between +3-4°C. This slowly decreased with distance, although a +1-2°C difference was still present in the last subreach. Complete mixing did not occur along the study site. This is due to the size of the river here. In contrast, rivers significantly smaller than Danube exhibit usually quicker mixing and slower decrease of temperatures; thus their ecosystems are indeed more exposed to thermal pollution (Worthington et al. 2015, Prats et al. 2010). Vertical temperature profiles showed that 1) the temperature was uniform along depth in regions not affected by the warm effluent, and that 2) the highest temperatures (that is lower density water bodies) were always observed near the water surface in the heat tail (Figure 2). This justifies the relevance of thermal imaging in future research. Our results match the character of the findings of Szolnoky and Raum (1991), except we found a more intensive temperature decrease, when reaching the reference cross-section, in subreach No. 4.

### 3.2 Fish assemblages

A total 2537 individuals of 27 species were captured during the offshore benthic trawling in the campaign, the results are shown in Figure 3 (note the logarithmic scale). Three species accounted for ca. 85% of the individuals: the whitefinned gudgeon, *Romanogobio vladykovi* (1052); the round goby, *Neogobius melanostomus* (752); and the Danube streber, *Zingel streber* (334). The spatial distribution of captured specimens shows high variability, except two subreaches presenting regular pattern: the ratio of individuals collected in subreach No. 4 were uniformly low in all the three seasons (not the lowest, however); while subreach No. 6 uniformly provided the highest ratios. The five separate trawl paths of these two subreaches were further investigated. There was no detectable shifting towards either of the shores in subreach No. 4. The distribution along the cross-section appeared to be random, not particularly affected by the warm effluent on the right side of the river (+3-4°C difference). This also fits in the line of controversial results about thermal pollution published so far. For example, Xu et al. (2021) reported phytoplankton communities efficiently adapting to a much higher, +5-11°C increment with no significant changes in community structure; while Schiel et al. (2004) found significant decrease in the abundance of specific marine benthic communities by a similar, 3.5°C surplus temperature. Regarding fish communities, no considerable changes were found by Jan et al. (2001) at a site impacted by a nuclear power plant, however, relatively small temperature differences were measured there (0.08-0.33°C higher monthly averages). In subreach No. 6. a clear shifting towards the right shore was detected in every season. Apart from the +1-3°C thermal increment, the subreach showed no unique abiotic small-scale characteristics, but it was located closely downstream to the mouth of a considerable sized side arm. The mesoscale variability developed by the side arm–Danube joining is indeed unique to the study site, and thus may account for the outstanding abundance of sampled individuals. This is in line with Teixeira et al. (2012) who found that habitat complexity may attenuate, even override the effects of elevated temperatures.

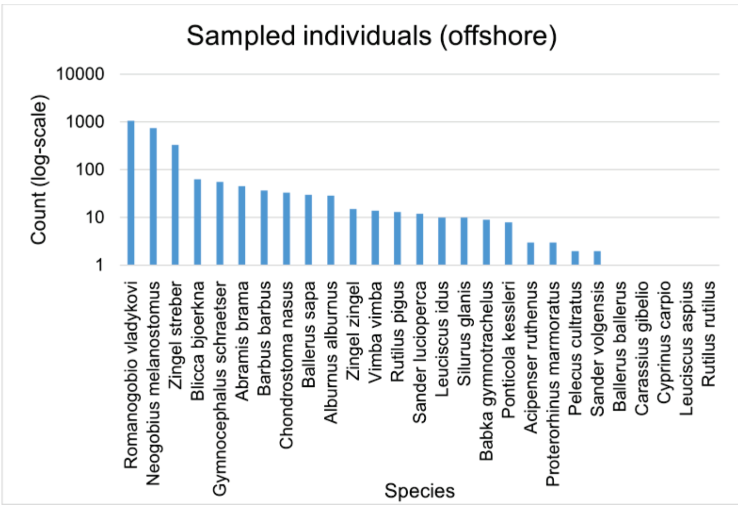


**Figure 3.** The count of individuals of each species collected by the offshore benthic trawling.

We note that the increment ratio to ambient temperatures was similar in all the three survey events. In fact, a winter sampling could have provided a very different ratio; however, the utilized trawling method is observed to have lower capture efficiency in winter, due to the known reduced activity of fish. The personal observations of the fishing community confirm significant fish abundance in the heat tail in winter. These reports eventually provide good utility of citizen science regarding fish related research, see Lima et al. (2016) as an example.

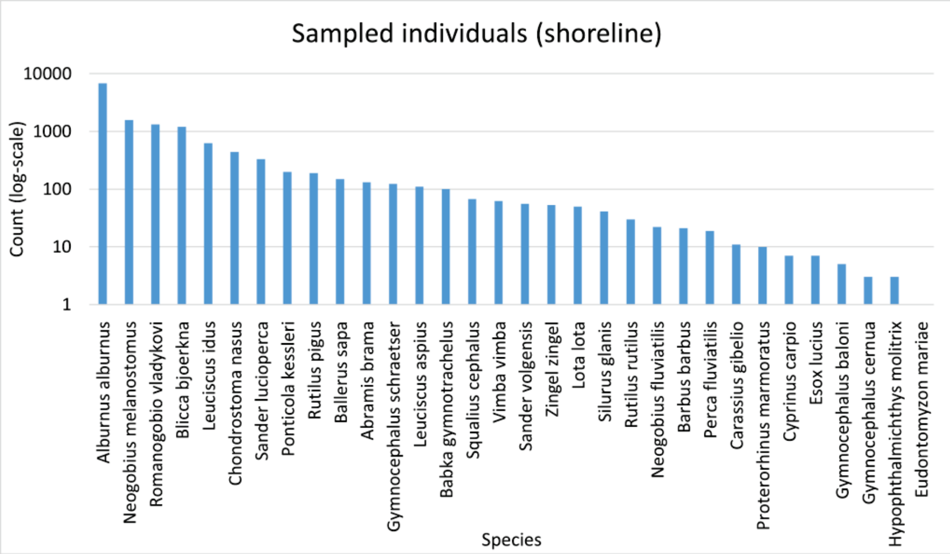


**Figure 4.** The count of individuals of each species collected by the shoreline electric fishing.

A sum of 13861 individuals of 32 species were collected by the shoreline sampling in the three survey events, the results of which are shown in Figure 4 (note the logarithmic scale). Four species composed ca. 80% of the individuals: the bleak, *Alburnus alburnus* (6866); the round goby (1583); the whitefinned gudgeon (1332); and the white bream, *Blicca bjoerkna* (1207). The spatial distribution did not follow the patterns of the offshore results. No outstanding quantities were observed in the right shore sections near subreach No. 6. The number of collected fish varied non-uniformly during the campaign in most of the shoreline sections. The only exception is a natural section near subreaches No. 1-2. on the left side of the Danube, which yielded a uniformly high ratio of the individuals in all the three seasons. This area is located at the recirculation zone past a groin. The bank slope is relatively high; thus water stage did not affect the efficiency of the shoreline sampling here. In contrast, a sizeable sand platform developed on the right side by the joining in subreach No. 6., which caused the section to be more exposed to the change of water stage through the survey events. Accordingly, this was a relatively shallow region in low flow conditions observed in spring and autumn.

The ratio of sampled specimens on the four warm effluent affected shoreline sections was the highest in summer, by the highest flow discharges and also the highest temperatures (ambient and elevated as well). In this regard, we can detect no harmful effect of the thermal discharge. On the other hand, these highest temperatures did not exceed 23-24°C, thus the thermal conditions of these habitats may still be below the thermal optimum of the occupying species, as discussed by Hester and Doyle (2011).

## 4. CONCLUSIONS

This paper presented a qualitative assessment of the effects of a warm effluent on biotic assemblages, focusing on fish abundance. The supporting data will be subjected to detailed statistical analysis in the following, to quantify relations between assemblage structure and hydromorphologic features.

The 15 km Danube reach by the Paks Nuclear Power Plant in Hungary has diverse hydromorphology with occasionally high gradients in abiotic characteristics. The spatial distribution of the number of specimens showed great variability, although there were distinguished areas (inshore and offshore) yielding higher abundances regardless of season. Our measurements show that spatio-temporal changes in fish abundance are mainly influenced by naturally developed heterogeneity, while harmful effects of thermal pollution could not be proven.

The increment ratio to ambient water temperatures were similarly low in all the three survey events. As the fish collecting method is experienced to have lower efficiency in winter samplings, no occasional effect of the fluctuation of this ratio could be shown; although personal observations of the fishing community report high abundance of fish in the heat tail in winters. After an appropriate redesign of the applied methodology, a winter survey could provide valuable data to further investigate this assumption.

Overall, contrary to research which show destructive effects of thermal pollution on biotic assemblages, such an impact was not significantly detected in this study site. We note that the warm effluent seemed to have low influence on mesoscale hydromorphology, the direct effects were limited to a local spatial scale. Our findings, that diverse hydromorphological features may dominate over anthropogenic impact, are in line with those of Teixeira et al. (2012). It is important to explore not only microscale, but also mesoscale characteristics and their influence on biotic assemblages, when assessing effects of thermal pollution.

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## 6. REFERENCES

Baranya, S., Olsen, N.R.B., and Józsa, J. (2015). Flow Analysis of a River Confluence with Field Measurements and Rans Model with Nested Grid Approach. *River Research and Applications*, 31, 28-41. doi:10.1002/rra.2718

Benda, L., Andras, K., Miller, D., and Bigelow, P. (2004). Confluence effects in rivers: Interactions of basin scale, network geometry, and disturbance regimes. *Water Resources Research*, 40, W05402. doi:10.1029/2003WR002583

Bódis, E., Nosek, J., Oertel, N., Tóth, B., Hornung, E., and Sousa, R. (2011). Spatial distribution of bivalves in relation to environmental conditions (middle Danube catchment, Hungary). *Community Ecology*, 12 (2), 210-219. doi:10.1556/comec.12.2011.2.9

Boyer, C., Roy, A.G., and Best, J.L. (2006). Dynamics of a river channel confluence with discordant beds: Flow turbulence, bed load sediment transport, and bed morphology. *Journal of Geophysical Research*, 111, F04007. doi:10.1029/2005JF000458.

Bukola, D., Zaid, A., Olalekan, E.I., and Falilu, A. (2015). Consequences of Anthropogenic Activities on Fish and the Aquatic Environment. *Poultry, Fisheries & Wildlife Sciences*, 3:138. doi:10.4172/2375-446X.1000138

Daufresne, M., Roger, M.C., Capra, H., and Lamouroux, N. (2003). Long-term changes within the invertebrate and fish communities of the Upper Rhône River: effects of climatic factors. *Global Change Biology*, 10 (1), 124-140. doi:10.1046/j.1529-8817.2003.00720.x

Dudgeon, D., Arthington, A., Gessner, M., Kawabata, Z., Knowler, D., Lévêque, C., Naiman, R.J., Prieur-Richard, A-H., Soto, D., Stiassny, M.L.J., and Sullivan, C.A. (2006). Freshwater biodiversity: Importance, threats, status and conservation challenges. *Biological Reviews*, 81 (2), 163-182. doi:10.1017/S1464793105006950

Ebersole, J.L., Liss, W.J., and Frissell, C.A. (2001). Relationship between stream temperature, thermal refugia and rainbow trout Oncorhynchus mykiss abundance in arid-land streams in the northwestern United States. *Ecology of Freshwater Fish*, 10, 1-10. doi:10.1034/j.1600-0633.2001.100101.x

Goniea, T.M., Keefer, M.L., Bjornn, T.C., Peery, C.A., Bennett, D.H. and Stuehrenberg, L.C. (2006). Behavioral Thermoregulation and Slowed Migration by Adult Fall Chinook Salmon in Response to High Columbia River Water Temperatures. *Transactions of the American Fisheries Society*, 135, 408-419. doi:10.1577/T04-113.1

Hester, E.T., and Doyle, M.W. (2011). Human Impacts to River Temperature and Their Effects on Biological Processes: A Quantitative Synthesis. *Journal of the American Water Resources Association*, 47 (3), 571-587. doi:10.1111/j.1752-1688.2011.00525.x

Jan, R-Q., Chen, J-P., Lin, C-Y., and Shao, K-T. (2001). Long-term monitoring of the coral reef fish communities around a nuclear power plant. *Aquatic Ecology*, 35, 233-243. doi: 10.1023/A:1011496117632

Jones, N.E., and Schmidt, B.J. (2016). Tributary effects in rivers: interactions of spatial scale, network structure, and landscape characteristics. *Canadian Journal of Fisheries and Aquatic Sciences*, 74 (4), 503-510. doi:10.1139/cjfas-2015-0493

Lima, E.G., Begossi, A., Hallwass, G., and Silvano, R.A.M. (2016). Fishers' knowledge indicates short-term temporal changes in the amount and composition of catches in the southwestern Atlantic. *Marine Policy*, 71, 111-120. doi: 10.1016/j.marpol.2016.05.008

Madden, N., Lewis, A., and Davis, M. (2013). Thermal effluent from the power sector: an analysis of once-through cooling system impacts on surface water temperature. *Environmental Research Letters*, 8, 035006. doi:10.1088/1748-9326/8/3/035006

Prats, J., Val, R., Armengol, J., and Dolz, J. (2010). Temporal variability in the thermal regime of the lower Ebro River (Spain) and alteration due to anthropogenic factors. Journal of Hydrology, 387 (1-2), 105-118. doi:10.1016/j.jhydrol.2010.04.002

Raptis, C.E., van Vliet, M.T.H., and Pfister, S. (2016). Global thermal pollution of rivers from thermoelectric power plants. *Environmental Research Letters*, 11, 104011. doi:10.1088/1748-9326/11/10/104011

Reid, A.J., Carlson, A.K., Creed, I.F., Eliason, E.J., Gell, P.A., Johnson, P.T.J., Kidd, K.A., MacCormack, T.J., Olden, J.D., Ormerod, S.J., Smol, J.P., Taylor, W.W., Tockner, K., Vermaire, J.C., Dudgeon, D. and Cooke, S.J. (2019). Emerging threats and persistent conservation challenges for freshwater biodiversity. *Biological Reviews*, 94, 849-873. doi:10.1111/brv.12480

Rice, S.P., Ferguson, R.I., and Hoey, T.B. (2006). Tributary control of physical heterogeneity and biological diversity at river confluences. *Canadian Journal of Fisheries and Aquatic Sciences*, 63 (11), 2553-2566. doi:10.1139/f06-145

Roy, P., Rao, I.N., Martha, T.R., and Kumar, K.V. (2021). Discharge water temperature assessment of thermal power plant using remote sensing techniques, *Energy Geoscience*, in press. doi:10.1016/j.engeos.2021.06.006

Schiel, D.R., Steinbeck, J.R., and Foster, M.S. (2004). Ten years of induced ocean warming causes comprehensive changes in marine benthic communities. *Ecology*, 85, 1833-1839. doi:10.1890/03-3107

Szalóky, Z., György, Á.I., Tóth, B., Sevcsik, A., Specziár, A., Csányi, B., Szekeres, J., and Erős, T. (2014). Application of an electrified benthic frame trawl for sampling fish in a very large European river (the Danube River) – Is offshore monitoring necessary? *Fisheries Research*, 151, 12-19. doi:10.1016/j.fishres.2013.12.004

Széchy, M.T.M, Koutsoukos, V.S., and Barboza, C.A.M (2017). Long-term decline of brown algal assemblages from southern Brazil under the influence of a nuclear power plant. *Ecological Indicators*, 80, 258-267. doi:10.1016/j.ecolind.2017.05.019

Szolnoky, Cs., and Raum, L. (1991). Regulation of the thermal loading by Paks Nuclear Power Station. *Periodica Polytechnica Civil Engineering*, 35 (1-2), 41-50.

Teixeira, T.P., Neves, L.M, and Araújo, F.G. (2009). Effects of a nuclear power plant thermal discharge on habitat complexity and fish community structure in Ilha Grande Bay, Brazil. *Marine Environmental Research*, 68 (4), 188-195. doi:10.1016/j.marenvres.2009.06.004

Teixeira, T.P., Neves, L.M, and Araújo, F.G. (2012). Thermal impact of a nuclear power plant in a coastal area in Southeastern Brazil: effects of heating and physical structure on benthic cover and fish communities. *Hydrobiologia*, 684, 161-175. doi:10.1007/s10750-011-0980-1

Vörösmarty, C.J., McIntyre, P.B., Gessner, M.O., Dudgeon, D., Prusevich, A., Green, P., Glidden, S., Bunn, S.E., Sullivan, C.A., Liermann, C.R., and Davies, P.M. (2010). Global threats to human water security and river biodiversity. *Nature*, 467, 555-561. doi:10.1038/nature09440

Worthington, T.A., Shaw, P.J., Daffern, J.R., and Langford, T.E.L. (2015). The effects of a thermal discharge on the macroinvertebrate community of a large British river: implications for climate change. *Hydrobiologia*, 753, 81-95. doi:10.1007/s10750-015-2197-1

Xu, D., Wang, H., Han, D., Chen, A., and Niu, Y. (2021). Phytoplankton community structural reshaping as response to the thermal effect of cooling water discharged from power plant. *Environmental Pollution*, 285, 117517. doi:10.1016/j.envpol.2021.117517