Assessment of Hydropeaking Impact on Macrozoobenthos Using Habitat Modelling Approach

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Abstract

The effects of daily discharge variation as a result of hydropeaking on the macrozoobenthos species of Litzauer Schleife, one of the last few free-flowing reaches of the River Lech in Germany, are assessed using habitat modelling approach. Integrated distributions of habitat quality within a river reach under two typical hydropeaking regimes with the range of the base to peak discharges of 10 m^3/s to 155 m^3/s and 25 m^3/s to 135 m^3/s respectively are compared to the habitat quality distribution at the reference constant discharge of 30 m^3/s. Habitat quality is assessed using the so called Fliesswasserstammtisch (FST) preference curves for the selected macrozoobenthos species *Baetis alpinus, Baetis rhodani, Rhithrogena semicolorata, Allogamus auricollis,* and *Hydropsyche incognita*. Hydropeaking causes a pronounced reduction in suitable habitats compared to the situation at a constant flow. While large areas of suitable habitats can still be found for the species *B. rhodani, R. semicolorata,* and *H. incognita* at the tested flow regimes, very less areas remain suitable for *B. alpinus* and *A. auricollis.* All target species react sensitive to flows below the reference discharge while only *B. rhodani, R. semicolorata,* and *H. incognita* show tolerance to high flows. Modelling results show that riffle areas offer more sustainable habitat during the whole range of hydropeaking discharges as pool areas for macrozoobenthos species. Among the target species, *R. semicolarata* is the most tolerant to changes in hydraulic conditions while *A. auricollis* is the least. From the analysis of habitat modeling results a hydropeaking regime with the base flow of 30 m^3/s and a peak flow of 70 m^3/s is suggested to be acceptable for the selected macrozoobenthos species of Litzauer Schleife.

Keywords: hydropeaking, FST hemisphere number, preference function, habitat modelling, macrozoobenthos

1. Introduction

Various studies on the impacts of hydropeaking on macrozoobenthos species have been conducted through actual measurements and field sampling (e.g. Céréghino and Lavandier 1998, Céréghino *et al*. 2002, Céréghino *et al*. 2004, Cristina Bruno *et al*. 2010). Results of such studies are very important but usually difficult to interpret and apply in case the specific recommendations on hydropeaking regime have to be met. Habitat modelling on the other hand can help to predict impacts under various operating scenarios before they are implemented in reality. Recommendations on hydropeaking strategies thus can be made to prevent possible negative effects.

The impact of hydropeaking on riverine organisms can be assessed by analyzing its effects on the organisms' habitat. One measure of habitat quality of a spatial unit is the Habitat Suitability Index (HSI). The habitat simulation software Computer Aided Simulation Model for Instream Flow Requirement (CASiMiR) developed in the early 90's at the Institute of Hydraulic Engineering of Stuttgart University in partnership with sje Ecohydraulic Engineering GmbH allows calculation of HSI via either preference functions or fuzzy logic approach (Schneider *et al*. 2010). One approach to assess habitat suitability for macrozoobenthos is to use the so called Fliesswasserstammtisch (FST) preference curves. Statzner and Müller (1989) developed the FST-hemispheres method to measure near-bed flow forces. The abbreviation "FST" stands for the German word "Fliesswasserstammtisch" (regular's table) while a "hemisphere" refers to an equipment used in this method. Studies revealed that some organisms actually have certain preferences for a specific range of FST-hemisphere numbers. Thus description of habitat suitability for benthic species can be based on the FST-hemisphere number and FST preference curves can be defined for different benthos species. According to DVWK (1999), 53 standard preference curves transferable within rivers in Germany are available. Recently-developed computational method to replace the field measurements of FST hemispheres' distributions (Kopecki 2008) is used in this study. This method combines water depth, velocity, and substrate information to calculate forces acting on a hemisphere.

This study concentrates on assessing hydropeaking effects on the macrozoobenthos species of Litzauer Schleife. Litzauer Schleife is one of the last few free-flowing reaches of the River Lech, a right tributary of the River Danube in Germany. With a total length of about 6 km, it is hallmarked by almost natural morphology and is a conservation area since 1986 (Wieprecht and Kopecki 2011). The hydrological regime of Lech by Litzauer Schleife however is far from natural. Currently the flow in the reach is controlled by the chain of E.ON Wasserkraft hydropower stations operating in a hydropeaking regime with one or two daily peaks of discharges.

To account for the daily flow changes on macrozoobenthos the special analysis of common habitat modeling results is applied. The concept of "persistent habitat" (Schneider *et al.* 2010) suggests that permanently the only suitable habitats for the specific species can be the areas exhibiting high suitability over the whole range of hydropeaking discharges. Identification of persistent habitats is done through the calculation of minimum HSI at every spatial unit in the range of the base and peak discharges of a considered hydropeaking regime. In this study the model CASiMiR implemented as a Toolbox for ESRI ArcGIS Desktop is used. CASiMiR arctools exploit different analysis and visualization tools provided by ArcGIS. This study is one of the first applications of this software in assessing hydropeaking impacts on macrozoobenthos.

2. Method

A 700 m long reach of Litzauer Schleife of the River Lech located about 700 m downstream of the hydropower station Dessau was chosen as the study area. Two hydropeaking scenarios were considered in this study - the typical hydropeaking flow regime in 2003 (10 m^3/s – 155 m^3/s) and the present hydropeaking flow proposed by Landesfischerereiverband (LFV) Bayern (25 m^3/s -135 m^3/s). These were compared to the habitat quality at historical flow of 30 m^3/s (average winter flow from 1954-1999). To determine how the habitat of the target species change, move, or vanish with increasing flow, flowrates of 10 m^3/s to 150 m^3/s in increments of 10 m^3/s were also simulated.

2.1 Hydraulic Model

Using a two-dimensional hydraulic model Hydro AS-2D (Nujić 2003) with Surface Water Modelling System (SMS 2003) for pre- and post-processing, a calculational mesh was built and the variation of depth and velocity with discharge was simulated. The model consisted of approximately 27000 elements and was discretized using 2 x 2 meter grids for the main channel and 2 x 1 meter grids for the banks.

2.2 Habitat Model

Using ArcGIS-CASiMiR, FST-hemisphere numbers were computed for every flow condition. According to the target species' FST preference curves shown in Figure 1, spatial variation in habitat suitability of the investigation reach were calculated. This value is expressed as the habitat suitability index (HSI) ranging from 0 to 1. The HSI is calculated for every mesh cell and is mapped to allow visual comparison between different flow scenarios with respect to the distribution and location of areas with low or high habitat suitability. The dimensionless hydraulic habitat suitability (HHS) index value is further calculated to compare the overall habitat quality at different flow situations. HHS which also ranges from 0 to 1 is obtained by multiplying the area of each mesh cell by its HSI value and dividing the product by the total wetted area (Schneider *et al.* 2010). Critical flows for the different species are determined from the results and from this an optimized hydropeaking scheme is suggested.

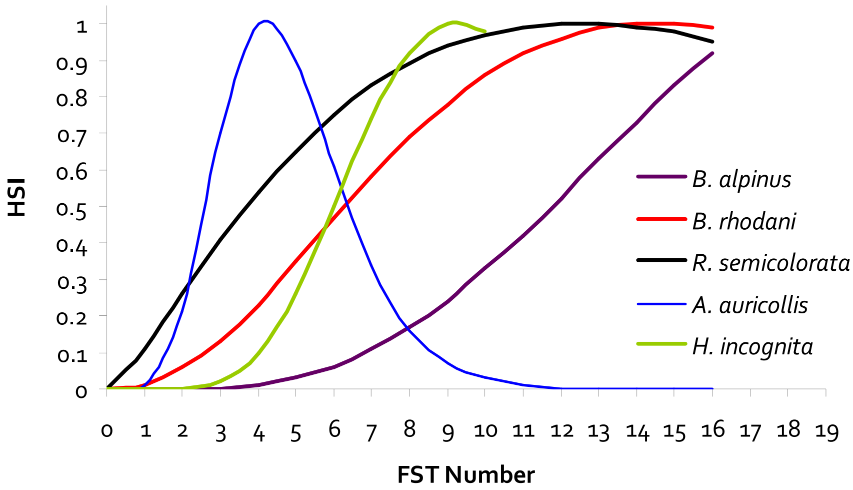

Figure 1. FST preference curves of the species *Baetis alpinus, Baetis rhodani, Rhithrogena semicolorata, Allogamus auricollis* and *Hydropsyche incognita* (Adapted from DVWK 1999).

2.3 Target Species

Baetis alpinus, Baetis rhodani, Rhithrogena semicolorata, Allogamus auricollis, and *Hydropsyche incognita* were selected as target species upon consultation with a local biologist. The species were selected because they have different flow tolerances hence were likely to be strongly influenced by hydraulic disturbances and they are also important to the diet of running-water fishes present in the reach (J. Ortlepp - personal communication). More importantly, they are found in Litzauer Schleife and their FST preference curves exist.

B. alpinus are rheobiont organisms. Their preferred habitats are coarse gravel, stones, and boulders. They are regarded as grazers/detritus eaters (DVWK 1999) but can also be herbivorous (Baekken 1981). *B. rhodani* are rheophils. They find their habitats in coarse gravel, stone, boulders and in aquatic algae, mosses and higher aquatic plants. They are regarded as typical scrapers and feed mostly on detritus (DVWK 1999). As rheophils *R. semicolorata* are well-adapted to fast-flowing habitats (Céréghino and Lavandier 1998). They are grazers typically which feed exclusively on aufwuchs, and inhabits coarse gravel, stone, and boulders (DVWK 1999). The case-bearing caddisfly *A. auricollis* are limnophils which often stay near the bank (Kiauta and Kiauta 1979). They are identified as grazers/filter feeders (DVWK 1999) while their larvae feed probably exclusively on detritus (Waringer 1989). They have clear preference for stones and rocks with more or less rough or uneven surface. *H. incognita* are rheophil organisms and are regarded typically as filter feeders. They find their habitats under rocks, in gravel or coarse substrates and among living and dead vegetation (DVWK 1999).

3. Results and Discussions

3.1 Habitat Suitability Indices (HSI)

Figure 2 shows the maps of the minimum HSI at different hydropeaking regimes calculated for the different species. It reflects the extent to which hydropeaking operations negatively affects the suitability of the reach for the benthos organism. It also helps identify "persistent habitats" where a particular species can stay during the entire hydropeaking event. Riffle (shallow, fast-flowing) and pool (deep, slow-flowing) areas in the reach have been identified beforehand. Maps showing HSIs calculated at flow rates in increments of 10 m^3/s are shown in Figure 3.

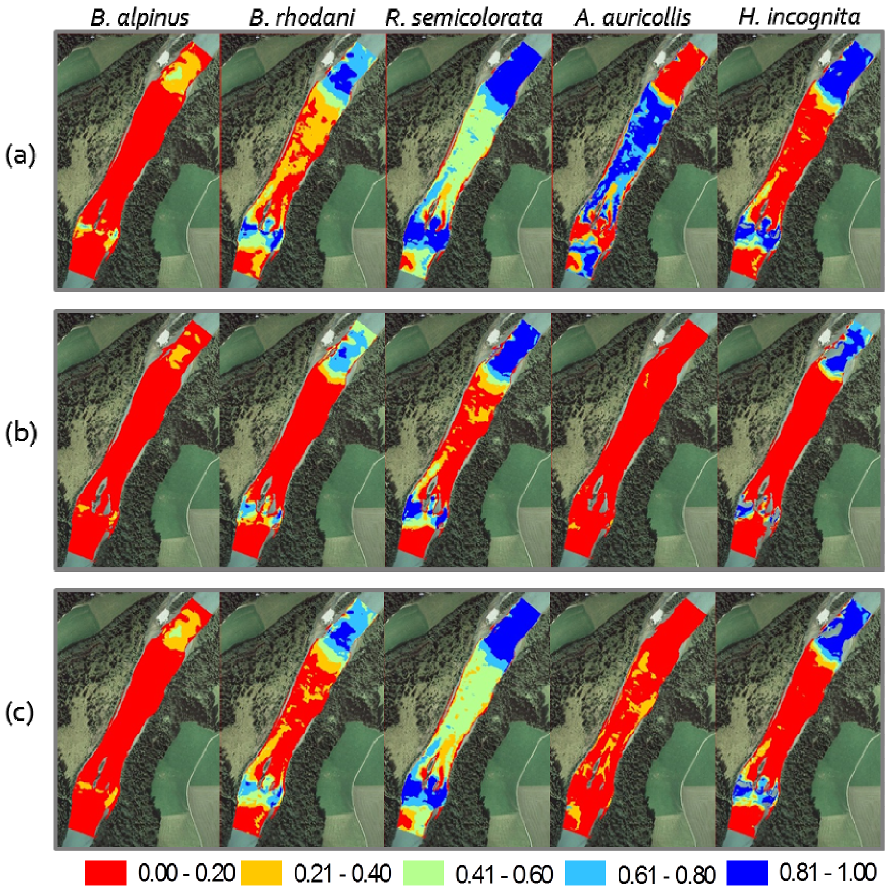

Figure 2. Habitat Suitability Index (HSI) maps at (a) Reference condition: Q = 30 m³/s and minimum HSI maps for (b) 2003 hydropeaking flow regime (10 to 155 m³/s) and (c) LFV-proposed hydropeaking flow regime (25 to 135 m³/s).

Red areas indicate very low habitat suitability (HSI ≤ 0.2), gold – low habitat suitability (0.2 < HSI ≤ 0.4), green – medium habitat suitability (0.4 < HSI ≤ 0.6), light blue – high habitat suitability (0.6 < HSI ≤ 0.8), deep blue - very high habitat suitability (0.8 < HSI ≤ 1.0)

Referring to Figure 2, the quality of the reach as habitat for *B. alpinus* was already not optimal at historical flow conditions. But hydropeaking further lowered the habitat quality as evidenced by the decrease of the amounts of gold and green areas (0.2 < HSI ≤ 0.6) and increase of red areas (0 < HSI ≤ 0.2). In Figure 3, a slight improvement of habitat conditions is observed with stepwise increase in flow. Improved habitats are found especially in the riffle areas which suggests the need of *B. alpinus* for much higher velocities. For its habitat quality to be at least comparable to that at historical flow situation, Q > 30 m³/s is preferable.

Areas having low suitability for *B. rhodani* dominated over the hydropeaking event (Figure 2) with suitable habitats being lower in quality and quantity for 2003 hydropeaking flow. For the two hydropeaking scenarios, habitats of higher suitability dominated in riffle areas. In Figure 3 it is shown that low flows are critical as suggested by the dominant red and gold areas at low flows (Q = 10 to 50 m³/s). Areas with optimum conditions are found at higher flows (Q ≥ 110 m³/s).

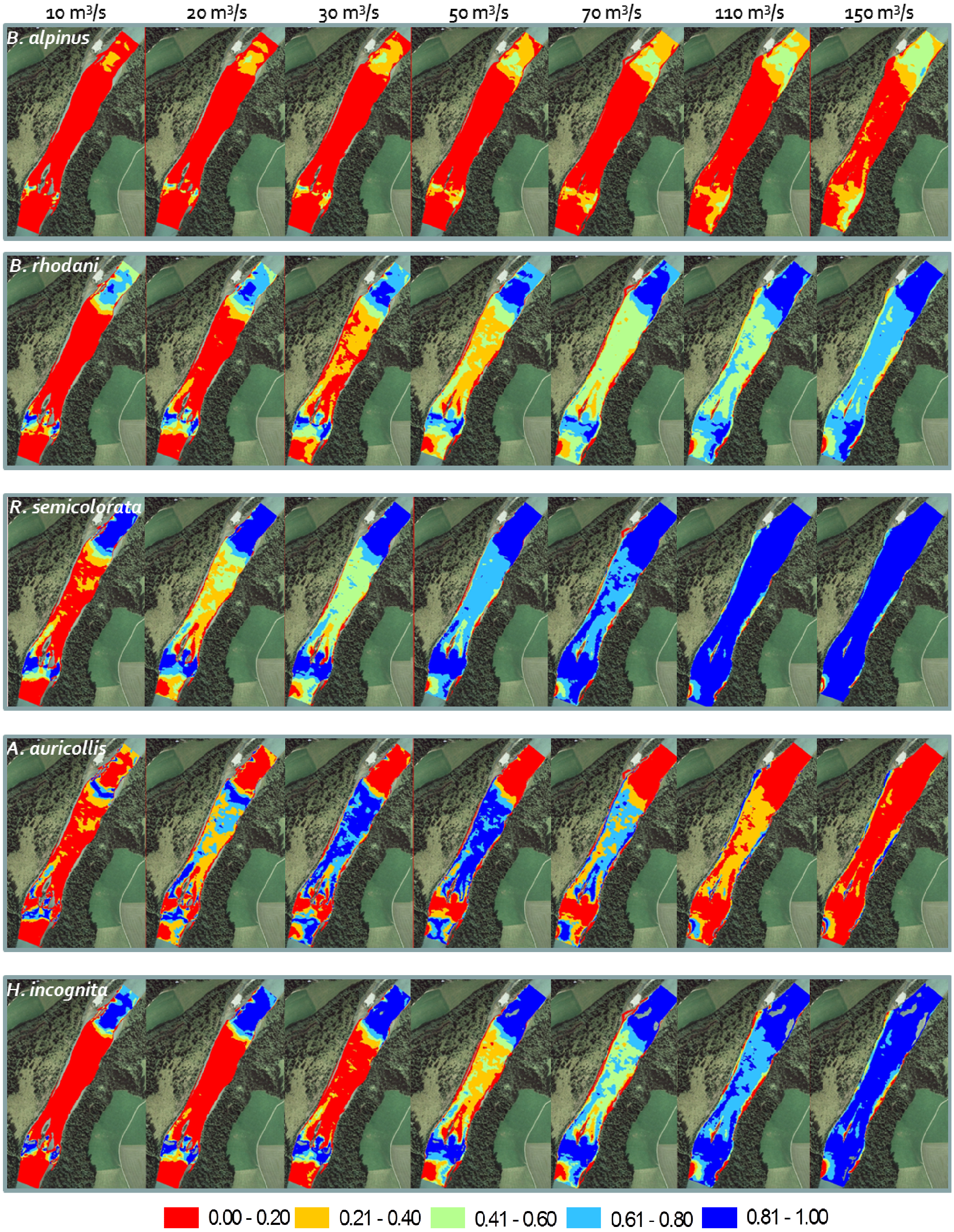

Figure 3. Habitat Suitability Index (HSI) maps at different flowrates for (top row) *B. alpinus,* (2nd row) *B. rhodani,* (3rd row) *R. semicolorata,* (4th row) *A. auricollis,* and (bottom row) *H. incognita*

Red areas indicate very low habitat suitability (HSI ≤ 0.2), gold – low habitat suitability (0.2 < HSI ≤ 0.4), green – medium habitat suitability (0.4 < HSI ≤ 0.6), light blue – high habitat suitability (0.6 < HSI ≤ 0.8), deep blue - very high habitat suitability (0.8 < HSI ≤ 1.0)

Being well-adapted to fast-flowing conditions, sufficient habitats are found for *R. semicolorata* especially in the fast flowing sections of the reach for the two hydropeaking regimes considered (Figure 2). Whereas more areas with low habitat suitability are found for the 2003 hydropeaking event, the quality of the reach for the LFV Bayern-proposed flow is comparable to the situation at historical flow, i.e. the location and distribution of areas belonging to specific HSI classes are similar. Looking at Figure 3, this slight difference may come from the low HSIs at low/base flows. At high flow rates (100 m³/s to150 m³/s) almost 100% of the reach is suitable for the organism. Optimal condition therefore is at Q > 30 m³/s.

At reference conditions, areas suitable for *A. auricollis* are still found. These habitats vanished during hydropeaking operations as almost 100% of the area fell into the HSI ≤ 0.2 class (Figure 2). The change in HSIs at different flowrates suggests that the favorable range of flow rates for *A. auricollis* is narrow (Figure 3). At flows lower than 30 m³/s, areas with poor suitability (HSI < 0.4) dominated. At flows 30 m^3/s to 70 m³/s, suitable habitats (HSI > 0.6) are found in pool areas. Suitable areas tapered off as flow increased. Thus, in both hydropeaking flow regimes, the low HSIs come from the base flows and peak flows.

A similarity in the location of suitable/unsuitable habitats for *H. incognita* is seen for the hydropeaking scenarios with that at historical flow condition although the amount of suitable habitats decreased especially for the 2003 hydropeaking regime (Figure 2). The riffle areas offer suitable habitat in all flow situations considered. An inspection of the HSI maps in Figure 3 suggests that base flows are responsible for the low minimum HSI values. The reach is found to be highly suitable at tested flows greater than 100 m³/s. At flows lower than 30 m³/s the slow-flowing pool areas also have very low HSI which suggests the species' low tolerance for low flows. Based on this parameter, optimal conditions are at Q ≥ 30 m³/s.

3.2 Hydraulic Habitat Suitability (HHS)

The graph showing computed HHS based on the minimum HSI for the two hydropeaking operations and the HSI at reference condition is shown in Figure 4.

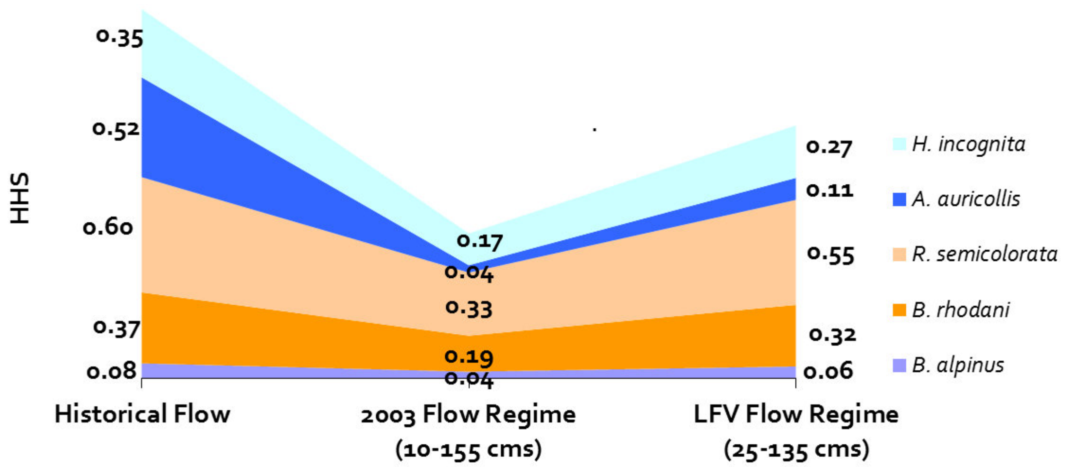

Figure 4. Hydraulic Habitat Suitability (HHS) at reference condition and hydropeaking flows

Referring to this graph, the HHS values computed at both hydropeaking situations were significantly lower than that at reference conditions especially in the 2003 hydropeaking situation. The drop of HHS was highest for *A. auricollis* and least for *R. semicolorata*. These values suggests that the hydropeaking operations caused a reduction in suitable habitats and this negative effect is more pronounced for the 2003 hydropeaking regime which has lower low flows and higher high flows. Among the target species, *R. semicolorata* is the most tolerant of hydropeaking while *A. auricollis* is the least.

A graph showing the computed HHS at flowrates of 10 m³/s - 150 m³/s in increments of 10 m³/s is shown in Figure 5. For all the species, HHS values were lower for flows lower than the historical flow of 30 m³/s. The values generally increased as flow increased except for *A. auricollis* for which HHS was highest at Q = 40 m³/s. *R semicolorata* had the highest HHS values while *B. alpinus* had generally the lowest. These results suggests that low flows were critical for all the target species; the tested flowrates were not favorable to *B. alpinus*; the preferable flowrates for *A. auricollis* was narrow with optimum conditions at Q = 40 m³/s; and *H. incognita, B. rhodani, and R. semicolorata* could tolerate high flows.

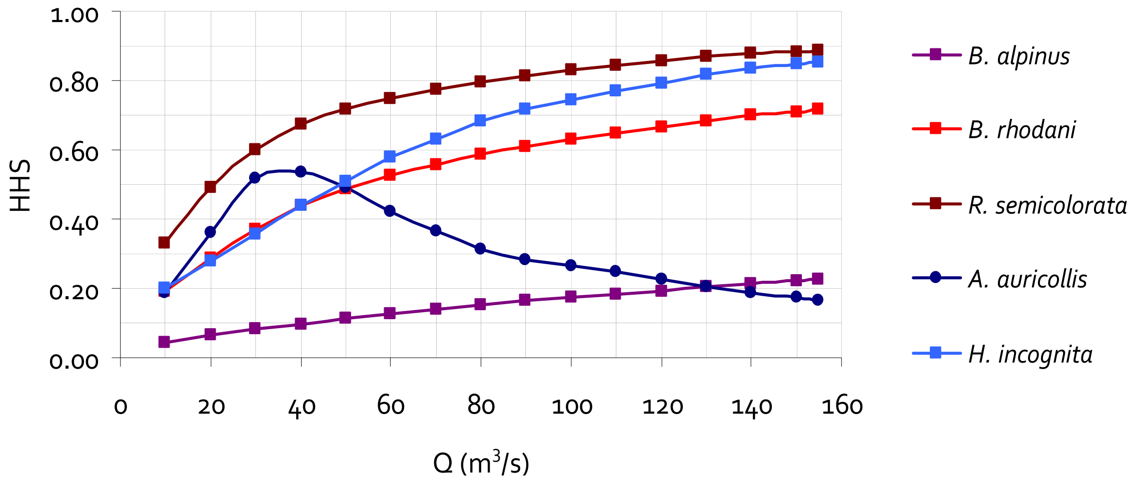

Figure 5. Hydraulic Habitat Suitability (HHS) at increasing flow rates

3.3 Optimal Hydropeaking Flow Regime for the Macrozoobenthos

It is clear that the organisms that were investigated do not react in the same way to hydropeaking. The preferable flow rate and areas for the target species are summarized in Table 1. The table also showed the importance of riffle areas for macrozoobenthos. These areas are persistently suitable for them during hydropeaking events and this is also where they could possibly start rebuilding their communities after hydropeaking.

Table 1. Summary of results

Target Specie	Critical flows	Areas with persistently optimal conditions over hydropeaking event	Preferable flow rates[1]
B. alpinus	low flows	riffle areas	$Q > 30$ m³/s
B. rhodani	low flows	riffle areas	$Q > 30$ m³/s
R. semicolorata	low flows	riffle areas	$Q \geq 30$ m³/s
A. auricollis	low and high flows	almost none	30 m³/s $\leq Q \leq$ 70 m³/s
H. incognita	low flows	riffle areas	$Q \geq 30$ m³/s

[1]Flowrates simulated range from10 m^3/s to 150 m^3/s

So far, there exists no standard methodology yet in selecting optimal flows based on computed HHS (e.g. which limit of HHS can still be considered good, how much reduction in HHS is acceptable). In this study, the proposal of an optimal hydropeaking scheme for the organisms involved the determination of the critical flows for the different target species. No threshold value of HHS was set instead the evolution of HHS values as flow increased was analyzed per specie. Also the distribution of areas falling under certain HSI classes for each flow condition was analyzed. For all the species, the base flow of 30 m³/s is critical. Except for *A. auricollis*, all the species tend to favor high flow rates (within tested range). Thus, from an ecological point of view, a hydropeaking scheme with 30 m³/s as baseflow and 70 m³/s as peak flow is proposed. Minimum HSI maps by the proposed regime with their corresponding HHS values are shown in Figure 6. The maps and the HHS values are comparable to the reference flow situation.

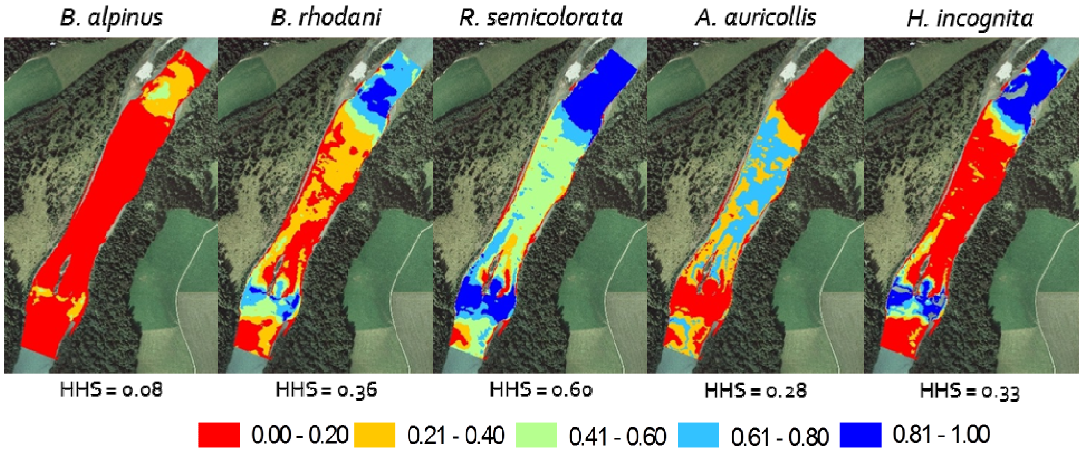

Figure 6. Minimum Habitat Suitability Index (HSI) maps at proposed hydropeaking regime of 30-70 m^3/s.

Red areas indicate very low habitat suitability (HSI $\leq$ 0.2), gold – low habitat suitability (0.2 < HSI $\leq$ 0.4), green – medium habitat suitability (0.4 < HSI $\leq$ 0.6), light blue – high habitat suitability (0.6 < HSI $\leq$ 0.8), deep blue - very high habitat suitability (0.8 < HSI $\leq$ 1.0)

5. Conclusion

The study provided an evaluation of the impact of hydropeaking operations on the macrozoobenthos population of Litzauer Schleife by looking at how the quality of their habitats is affected. The results showed that the typical hydropeaking regime in 2003 of 10 to 155 m^3/s caused the greatest reduction in suitable habitats compared to the present hydropeaking regime of 25 m^3/s to 135 m^3/s. All the target species reacted sensitively to low flows. *B. rhodani, R. semicolorata,* and *H. incognita* showed tolerance of high flows and suitable habitats were found for them at the tested hydropeaking flow regimes No suitable habitats on the other hand are found in the reach for *B. alpinus and A. auricollis*. Among the target species *R. semicolarata* was the most tolerant of changing flow conditions while *A. auricollis* was the least. From an ecological point of view, a hydropeaking flow of 30 m^3/s to 70 m^3/s is proposed. Clearly, the choice of representative organisms can have a significant effect on the results of the study hence it is imperative that they are selected with the help of a local expert/biologist. Decisions made out of the results must also be consulted with biologists before recommendations can be made.

Habitat models can be set up for any river reach to assess the effects of any operation strategies on the riverine organisms. Care must be exercised however in choosing the target species, identifying factors deemed important for the organisms, and applying tools such as preference functions that describe the relationship of the identified factors to the habitat preferences of organisms. The use of Fliesswasserstammtisch (FST) preference function in this study is sufficient with the assumption that benthic organisms are more directly affected by near bed flow velocities or bottom shear stresses and that the influence of other factors such as substrate size, colmation, and availability of food is more or less uniform or less significant. For instance in this study, the selected species tolerate a wide spectrum of substrate size, colmation at the site is low, and the water is shallow which implies availability of algae as food for the benthos organisms. Thus the description of habitat suitability based on the FST preference curves is acceptable.

Given the high costs of restoration measures of negatively impacted river systems, the models are a great aid for reservoir managers, biologists, ecologists, and engineers in making decisions that would help prevent the deterioration of our rivers.

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