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D2.6. Simulation and modelling methodology with indicators ('habitat stress days') for management scenario comparisons.

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March, 2019.

AMBER Project - H2020 - Grant Agreement #689682

History of changes

Version	Date	Changes	Pages
1.0	22 March 2019		

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The opinion stated in this report reflects the opinion of the authors and not the opinion of the European Commission.

Executive summary

This is version 1.0 of D2.6 Simulation and modelling methodology with indicators ('habitat stress days') for management scenario comparisons. This report is a deliverable of the AMBER project. This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 689682.

Rivers are "arteries of life" connecting aquatic and terrestrial environments of our planet. These communication and transportation pathways are very frequently blocked and disturbed by human activities that create physical and chemical barriers. The European Barrier Atlas prepared by the AMBER project documents the magnitude of this impact using the example of physical barriers such as dams or weirs. The impact of these features is not only related to blocking up- and downstram migration, but also to the modification of adjacent habitats. Due to the number of such barriers averaging one dam every river kilometer, this causes massive alteration of flora and fauna composition. These changes are caused by the change of spatio-temporal habitat availability and structure. Within the MesoHABSIM habitat simulation approach we developed appropriate indicators of habitat quantity, structure and temporal shortages, creating so called Habitat Stress Days. The indices are applied to compare alternative dam management scenarios, also taking into account expected climate change driven modification of flows with the help of the Restoration Alternative Analysis diagram. Such diagrams indicate the expected habitat impacts in Euclidian space. The tool is demonstrated using the example of a small barrier on the low gradient River Mienia in Poland.

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Contributing Authors: Zbigniew Kaczkowski (ERCE), Mikołaj Piniewski (WULS), Iwona Pinskwar (Warsaw Politechnic).
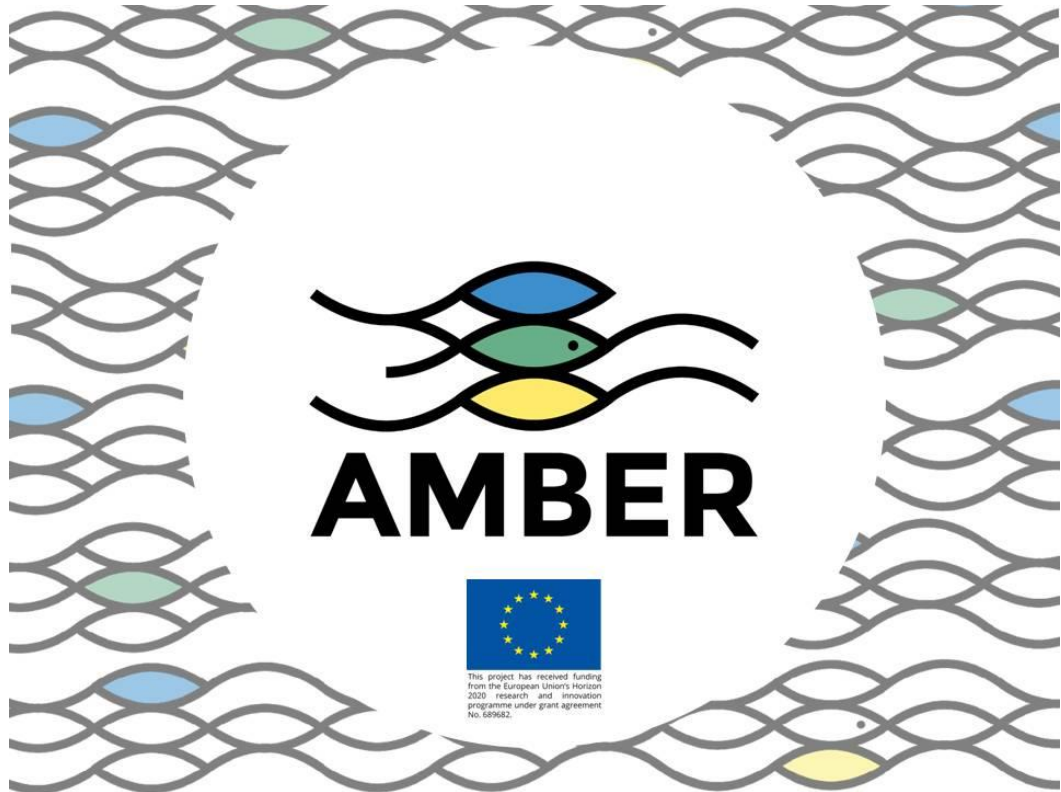
Contents

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1. Software information

The core software applied for the presented MesoHABSIM analysis is Sim-Stream 8.0 by the Rushing Rivers Institute, www.Sim-Stream.org.

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2. Introduction

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Editors

Piotr Parasiewicz (SSIFI), Paweł Prus (SSIFI), Katarzyna Suska (SSIFI), Kamila Belka (ERCE), Małgorzata Lapinska (ERCE), Mikołaj Adamczyk (SSIFI)

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Executive summary

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Barrier impact on up- and downstream habitats are evaluated with habitat simulation model MesoHABSIM and indicators of habitat quantity, structure and temporal deficits (Habitat Stress Days). The indices are applied to compare climate change driven management scenarios with help of Restoration Alternative Analysis diagram, which allows to plot the expected habitat impacts in Euclidian space. The tool is demonstrated using the example of small barrier on low gradient Mienia River in Poland.

Figure 1. Slides 1-3. About AMBER (https://amber.international/about/). Improving stream connectivity has been flagged as one of the priorities for more efficient stream restoration. To achieve 'good status' under the Water Framework Directive (WFD), one of the major challenges is the fragmentation of stream habitats. This fragmentation is mainly caused by tens of thousands of man-made barriers, many of which are old and no longer in use.
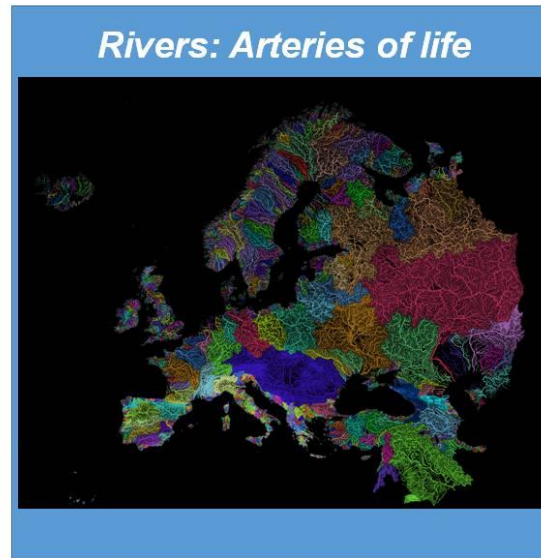
This project seeks to apply adaptive management to the operation of dams and barriers in European rivers to achieve a more efficient restoration of stream connectivity and address impacts caused by river fragmentation.

We target the main limitations of current stream restoration efforts to achieve more effective restoration of river ecosystems that is compatible with other water uses. This will improve the energy-generation security, help protect jobs, and boost European competitiveness, particularly in rural economies.

AMBER will have beneficial effects on the restoration of freshwater flora and fauna. The project will serve to protect global biodiversity in running waters by decreasing river fragmentation, promoting habitat connectivity, and evaluating the merits of different restoration actions through several quantified targets. The presentation will be available with audio commentary on the AMBER website https://amber.international/.

Figure 2. Slide 4. Rivers serve as distribution pathways for life entering from the ocean on the continents. Like blood vessels in our bodies, rivers distribute nutrients up- and downstream and provide living space for numerous plants and animals. Here we can see just how prominent they are within our landscape. We also depend on them for many of our resources: water, fish, recreational opportunities, birdlife, and so much more.
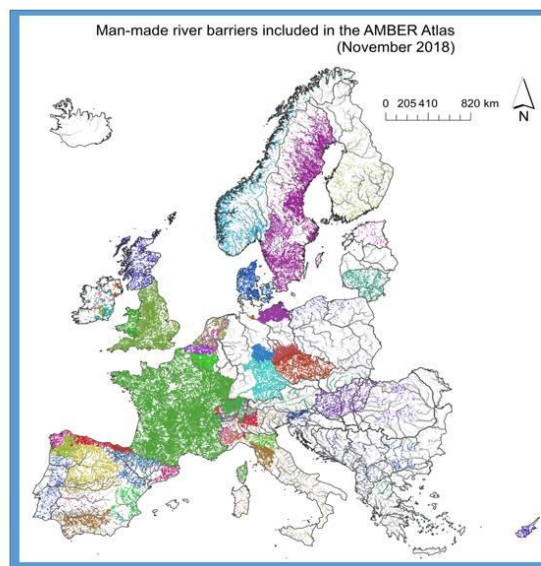
Figure 3. Slide 5. Unfortunately, human activities clogged these pathways by the construction of millions of dams and barriers. We had estimated that there is a "barrier every river kilometer". In its current, as yet incomplete, version the AMBER Barriers Atlas includes over 400 000 barriers.
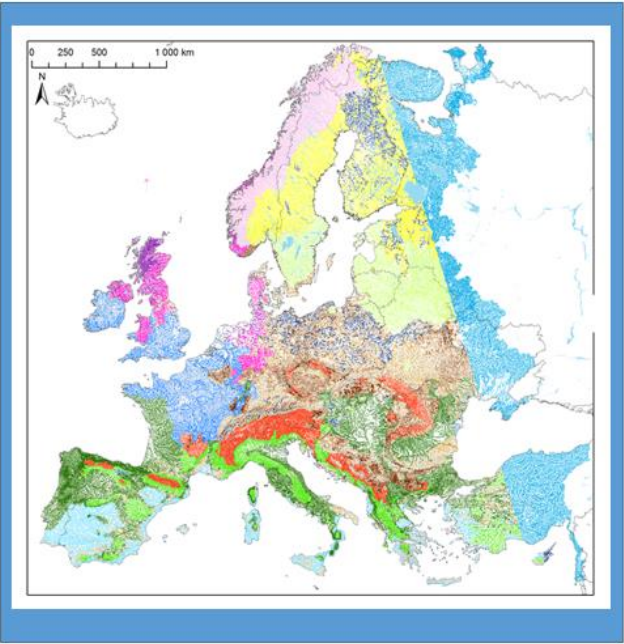
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Figure 4. Slide 6. We consider here all barriers that limit migration of the fauna up and downstream. The slide presents the types of barriers identified in the AMBER project. The impact of those barriers on river ecosystems is not uniform, as some of them have a much stonger effect on the aquatic communities than others.

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Figure 5. Slide 7. Impact also depends on the aquatic fauna living in rivers, which is also not uniform accross the Europe. Scientists from the AMBER project developed a map of Fish Community

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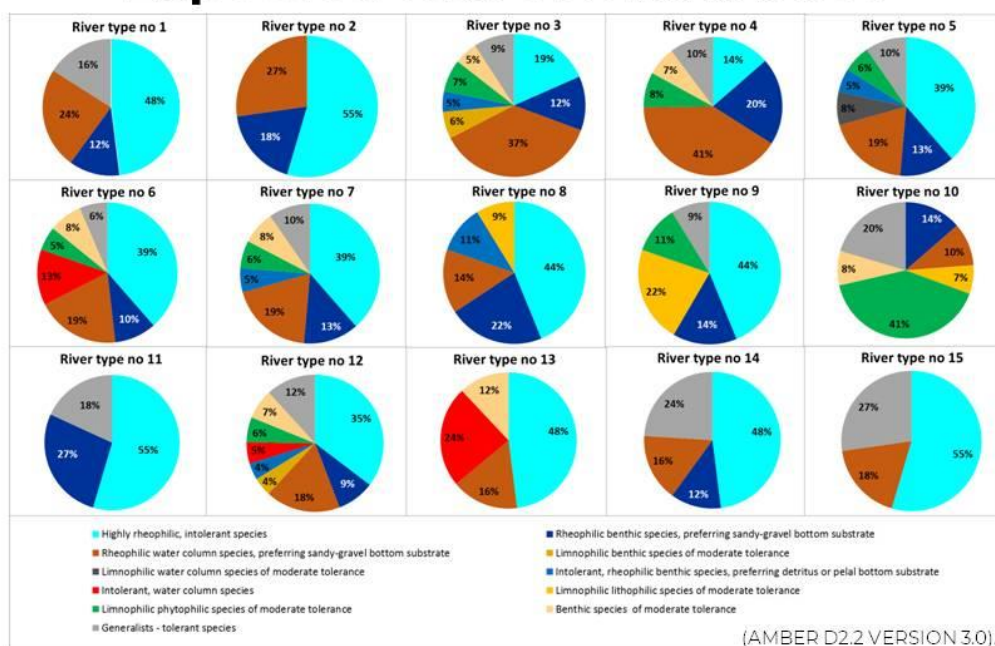March, 2019.

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MacroHabiat Types. These are river sections with a specific fish community structure. Fish serve here as indicator organisms.

Data sources: [źródło danych o rybach], Catchment Characterisation and Modelling River and Catchment Database, version 2.1 (CCM21) (Vogt, J.V. et al., 2007), European Soil Database v2.0 (ESDB v 2.0; Panos, 2006), IHME1500 - International Hydrogeological Map of Europe 1:1,500,000, Environmental Stratification of Europe version 8: Metzger, Marc J. (2018). The Environmental Stratification of Europe, [dataset]. University of Edinburgh. https://doi.org/10.7488/ds/2356, Water Information System for Europe Water Framework Directive (WISE WFD) database (EEA, 2017).

Figure 6. Slide 8. This slide presents proportions of fish habitat use guilds (i.e. groups of species using the same habitats) expected in each macrohabitat type.

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Figure 7. Slide 9. Most known impacts on fish are blockage of fish migration and mortality at turbines.
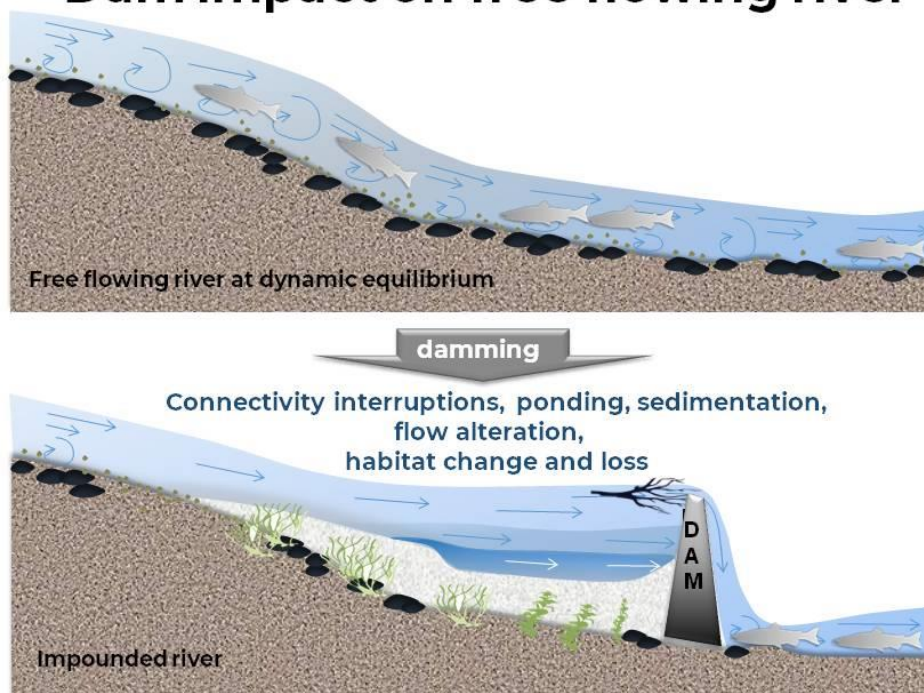
Figure 8. Slide 10. In general, barriers do not only affect the fish migration but also modify adjacent habitats. Upstream sections are impounded and downstream have disturbed flow patterns.

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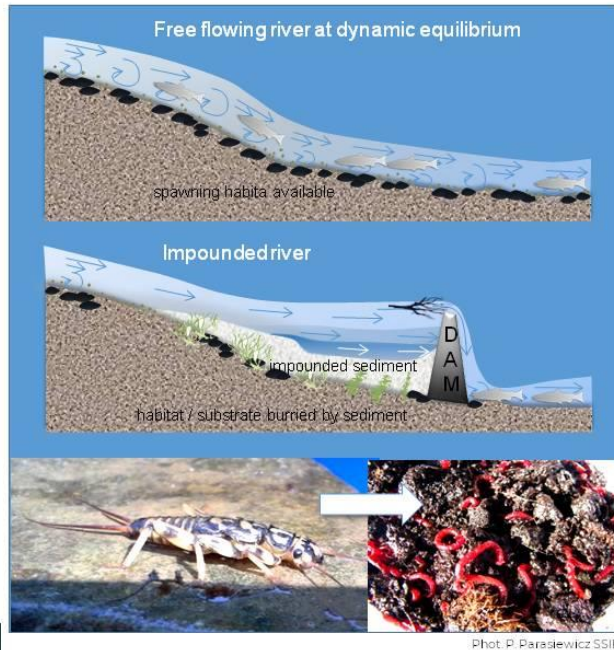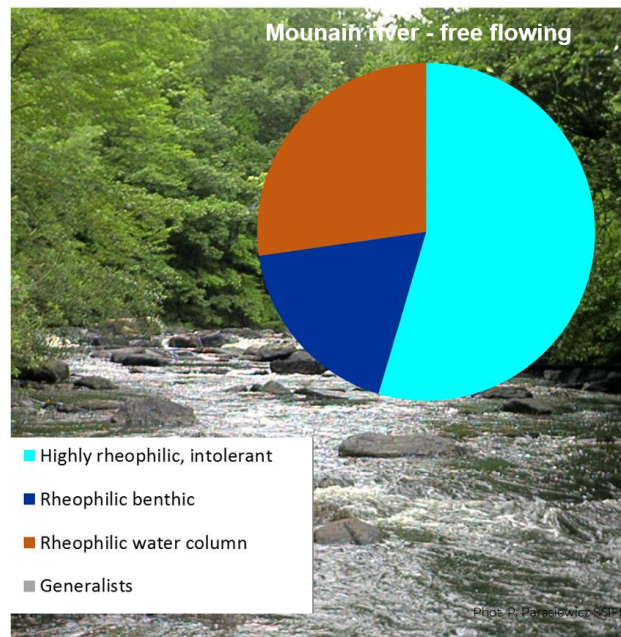AMBER Project - H2020 - Grant Agreement #689682

Figure 9. Slide 11. The impoundments increase water depth and slow water flow, causing siltation, lower oxygenation, higher temperature and eutrophication. Biological effects are shifts in vegetation patterns and benthic communities.

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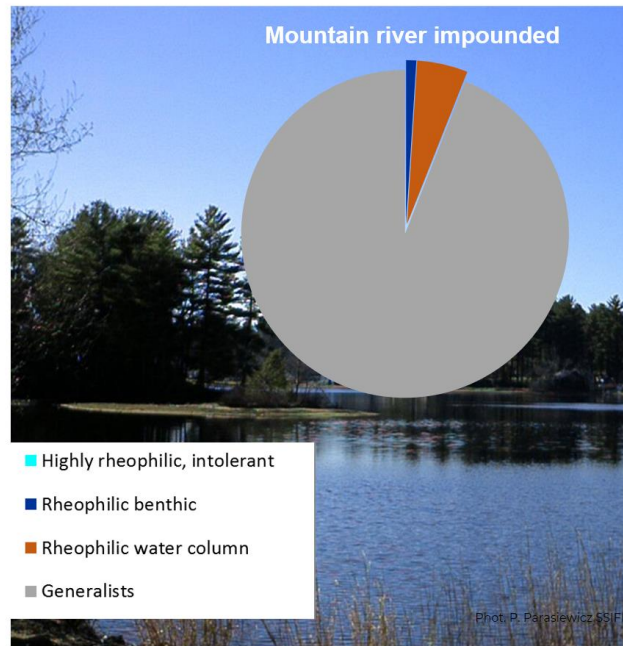AMBER Project - H2020 - Grant Agreement #689682

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Figure 10. Slide 12. Impounding of free flowing rivers changes habitat conditions in the impoundment so far that the structure of the fish community is changing from fish using fast flowing habitat (i.e. river fish) to more generalists (i.e. pond fish).
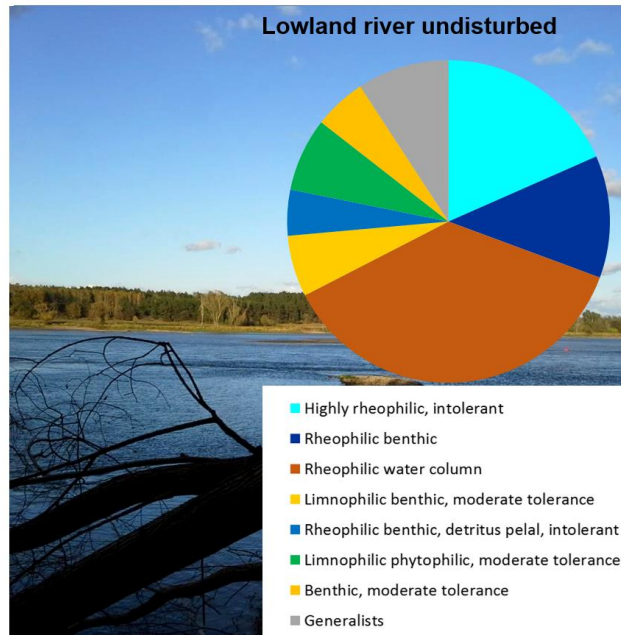

Figure 11. Slide 13. Downstream effects include change of flow regime that frequently cause erratic fluctuations of flow velocity, depth and temperature. Sediment deficits lead to riverbed erosion. Due to blocked fish migrations, we can expect increased density of some species as well as mortality due to dewatering of the riverbed.

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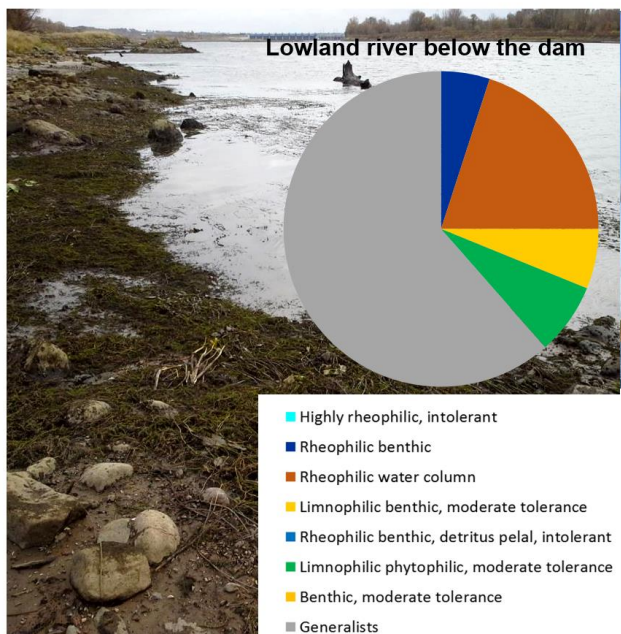AMBER Project - H2020 - Grant Agreement #689682

Figure 12. Slide 14. In downstream areas, fish community structure changes in direct consequence of habitat alteration, leading again to an increase of more generalist species, which are more resistant to the changes.

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Figure 13. Slide 15. Consequently, to fully understand the impact of dams on riverine ecosystems and determine the best management actions we need to investigate change of habitats adjacent to the barrier.

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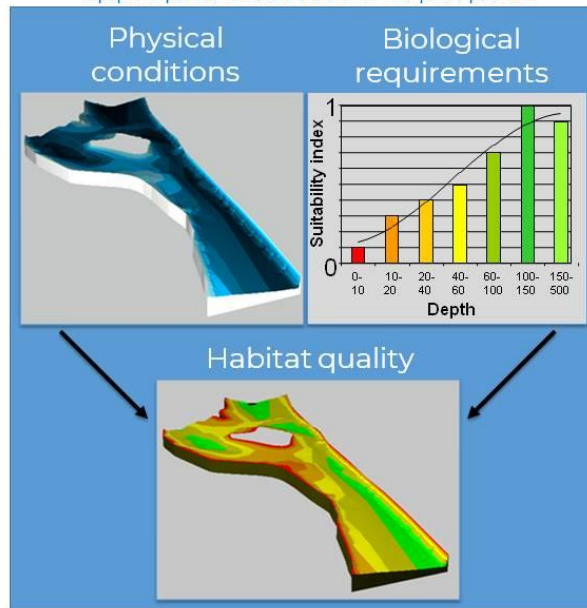
3. Methodology slideshow

Figure 14. Slide 16. As visible from the analysis, there are major factors to be considered when performing such analysis. These are change in habitat structure and spatio-temporal alteration of habitat availability. Habitat simulation models allow such analyses. These are tools that create a computer model of the riverbed structure and a mathematical model describing the ways in which fish (or other animals) use their habitat (s.c. Preferences). The preferences are applied to validate the riverbed structure and hydraulics in terms of habitat suitability. Eventually the models quantify the amount of suitable habitat as suitable areas. In combination with hydrological time series analysis, all the above parameters can be determined.
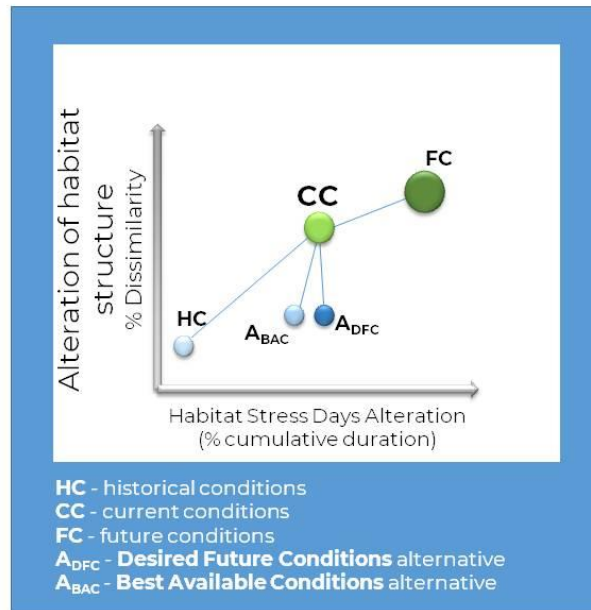
Figure 15. Slide 17. The results can be plotted for a variety of scenarios on the Restoration Alternatives Analysis (RAA) diagram. The historical, current and future condition can be plotted together with restoration alternatives. The closer to the origin of the diagram the lower the habitat impact of the scenario.

Figure 16. Slide 18. Now we will demonstrate how to calculate the three components necessary to draw RAA diagrams: Alteration of Habitat Structure, Alteration of Habitat Stress Days and Unsuitable Habitat Area. First in general terms and then using the River Mienia in Poland as an example.

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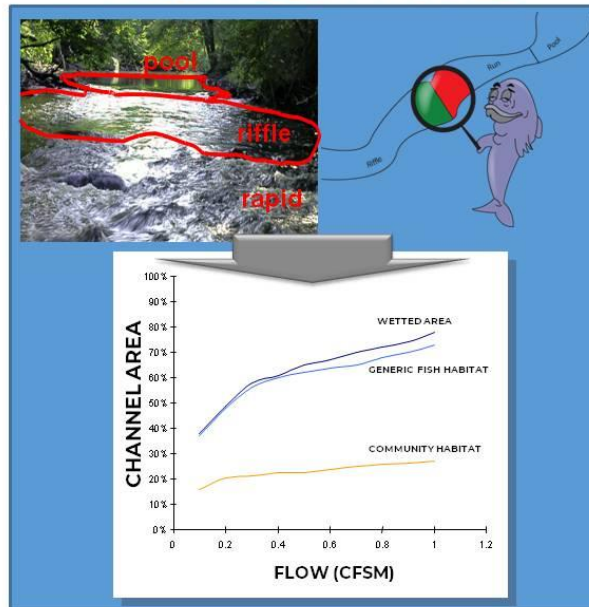AMBER Project - H2020 - Grant Agreement #689682

Figure 17. Slide 19. There are a number of habitat models available. Our model of choice is the MesoHABSIM habitat model, considered the best for this purpose. MesoHABSIM investigates riverbed structure and hydraulics at the scale of geomorphic units (riffles, pools, etc). Biological data is analyzed at a same scale. The model has also well-developed approaches to investigate habitats for entire aquatic communities and perform sophisticated time series analysis. Mesohabitats correspond in size and location to geomorphic or hydraulic units. Therefore, it offers a robust link between available geomorphic classification frameworks such as developed in REFORM project and ecohydraulic tools.

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MesoHABSIM MODEL

Collect necessary data to create habitat map

- **Mapping with help of drones**
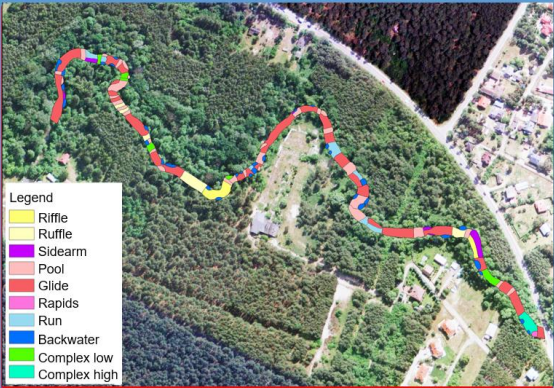 hydromorphological units (HMU-s) such as riffles or runs

Phot. K.Suska SSIFI

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MesoHABSIM MODEL

Collect necessary data to create habitat map

- **Mapping with help of drones**
  hydromorphological units (HMU-s) such as riffles or runs

Legend
- Riffle
- Ruffle
- Sidearm
- Pool
- Glide
- Rapids
- Run
- Backwater
- Complex low
- Complex high

Phot. K.Suska SSIFI

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MesoHABSIM MODEL

Collect necessary data to create habitat map

- **Mapping with help of drones**

  hydromorphological units (HMU-s) such as riffles or runs

- **Measure**
  - depth
  - velocity
  - substrate
  - UAV photos
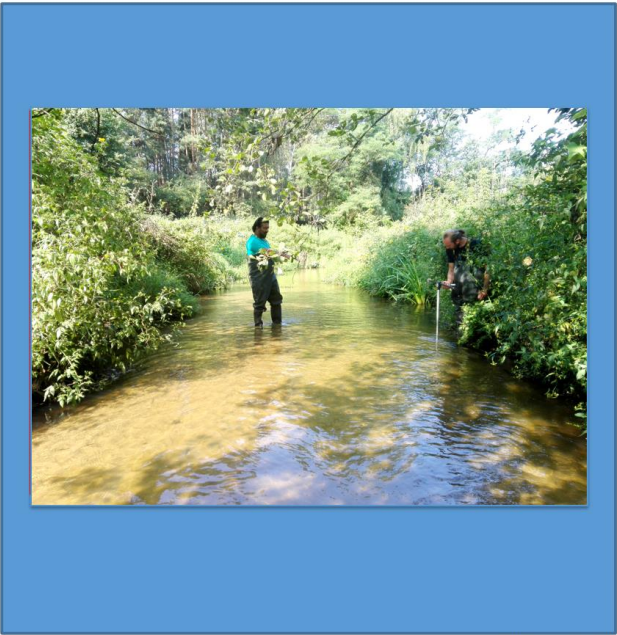
Phot. K.Suska SSIFI

Figure 18. Slide 20. The first step in model development is to gather the data necessary to create habitat maps. This consists of drone-supported mapping of hydromorphological units with attributes relevant for fish habitats and on-the-ground measurement of river hydraulics at multiple flows.

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MesoHABSIM MODEL

Evaluating habitat

- Suitability criteria for physical attributes are defined
- Suitability criteria are species guilds specific

Habitat suitability

| Fish Guild	Depth [m]	Velocity [m s⁻¹]	Substrate type (Choriotope)	HMU Type	Cover
Rheophilic water column	0.5-4.0	0.15-0.7	mesolithal, microlithal, psammal, akal, debris, xylal	run, fast run, pool, plunge-pool, backwater, riffle	boulders, undercut banks, woody debris, canopy shading

Figure 19. Slide 21. The biological model is established with help of literature analysis as sc. Conditional Habitat Suitability Criteria. Preferable ranges of depth and velocity, selected substrates and cover attributes are defined for every fish species habitat use guild.
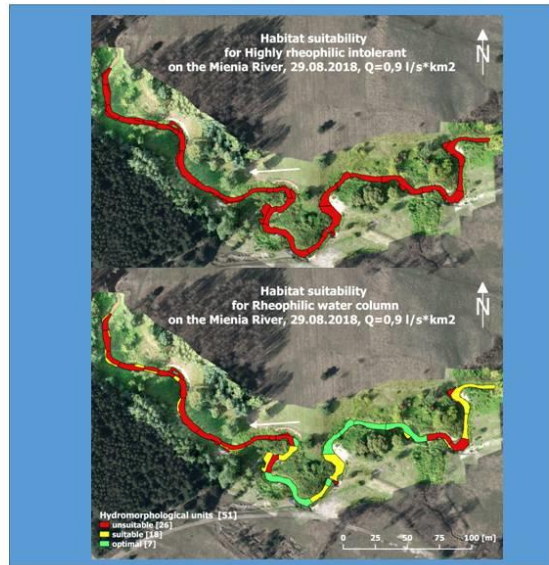
Figure 20. Slide 22. Habitat maps are created for every guild, distinguishing areas of suitable and not suitable habitats, which are determined by applying the suitability criteria to mapped units. Due to the dynamic nature of hydromorphological units, the habitat suitability changes with flow causing an increase or decrease of suitable area.
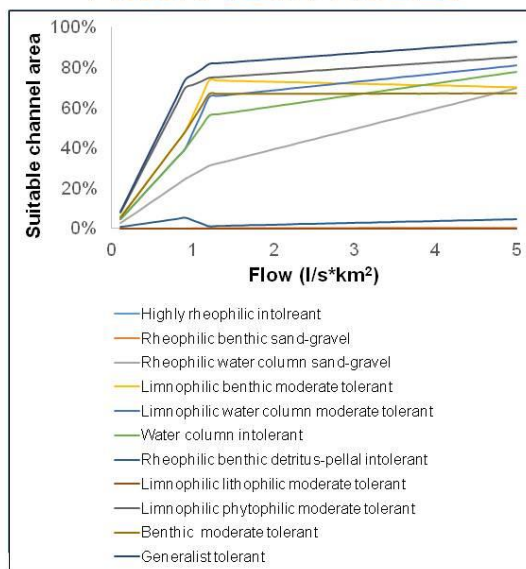
Figure 21. Slide 23. The change in habitat area is then demonstrated in the form of habitat flow rating curves showing how much of channel area (CA) is suitable for each species guild at each flow.

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**Figure 22.** Slide 24. The area under each curve at one selected flow (usually median i.e. most frequent flow) can be plotted in habitat structure diagrams. In this way, two scenarios can be compared by calculating distribution dissimilarity index. Here we see the comparison of expected fish community structure and observed habitat structure (which may also serve a selection of restoration scenarios). Dissimilarity of habitat structure between scenarios is one of the components of the RAA diagram plotted on the Y-axis.
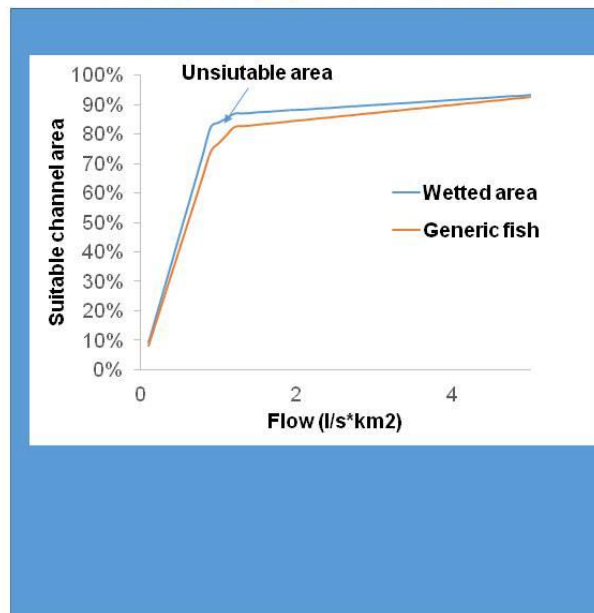
Figure 23. Slide 25. To determine the unsuitable area, habitat can be expressed as a generic fish habitat rating curve, which represents the entire habitat available for all members of the community.

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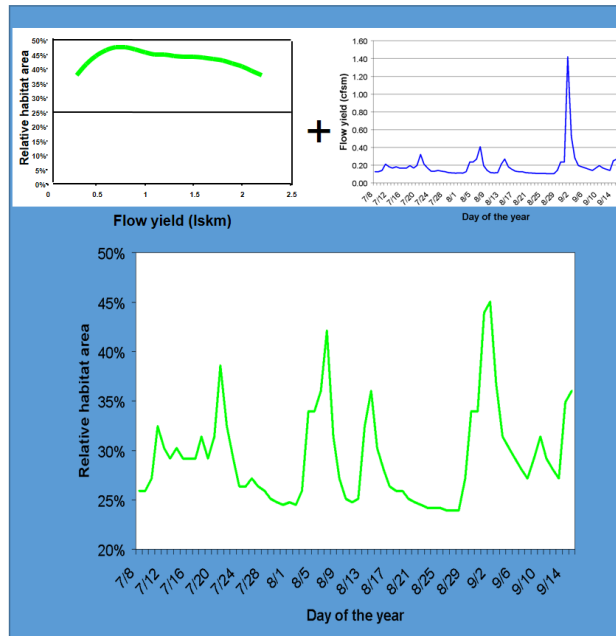AMBER Project - H2020 - Grant Agreement #689682

The difference between this rating curve and one representing entire wetted area, defines habitats not preferable by fish. It is the second component of the RAA diagram presented as a size of the circle representing a scenario.

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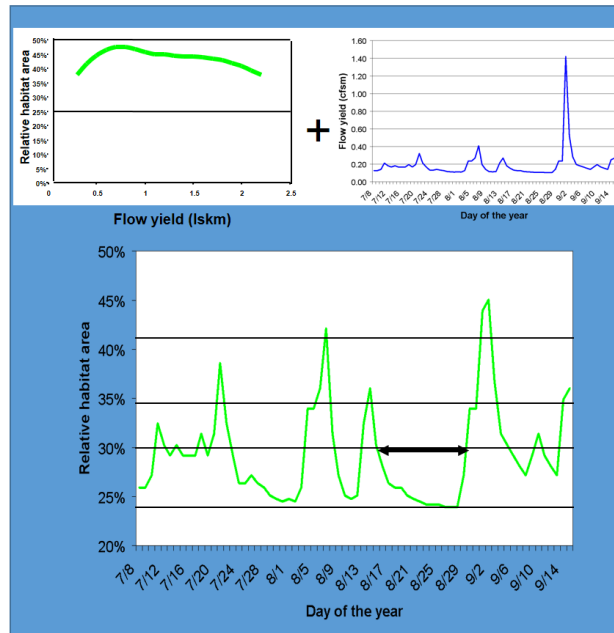AMBER Project - H2020 - Grant Agreement #689682

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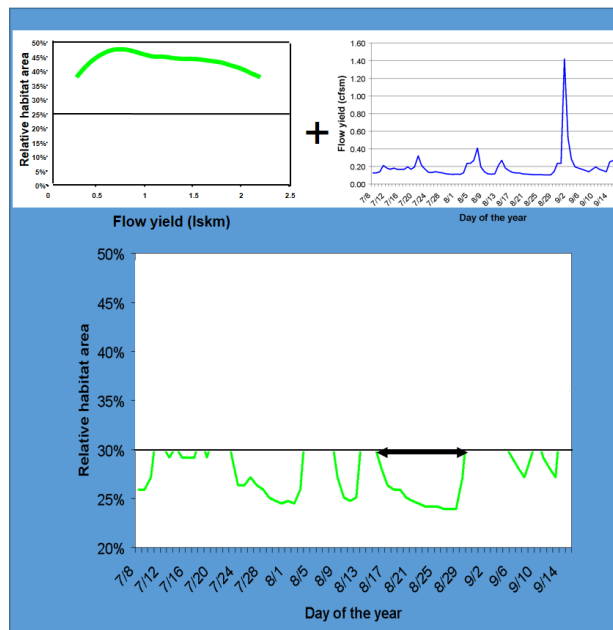
Figure 24. Slide 26. To define the third component of the RAA diagram habitat time series, analysis is needed. Habitat time series are created by using the community rating curve to translate flows of the long term daily flow time series into habitat time series (habitograph). Habitat stress occurs when deficits in habitat availability occur for persistent amount of time. To identify habitat stress days, we first need to determine the continuous duration of all events when habitat is below a threshold value. When the threshold is low such events are rare, and when it is high then they are quite common. Subsequently, duration frequency analysis identifies both rare and persistent events that can be considered as causing habitat stress.

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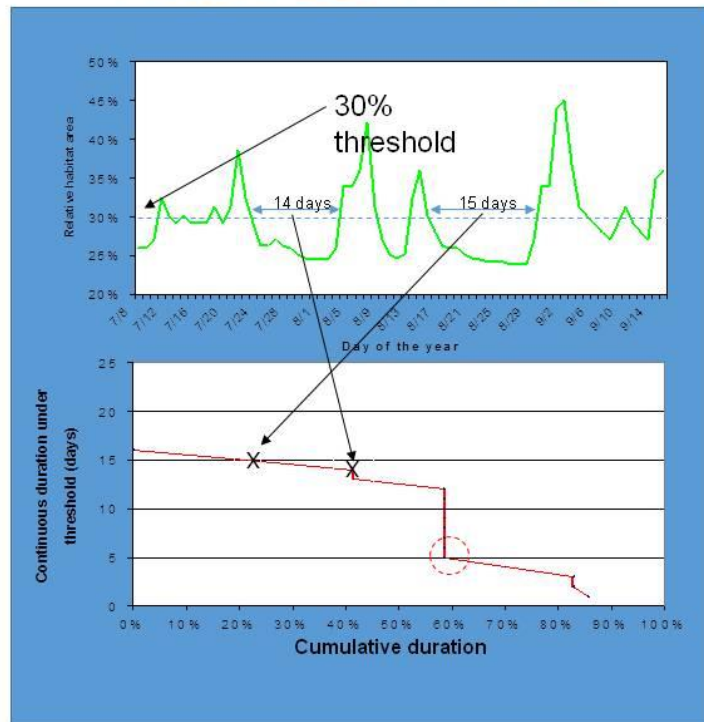
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Figure 25. Slide 27. To perform duration frequency analysis, the continuous under threshold durations are plotted on a cumulative duration frequency diagram. The x-axis represents the relative duration of the entire period (e.g. summer) and y-axis the continuous duration of the under threshold event. The longest event is plotted first - in the presented case, it is 15 days on the y and 20% on the x axis (15 days makes 20% of the entire period). Then sum of length of the next shorter event (14 days) is added and connected with a line. If the events do not occur (e.g. 13 days) the line drops vertically. If many events of the same length occur, the line flattens out. Beginning with the shortest duration (bottom of diagram) a point can be observed in which the curve rapidly steepens. This critical point of the curve is considered a transition to persistent durations.
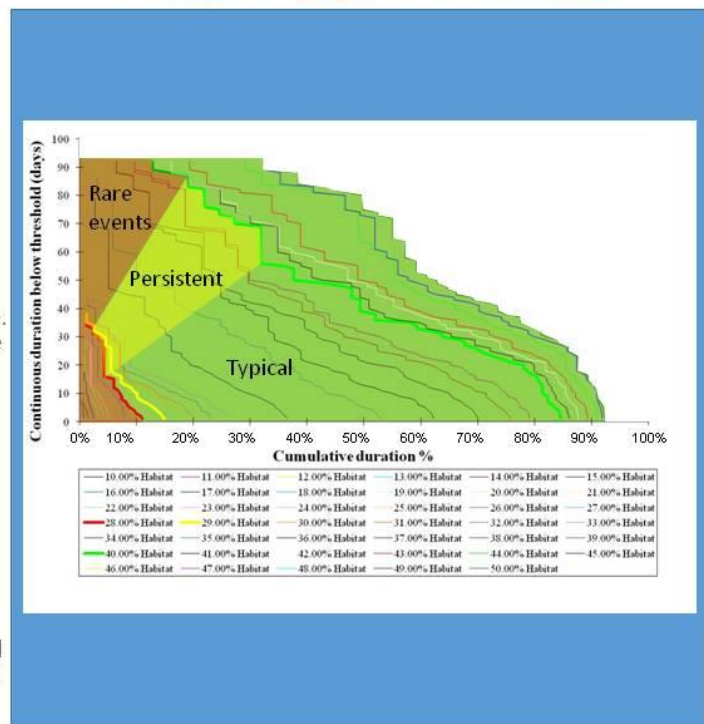
Figure 26. Slide 28. When multiple UCUT curves, each representing different thresholds, are plotted on one diagram, a pattern can be observed in the lower left corner of the diagram. Here the curves for low habitat thresholds are located. The spacing between the curves is at first very small and then increases rapidly as we move to the right. This is considered to be a transition value from rare events and the highest of the densely packed curves is called the rare habitat threshold. Similar pattern can be observed at the other side of the diagram for very high thresholds, the lowest of which is selected as a transition to common events. The critical points on both curves indicate transition to persistent events. One more value is plotted on each of the two curves: a duration that did not occur more frequently than every 10 years. This is considered a transition to events of catastrophic duration. As indicated on the diagram, we can then classify events into typical, persistent and catastrophic.

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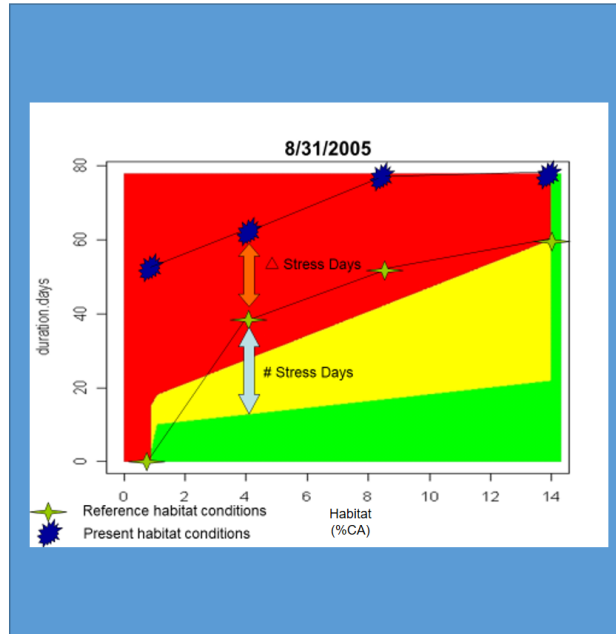AMBER Project - H2020 - Grant Agreement #689682

Figure 27. Slide 29. All non-typical events are considered to be stressful from the moment when habitat deficit duration is exceeding the duration of typical events. The number of days of this exceedance is called a number of habitat stress days (HSD). When comparing different scenarios we can measure change in HSD as an impact indicator.
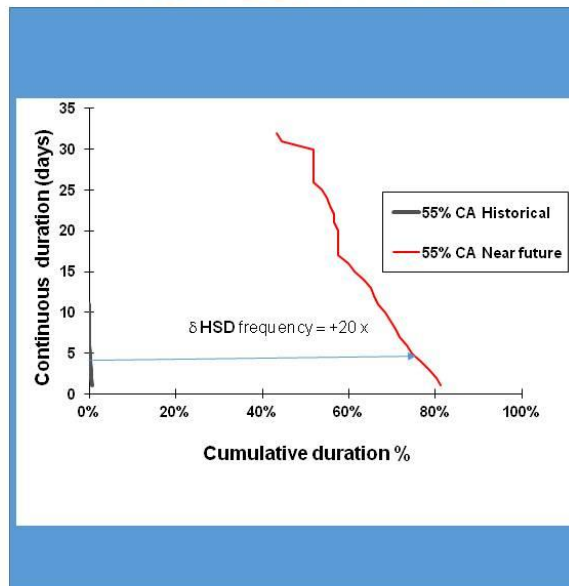
Figure 28. Slide 30. Alteration of habitat stress days in the long term habitat time series can be measured on the UCUT diagram by plotting rare thresholds for both scenarios. The distance between the critical points on the curves indicate the frequency change of persistent events. It is expressed as a ratio of HSD from reference scenario. In the above diagram the frequency increase is 2000% of the

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original, hence the habitat area will be under this threshold for a persistent amount of time about 20 times more frequent. This may be considered deleterious to the investigated fauna and could cause a shift in community structure by promoting more flexible and resilient species. This value is plotted on the x-axis of the RAA diagram.
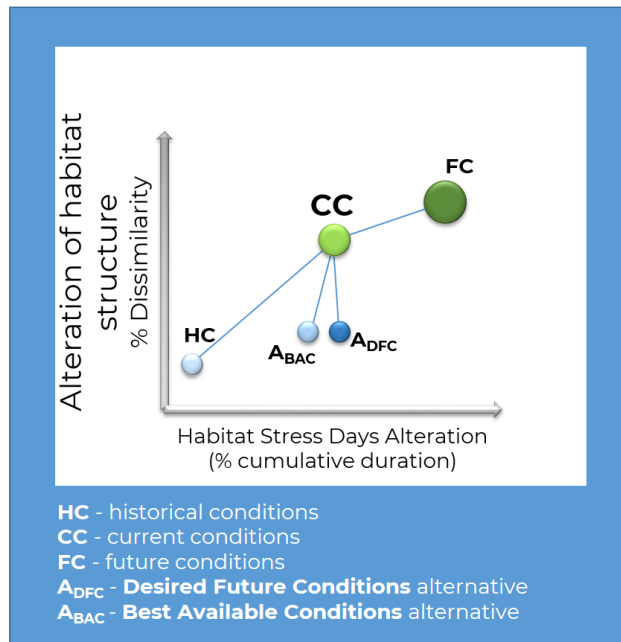
Figure 29. Slide 31. This slide represents a comparison of hypothetical scenarios on an RAA diagram. The closer the scenario is to the origin of the diagram, the lower the impact and the better the scenario.

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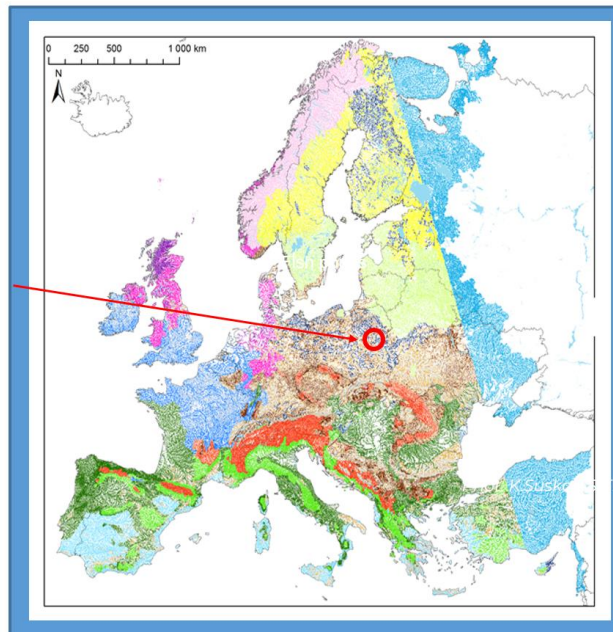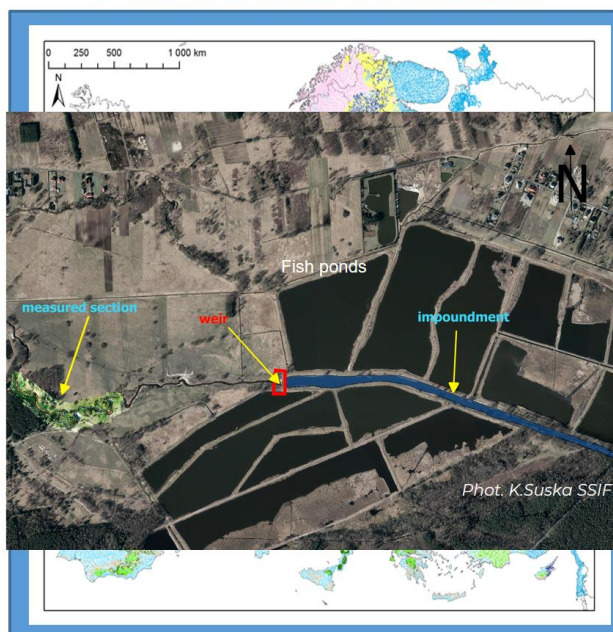
Figure 30. Slide 32. Now we will demonstrate the application of the above concept using habitat data collected on the River Mienia in Central Poland. This is a small lowland stream, a tributary of the River Świder, which flows into the River Vistula. In its lower section, the River Mienia flows through a conservation area, but further upstream it has been modified with the purpose of agricural irrigation. It therefore has a number of small barriers which are no longer in use. The large dam in the mid course supplies water to a fish farm.

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Figure 31. Slide 33. Here we see an aerial photograph taken from UAV. It presents the location of the dam and the impoundment at a low flow conditions. We surveyed this area 3 times in summer 2018.
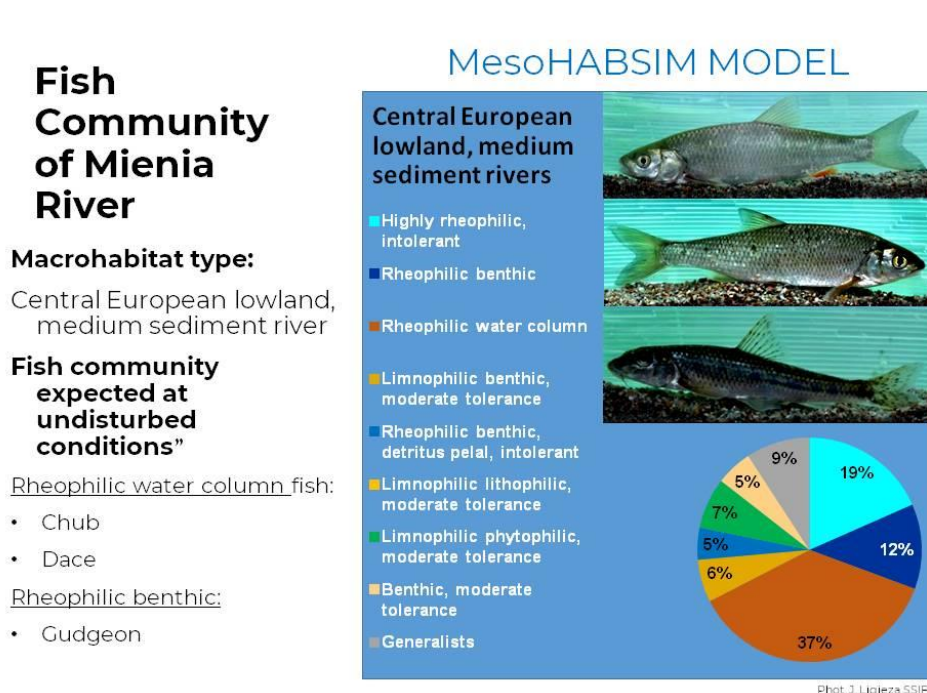

Figure 32. Slide 34. The River Mienia belongs to a Central European lowland, medium sediment Macrohabitat Type. The fish community is diverse, but consists mostly of cyprinid species and should be dominated by rheophilic water column fish guild with species such as chub and dace.

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Figure 33. Slide 35. The habitat use criteria that were used for habitat model development are presented in the table.
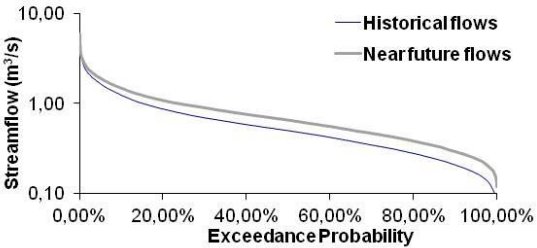

Figure 34. Slide 36. After model development, three scenarios were simulated and evaluated on an RAA diagram. Scenario one represents reference conditions: river without a dam and current habitat distribution as we found it in the downstream section. It includes a sub-scenario of near Future conditions under predicted climate change. Flows for this scenario have been simulated with help of SWAT model and nine climate change simulation models. To represent Near Future Conditions median values of daily flows predicted by these models were used in a habitat time series analysis. The flow duration curve demonstrates the change in flow rate due to climate change and indicates an overall increase of flows.
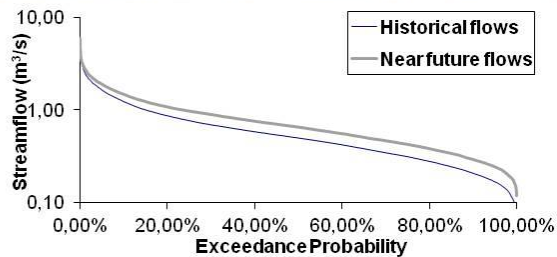
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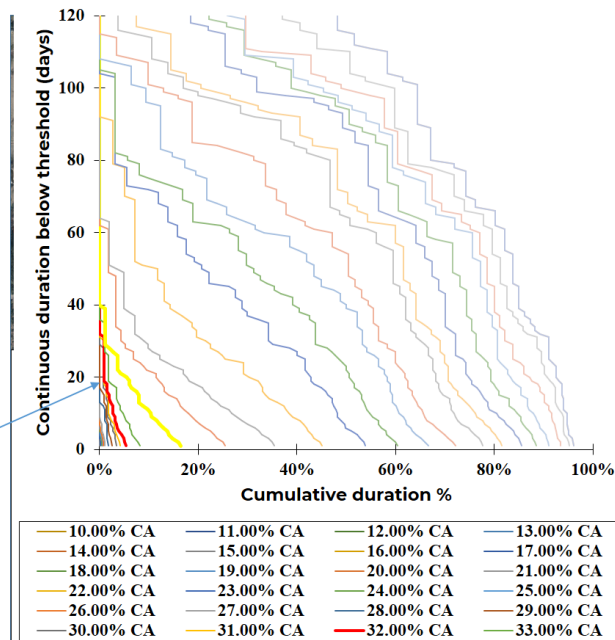AMBER Project - H2020 - Grant Agreement #689682

Figure 35. Slide 37. Scenario 2 represents the current situation of the river with the dam, but also considers historical and future flow conditions, the latter under climate change assumptions.

Figure 36. Slide 38. The third scenario is an investigation using the impoundment for flow augmentation in the river during the summertime lows. In order to define that, we first need to identify the rare-persistent habitat threshold and the associated flows. For this purpose, we conducted a habitat time series analysis for conditions in Scenario 1a and plotted a UCUT curve diagram. As a rare threshold, 32% of a channel area of suitable habitat was selected with 19 days of persistent duration. In this scenario, the amount of flow to 32% of the habitat would be equivalent to

180 l/s. To provide the same amount of habitat with the dam in place, 250 l/s would need to flow downstream of the dam.
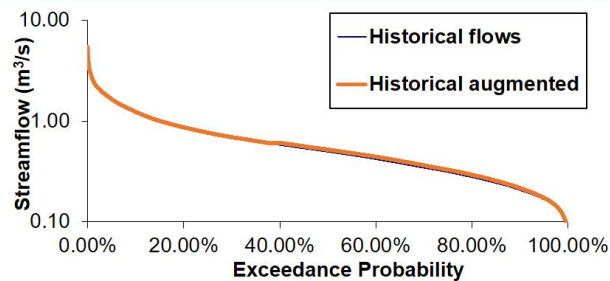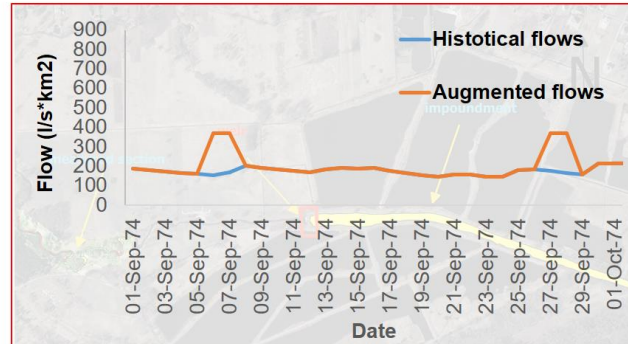

Figure 37. Slide 39. Therefore, for scenario 3, we simulated flow augmentation when the flows were under 250 l/s for longer than 18 days. The augmentation from the ponds would be equivalent to 400 l/s and last 2 days. This would cause only a small change in the historical flow duration curve.
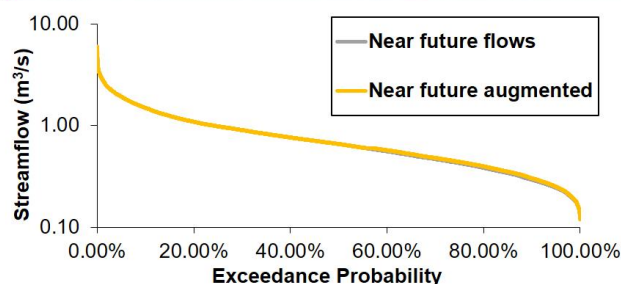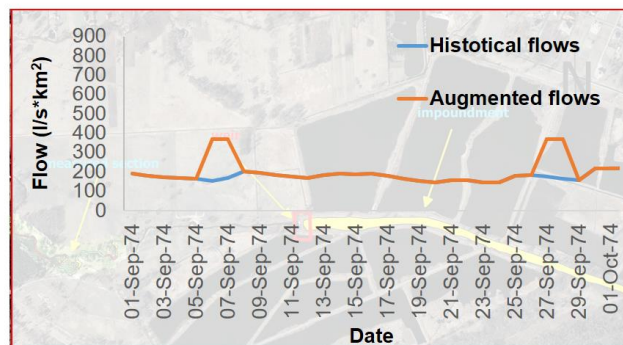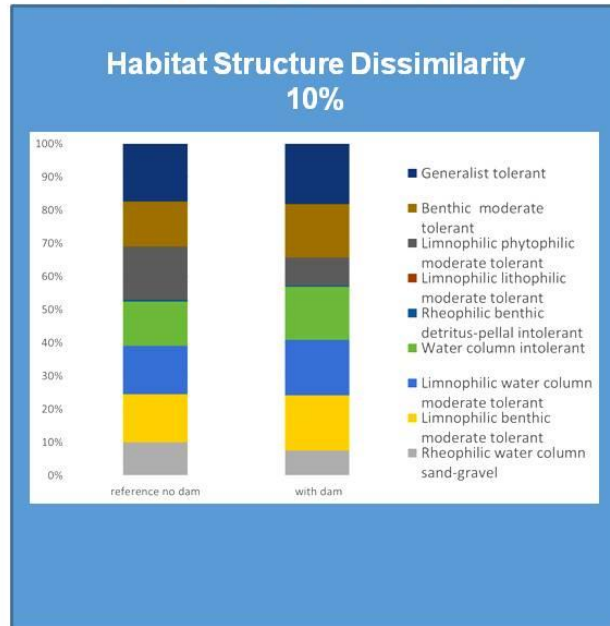
Figure 38. Slide 40. Scenario 3b simulates the same augmentation as Scenario 3a but under Near Future flow conditions.

**Figure 39.** Slide 41. Dam construction altered the habitat structure by only 10%. This is due to the habitat structure of a no-dam scenario being dominated by low gradient river habitats most suitable for lentic species. Comparison with expected fish community structure indicated a lack of rheophylic guild habitats overall. This may be a consequence of historical modifications of the watershed.
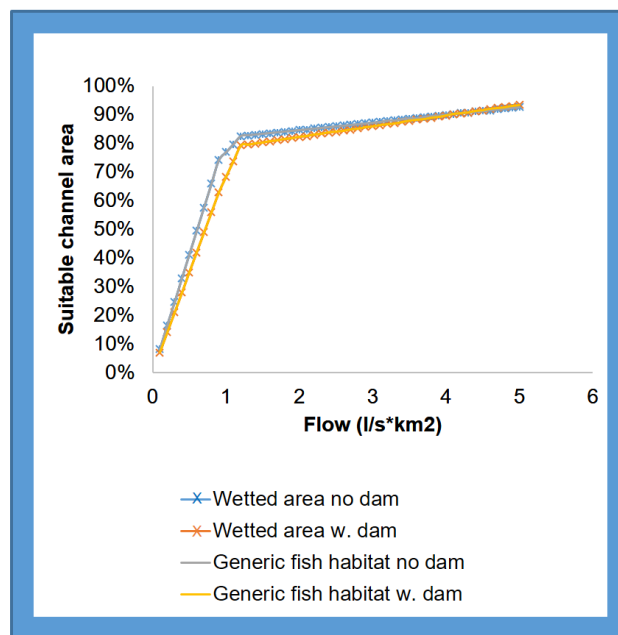
Figure 40. Slide 42. According to our model, the entire wetted area offered suitable habitat for generic fish with the dam in place.
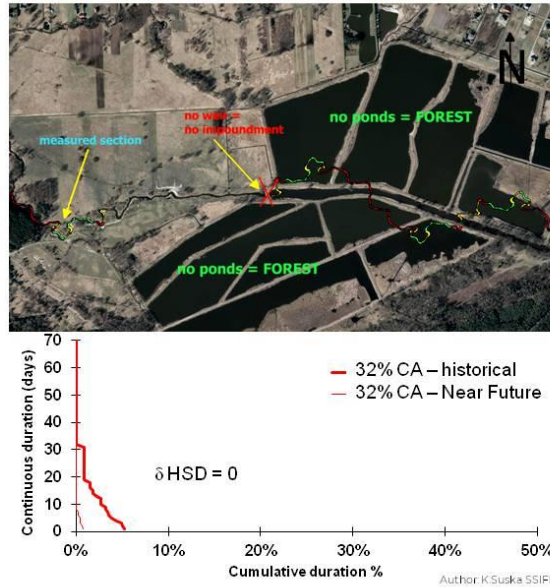
Figure 41. Slide 43. When comparing the number of HSD for no-dam scenarios (1a and 1 b), climate change will actually reduce the HSD. Since the River Mienia is still far from pristine, this can be considered a positive development.
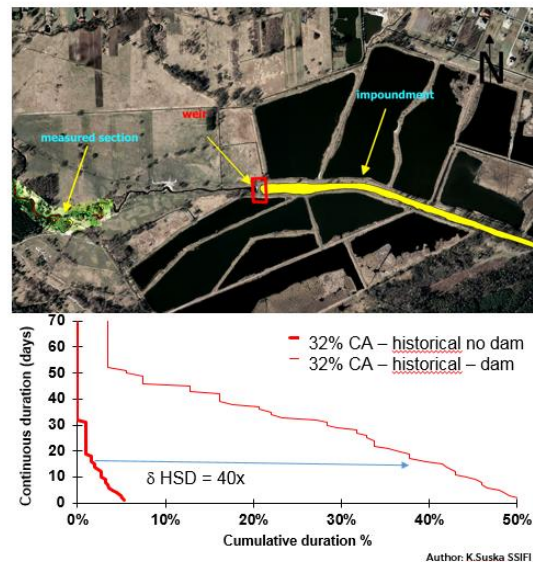
Figure 42. Slide 44. Comparing scenario 1a with 2a. With the dam in place, the HSD is increasing dramatically as the rare-persistent threshold changes by 4000%, i.e. there is a 40-times increase in stress days frequency (from 0.9% to 36.2%).

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Figure 43. Slide 45. Comparing scenario 1a with 2b. Under the climate change scenario, HSD will still greatly exceed the reference value and drops less than 3000%, i.e. 30-times increase in stress days frequency (from 0.9% to 26.6%)
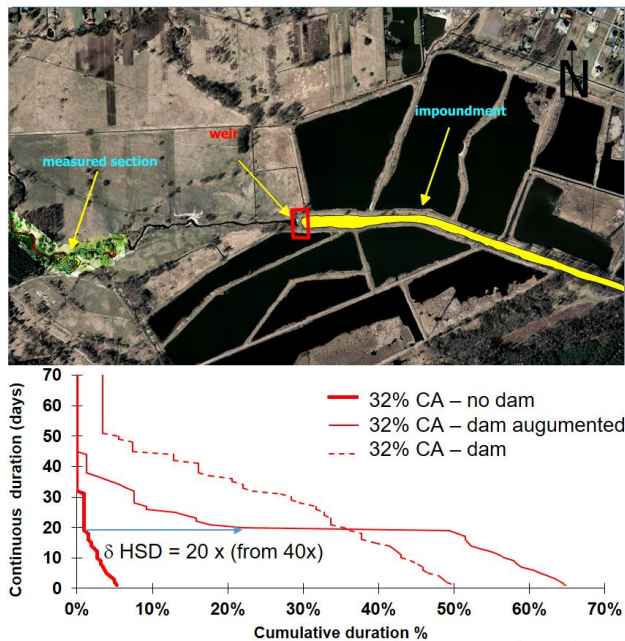
Figure 44. Slide 46. Comparing scenario 1a with 3a. Under historical conditions, flow augmentation would lower the HSD by half to a 20-times increase from reference value (from 0.9% to 22%).

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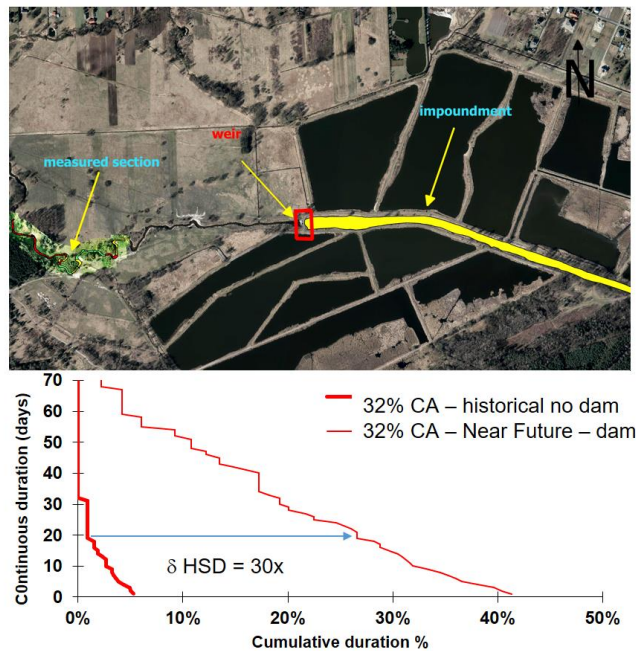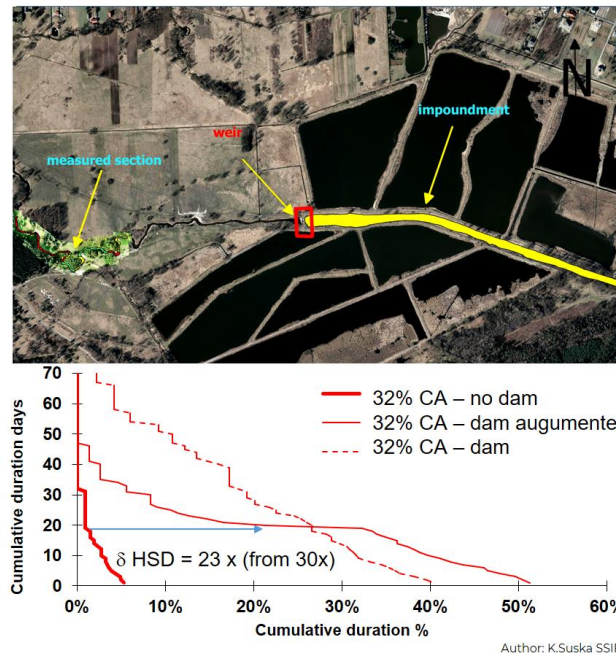**Figure 45.** Slide 47. Comparing scenario 1a with 3b. Under the climate change scenario, the augmentation would have less of an effect, as it would be implemented less frequently. It drops to 23 times the reference value (from 0.9% to 21.4%).
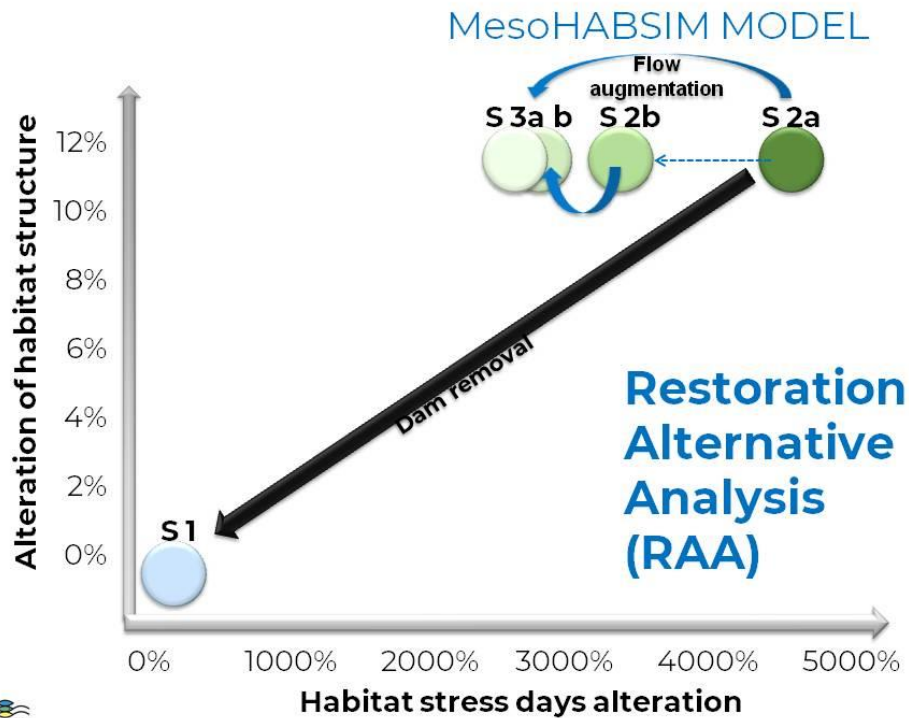
Figure 46. Slide 48. The Restoration Alternative Analysis (RAA) diagram demonstrates the simulated scenarios, clearly indicating that dam removal would be by far the best of these options. This scenario would also most successfully mitigate the impact of climate change. However, it is conceivable that

more sophisticated augmentation scenarios, combined with some habitat restoration, could offer better results while leaving the dam in place.

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Conclusions

- The **Restoration Alternative Analysis (RAA)** allows to identify impact of dams on fish habitat.
- Mitigation alternatives such as flow augmentation strategies can be tested.
- Best available scenarios can be easily identified.
- Even on small lowland river the impact of a dam is substantial.

Figure 47. Slide 49. This deliverable of the AMBER project demonstrated a concept of applying the Restoration Alternative Analysis (RAA) in investigating the impact of dams on adjacent habitats. The method allows for tests for alternatives and identification of the best available options. Even a small fish hatchery dam on a lowland stream could be shown as creating an impact on fish habitat. Futher tests on other facilities and dam types will be conducted during the AMBER project.

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Figure 48. Slide 50. Core references.

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Figure 49. Slide 51. AMBER project Partners.

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