

Use of Habitat models for decision support in water resources management

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Condensed abstract: An instrument of particular importance for the analysis of river systems and their ecology are physical habitat models. The application of this kind of models to rivers enables the prediction of habitat quality for organisms living in and at the edge of the water body. Especially in the context of the European Water Framework Directive and its implementation it is crucial to assess river “health”. Common approaches like structural quality or water quality indices don’t provide a direct linkage between physics and biology and therefore no prediction capabilities. The paper gives an overview of existing modelling approaches, provides an introduction to new fuzzy rule-based calculations and presents case studies for various fields of application.

1 INTRODUCTION

Due to the strong influence by human activities only few of the rivers and river systems in Europe and North America are in a natural or at least near-natural condition. At the same time riparian systems belong to the ecologically most significant landscapes on earth. In the last decades the negative effects of the intensive use are realized with a higher sensitivity in the public and consequently in politics too. This process of realignment can be observed in many states and finds expression in the Water Framework Directive (WFD) of the European Union. But other than some decades ago the focus is not only on water quality. Today structural deficits are identified as the main limiting factors for the development of “healthy” river ecosystems. In the WFD it is stipulated that surface waters have to be in a “good” condition, which is defined by “biological” but also by “hydro morphological” criteria.

For practical use this definition includes some problems. On one side the assessment of biological criteria by sampling or observation is time-consuming and expensive. On the other most of the biological components are characterized by temporal fluctuations, which necessitates repeated acquisition of data. Even more important is the fact, that common approaches only give information about the current situation. The potential development of rivers or the efficacy of hydro engineering measures can be estimated to minor degree.

This gap partly can be closed by the use of habitat models. These include relations between physical conditions in a river and the biological response in terms of habitat quality. While the change of physical parameters like flow velocity or substrate composition for different scenarios can be calculated quite precisely, using these relations it is also possible to predict the development of habitat availability as an indicator of ecological quality.

2 HABITAT MODELING

2.1 Principles and advantages

Ecological systems like rivers and associated habitats are complex systems integrating a lot of linkages between biotic and abiotic factors. Within these systems suitable environmental conditions and resources must be available in forms of quantity, quality and timing in order to sustain a viable long-term population (STATZNER 1988). Stream ecosystem productivity is determined by four major components (KARR & DUDLEY, 1981):

- Flow regime
- Physical habitat structure
- Water quality including temperature
- Energy inputs from the watershed

Since physical habitat modelling covers important aspects of these components and their interaction it is considered to be a suitable tool to investigate changes in these systems caused by human impact.

The advantages of connecting the physical parameters within a river system with habitat requirements for the investigation of ecological quality and its interference with management issues are explained by the following facts:

- The ecological quality of a river system is directly coupled with the living conditions of the typically resident organisms.
- Habitat models can predict the influence of discharge and structural changes on fish, invertebrates and macrophytes.

- Instream flow changes affect primarily water depths, flow velocities and substrate composition, which all are main factors for habitat quality.
- By relating habitat quality to discharge or river modifications a quantitative base is given for the comparison and evaluation of ecological values and the usage requirements.

2.2 Existing approaches

Habitat modelling is a common method for river management in North America. So far mainly fish, especially the economically interesting salmonides, were considered. Various approaches have been worked on and tested in the past and it has turned out that the characterization of physical habitat is very complex because of temporal and spatial heterogeneity. However as main physical parameters are considered:

- Flow velocity
- Water depth
- Substrate and choriotopes
- Cover

Common habitat models are based on the requirements of selected species and their life stages (i.e. brown trout adult, spawning, juvenile,...) regarding these parameters.

- Preference functions

The traditional approach for physical habitat modelling is the one using univariate preference functions, first introduced within the IFIM (BOVEE, 1998). Within this approach the demands of species concerning the physical parameters (see above) are defined by a suitability index (SI) reaching from 0 (no suitability) to 1 (optimum suitability). The parameters are considered independently from each other and are connected within the habitat modelling procedure only.

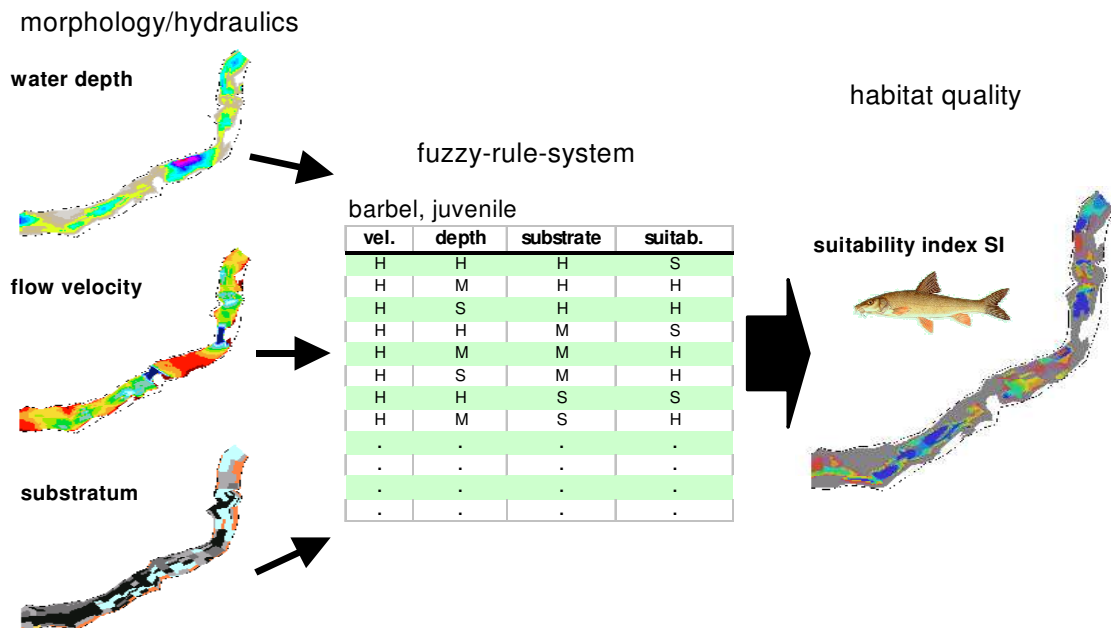


Figure 1: Principle of new fuzzy rule based approach used in CASIMIR

- Multivariate approaches

Because independent consideration of habitat parameters doesn't appropriately represent the complexity of habitat properties new approaches were introduced. Introduction of additional criteria, combined preference functions, multivariate preference functions, logistic regression, multivariate regression, neural networks (for references see SCHNEIDER, 2001) were used to improve the performance of habitat modelling. But there are some remaining problems within each of these methods:

- Habitat requirements, which in fact cannot be defined exactly, are given by crisp numbers,
- Input parameters are not independent as actually premised for multivariate regression,
- Implementation of new parameters is difficult,
- A lot of input data for calibration is needed.

2.3 New fuzzy-rule based approach

In the habitat simulation model CASIMIR (Computer Aided Simulation Model for Instream flow Requirements) developed at the Institute of Hydraulic Engineering, University of Stuttgart, a new fuzzy-rule based approach has been implemented. It is part of a highly resolved river model that enables the analysis of the aquatic and riparian zones as habitats for fish, macroinvertebrates and vegetation. Advantages of this approach are an easy implementation of expert knowledge and the opportunity of multivariate calculation. The principle of this method is given in Figure 1. Basis of the calculation is a fuzzy-rule system (see Figure 1) containing expert knowledge in terms of linguistic expressions as given in Table 1.

Table 1: Extract of a fuzzy-rule system defining the requirements of a selected species and life stage

Flow velocity	Water depth	Size of dominating substrate	Habitat suitability
• • H	• • H	• • M	• • S
If flow velocity is „High“	AND water depth is „High“	AND substrate size is „Medium“	THEN suitability is „Small“

As it can be seen, knowledge can be defined imprecise or in other words “fuzzy”. This kind of formulation meets the consideration of ecological linkages, because generally they cannot be defined exactly.

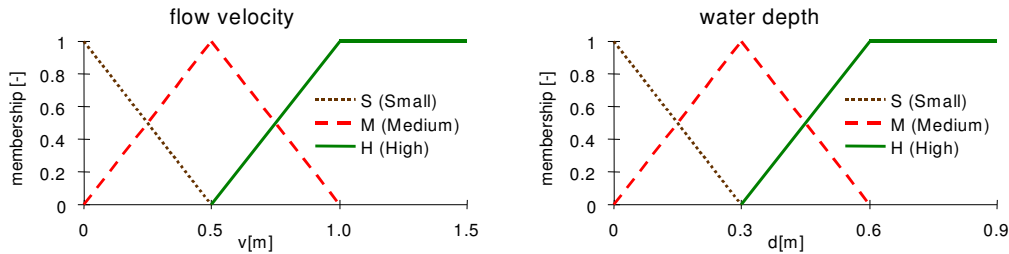


Figure 2: Fuzzy-sets for parameters flow velocity and water depth in an alpine creek

The fuzzy formulation of parameters is enabled by so called fuzzy-sets, which are defined by membership functions. Figure 2 gives an example of these membership functions for the parameters flow velocity and water depth defined for a creek in the alpine region. For more detailed information see SCHNEIDER (2001).

3 MODEL RESULTS

3.1 Habitat quality maps

In a first step of the modelling process suitability indices (SI) for each grid cell in the digital river model are calculated. Using these SI-values habitat maps, showing the spatial distribution of habitat qualities can be generated (see Figure 1, right side). This kind of visualisation is not only valuable for the evaluation of habitat availability in a river reach and the accessibility of good habitats. It also can be used for calibration and validation of the model comparing the results with fish positions derived by electro fishing or observation.

3.2 Habitat availability

For the analysis of habitat development over discharge or change of habitat for different scenarios (i.e. flood defense measures) an integrative value for habitat quality in a whole river reach (not only a single grid cell) is defined by the weighted usable area (WUA in m²) or hydraulic suitability index (HHS in %). WUA and HHS in that way are measures for habitat availability and calculated in the following way:

$$WUA = \sum_{i=1}^n A_i \cdot SI_i = f(Q) \quad (1)$$

$$HHS = \frac{1}{A_{ges}} \sum_{i=1}^n A_i \cdot SI_i = f(Q) \quad (2)$$

WUA = Weighted usable area [m²]

HHS = hydraulic habitat suitability index [-]

A_i = area of grid cell i [m²]

A_{ges} = wetted area of river reach

SI_i = suitability index of grid cell i [-]

WUA changes for scenarios of flood defense measures and WUA-function over discharge are given in Figure 4 resp. Figure 5.

3.3 Habitat dynamics

It is obvious that habitat quality changes with discharge and therefore with time. The integrative values WUA and HHS can also be used for time series analysis. Figure 3 shows the example of a river with nival flow regime.

At relatively low flows in winter increased discharges improve habitat quality, whereas floods during the summer might cause considerable problems. Habitat quality drops sharply because of increased hydraulic stress and fish possibly need to seek refuge.

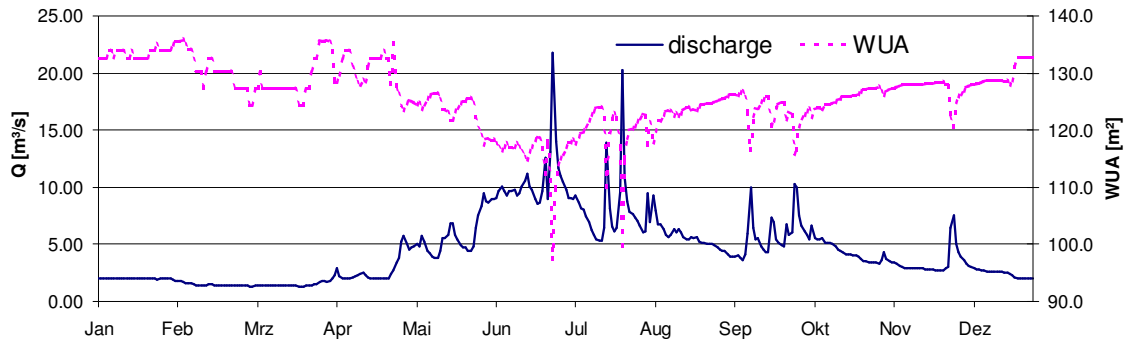


Figure 3: Example of habitat- and discharge-time series in a nival flow regime

4 RANGE OF APPLICATION AND EXAMPLES

Originally developed mainly for the investigation of instream flow questions meanwhile the range of application of habitat models has been extended. For example CASIMIR has been used in the following fields:

- Flow regulations
- Structural quality investigations
- Effects of river regulation and restoration
- Watershed management

4.1 Effects of flood defense measures

For lowering water levels during flood events excavations in narrow reaches of a river were planned in order to increase conveyance capacity. By these measures spawning grounds were estimated to be endangered.

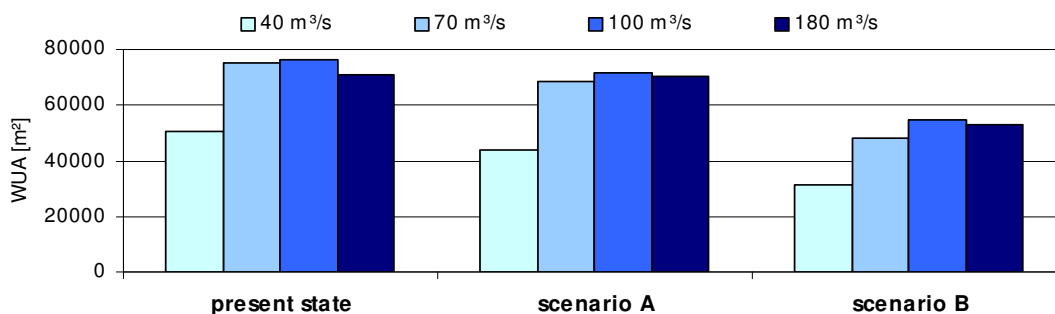


Figure 4: Habitat availability for different flow rates and alternatives of flood defense measures

Using a two-dimensional hydraulic model water depths and flow velocities for different scenarios of excavation measures were calculated. In a second step, activated by an interface, CASIMIR was used to calculate the availability of spawning grounds for the present state and for the suggested alternatives.

In Figure 4 the consequences in terms of habitat loss are given. It can be seen that particularly during low flow periods, a significant loss of habitats is to be expected. Furthermore the differences between the two scenarios become evident. While in scenario B spawning grounds are predicted to be reduced by maximum 50 % over the whole range of flows, reduction for scenario A are moderate, especially for higher discharges. Quantitative results like these are a valuable basis for decision-making.

4.2 Minimum flow regulation

Another frequent application of habitat models is the development of minimum flow regulations. Minimum flow is one of the major environmental impacts caused by hydropower use. WUA-functions giving the relation between habitat availability and flow rate are one of several criteria for the development of ecologically oriented flow regulations.

In Figure 5 it can be seen that habitats for different life stages are quite different. The suggested minimum flow regulation includes higher flow rates during the spawning periods of the indicator species grayling and brown trout, lower flows during the summer season (water temperatures were also considered).

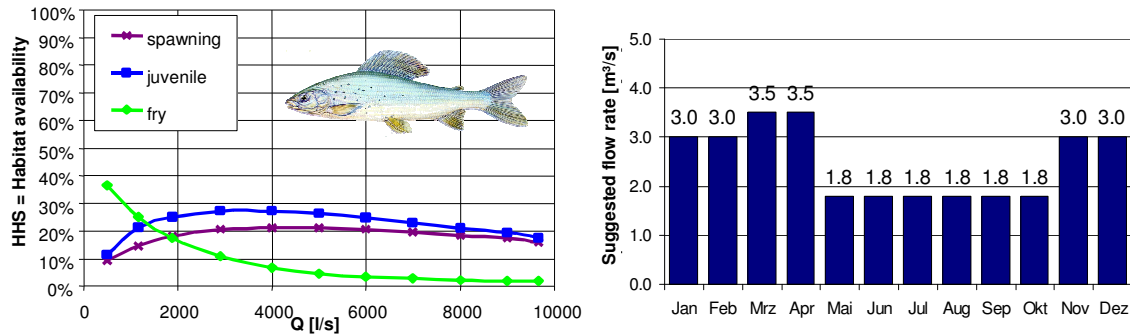


Figure 5: Functions of habitat availability for stages of grayling and derived minimum flow regulation

4.3 Watershed management

Many alpine river systems are strongly influenced by water intakes for hydropower use, which often are distributed all over the catchment area. A suitable flow management is essential for environmental integrity as well as for optimised energy production.

In the example reaches representative for larger sections of the river system were selected (Figure 6). Investigations of habitat in combination with other aspects like water temperature, sediment transport and many more lead to various requirements relating to quantity and temporal distribution of discharge. Quantitative statements about habitat qualities play a major role for a synthesis of the ecological and economical requirements. Within that kind of synthesis management strategies adapted to the specific conditions of the watershed can be found.

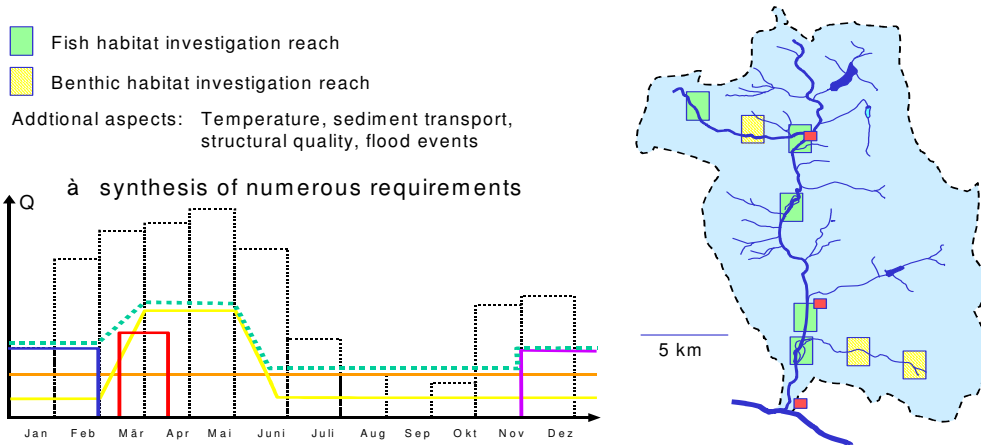


Figure 6: Catchment with location of habitat investigation reaches, synthesis of different requirements

5 CONCLUSION

Since the emphasis of the EU Water Framework Directive is on the improvement of the ecological conditions of surface waters tools for the assessment of these conditions are urgently needed. Within the implementation of the Directive furthermore there is demand for new technologies, in particular forecasting instruments for the efficacy of engineering measures and consequently for their optimisation. Habitat modelling covers both of these aspects and by that applies to many different fields of water engineering and management. The new fuzzy-rule-based approach implemented in the simulation model CASIMIR is highly suitable for the investigation of ecological problems and has proven its practicability in various applications.

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