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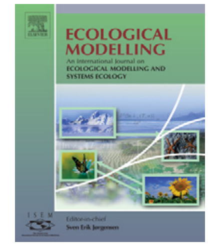

Optimisation of a fuzzy physical habitat model for spawning European grayling (*Thymallus thymallus* L.) in the Aare river (Thun, Switzerland)

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ABSTRACT

Ecological expert knowledge is often based on qualitative rules consisting of linguistic terms such as 'low', 'moderate' or 'high'. Since fuzzy systems transform these rules and terms into a mathematical framework, they allow implementing this expert knowledge in ecological models. However, the development of a reliable knowledge base is complex and time consuming. Recent research has shown that complementing fuzzy systems by data-driven techniques can solve this knowledge acquisition bottleneck. In this paper, a heuristic nearest ascent hill-climbing algorithm for rule base optimisation is applied to construct a fuzzy rule-based habitat suitability model for spawning European grayling (*Thymallus thymallus* L.) in the Aare river (Bern, Switzerland). Optimisation of the fuzzy rule-based model was based on two different training criteria, the weighted correctly classified instances (CCI_w) and Cohen's Kappa. The ecological relevance of the results was assessed by comparing the optimised rule bases with a rule base derived from ecological expert knowledge. Optimisation based on Kappa appeared to generate acceptable results (CCI = 0.70; Kappa = 0.32) and was more practical than optimisation based on CCI_w since the latter required fine tuning of a weight parameter, which accounted for the species prevalence. The optimal rules showed 74% similarity with the rules derived from expert knowledge, while 84% of all model errors was due to false positive predictions of the model. These errors might be due to the impact of variables, which were not included in this study on grayling presence and thus are not necessarily a model error. The habitat suitability model optimised in this paper is able to predict the effect of different impacts on the river system and to select the optimal restoration option. Hence, it could be a valuable decision support tool for river managers and ease the discussion between stakeholders.

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1. Introduction

The relation between fish presence and physical microhabitat features such as depth, flow velocity and substrate conditions of the river bed has been widely studied (Gorman and Karr, 1978; Poff and Allan, 1995; Armstrong et al., 2003). Consequently, physical habitat assessment in rivers is often used to analyse the impact of different management options, for instance river restoration, on target fish communities (Maddock, 1999). This resulted in the development of several physical habitat suitability models (Bovee, 1982; Jowett, 1997; Parasiewicz and Dunbar, 2001). River management can benefit from such predictive models as decision support tools to improve the efficiency of monitoring and assessment, for example by choosing the most optimal management option from a set of given restoration scenarios (Guisan and Zimmerman, 2000; Recknagel, 2002).

For the development of these decision support tools, there is today a growing interest in modelling techniques such as artificial neural networks (Lek and Guégan, 1999), decision trees (Džeroski, 2001) and fuzzy logic (Adriaenssens et al., 2004). To allow decision makers to assess the uncertainty associated with the model outputs, the model structure should be straightforwardly interpretable (Omlin and Reichert, 1999; Elith et al., 2002; Regan, 2002; Borsuk, 2003; Brugnach et al., 2003). Fuzzy logic has become an interesting technique to address this issue. It takes into account the inherent uncertainty of ecological variables during inference processing and it enables expressing non-linear relations between ecological variables in a transparent way (Salski, 1992; Silvert, 2000; Metternicht, 2001; Adriaenssens et al., 2006; Van Broekhoven et al., 2006).

Fuzzy systems use linguistic descriptions such as 'low', 'high' or 'moderate' for quantification of variables and transform these descriptions into a mathematical framework in which suitable data processing can be performed (Kampichler et al., 2000). This turns fuzzy systems into a popular technique for ecological modelling, resulting in numerous applications (Adriaenssens et al., 2004). However, a purely knowledge-driven approach, aiming at formalising problem-relevant human expert knowledge, is difficult and tedious. Recent research has shown that complementing fuzzy systems by data-driven techniques can solve this knowledge acquisition bottleneck (Chen and Mynett, 2003; Žnidaršic et al., 2006). For example, the induction of fuzzy rule-based models by heuristic search algorithms is often used in the field of fuzzy rule learning (Hüllermeier, 2005).

In this paper, a habitat suitability model was developed for spawning grayling in the Aare river (Bern, Switzerland). The model aims at supporting river management in the studied river stretch, which contains some of the major spawning grounds for grayling in Switzerland. To generate an ecologically relevant fuzzy knowledge base for the prediction of spawning grayling presence, a heuristic nearest ascent hill-climbing algorithm was applied. Starting from fixed fuzzy sets, the expert rules were optimised using two different performance measures during training: the weighted % correctly classified instances (%CCI_w) and Cohen's Kappa (Cohen, 1960). The aims of this research were: (1) to assess the impact of different performance measures on the optimisation results, (2) to compare the optimised rule base with available expert knowledge and (3) to generate an optimal fuzzy habitat suitability model for spawning grayling.

2. Materials and methods

2.1. Study area and collected data

The studied site is a 1300-m stretch of the Aare river in the Bern department, Switzerland, and is situated along the city of Thun (Fig. 1). Up to this point, the Aare river is draining an area of about 2490 km^2 and is classified as a 7th order stream (Strahler, 1957). The average flow is 111 m^3/s, with respective base and peak flows of 23 and 570 m^3/s. The Aare river at the studied site was originally a braided river with large gravel banks. However, since the beginning of the 18th century anthropogenic disturbances were introduced for flood control and hydropower generation (EAWAG, 2002). Hence, the flow regime is altered and controlled by flood control weirs. Never-

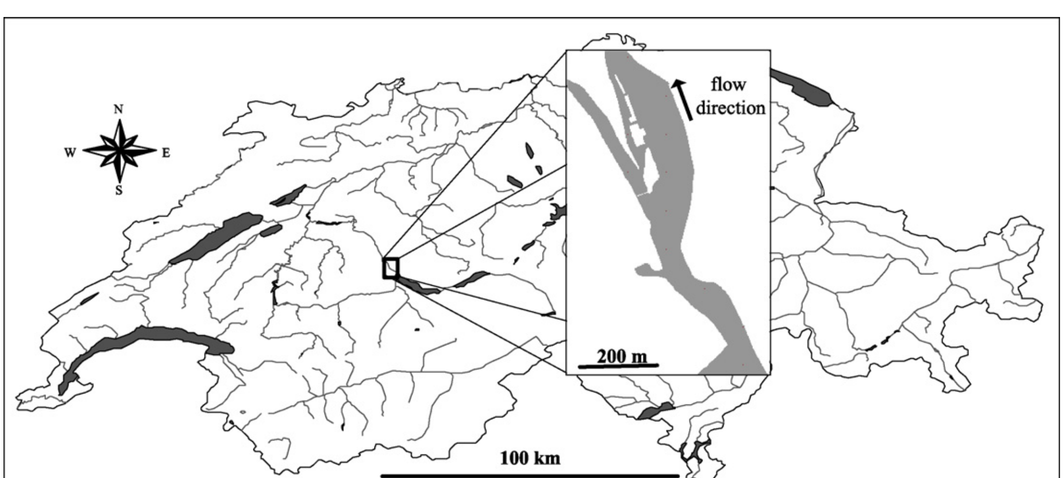

Fig. 1 – Location of the studied site in the Aare river at Thun, Switzerland.