# SPATIAL COMPARISON OF HABITAT SUITABILITY MAPS USING FUZZY-LOGIC

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A fuzzy-based map comparison is applied in this study to assess the performance of aquatic habitat simulation models. We compare simulated habitat suitability maps of spawning areas for European grayling against field observations as well as maps of juvenile habitat suitability, which we have simulated with different habitat modelling approaches. The fuzzy-based method enables a comparison of different rasterized river habitat suitability maps and provides a value of agreement by taking into account: (1) the development of cells in close vicinity to the target cell (fuzziness of location) and (2) the pre-categorized habitat suitability class such as ‘low’, ‘medium’ or ‘high’. (fuzziness of category). The results show an increase in performance, when fuzziness in location and category are considered. Hence, the fuzzy-based map comparison allows considering the degree of uncertainty involved in habitat modelling. Input parameters for the comparison, however, have to be chosen consciously in order to reflect the model dimensions without overstraining on the reliability of map agreement.

## 1 INTRODUCTION

The habitat of aquatic organisms is a key component of the integrated approach of the Water Framework Directive (WFD). To assess the impact of river engineering or restoration measures on aquatic habitats, habitat suitability models are frequently used. Meanwhile, a great variety of different habitat suitability models for fish has been developed and the scientific literature provides several reviews about the different approaches [e.g. 1]. However, similar to all model types, habitat suitability models contain some kind of uncertainty. One source of uncertainty is related to the applied input parameters including the appropriateness of selected habitat parameters to describe the environment sufficiently as well as the data quality of these habitat parameters itself. Another source of uncertainty includes the available knowledge about habitat preferences of certain species in certain life-stages, which can significantly vary among different studies as well as the transformation of this knowledge into mathematical approaches (e.g. univariate vs. multivariate approaches).

Most often, studies of model performance are realized by a cell-by-cell comparison to evaluate differences either visually or mathematically. It is clear that a visual judgment is highly subjective given the availability of quantitative approaches, which are usually area balances or use an error matrix [2]. However, it is questionable whether a cell-by-cell comparison is the most appropriate method to analyze the performance of fish habitat simulation tools. On the one hand, the habitat model includes the already mentioned uncertainties and on the other hand, fish are mobile organisms and presumably use a kind of “buffer zone” around suitable habitats.

Figure 1 demonstrate the difficulty of cell-by-cell-comparisons to evaluate model performance for simulated spawning habitats of brown trout [3]. In the left part of Figure 1, we can indicate a general satisfying agreement between simulated spawning habitats and observed redds. However, if we have a closer look on the circles A and B in the right part of Figure 1, a cell-by-cell comparison would lead to no agreement at all because the locations of the mapped spawning redds do not exactly agree with the locations of a ‘high’ or ‘very high’ habitat suitability. Consequently, a poor model performance would be the result, although the fish in nature would use the adjacent area for spawning.

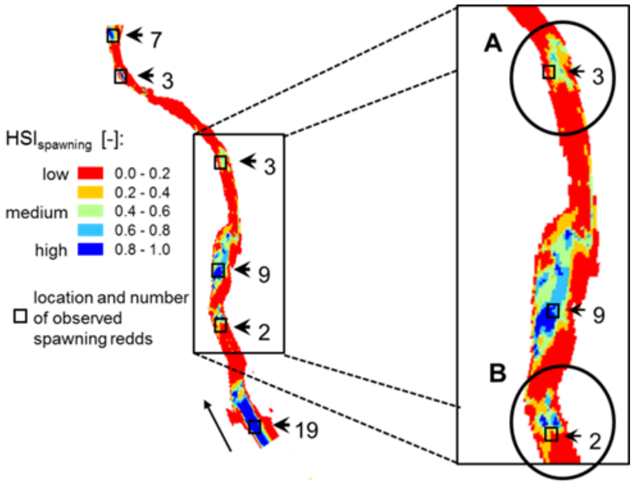


Figure 1. Comparison between simulated spawning habitats and mapped (observed) spawning redds [3].

In contrast to a cell-by-cell comparison, the fuzzy method for map comparisons allows not only to consider the values of neighboring cells (fuzziness of location) but also their category in terms of 'low', 'medium' or 'high' HSI-values (fuzziness of category). In this paper, we investigate both kinds of fuzziness regarding their influence on the comparison output. Therefore, we compare the map of simulated spawning habitat suitability of European grayling (*Thymallus thymallus*) with a map of observed spawning areas. Furthermore, we compare HSI-maps generated with different habitat modelling approaches to quantify the degree of uncertainty related to the model technique.

## 2 MATERIAL AND METHODS

For the map comparisons, we use the software 'Map Comparison Kit', which was developed by the Research Institute for Knowledge Systems, based at Maastricht, Netherlands (RIKS) [4].

The fuzziness of category expresses the uncertainty in whether the habitat suitability is 'low', 'medium' or 'high' and is assigned by a higher degree of membership for categories that are more similar to the original category [5]. That means, if the simulated and observed category are identical than a full membership degree of 1 will be assigned. For other categories, the membership can be between 0 and 1, according to the predefined level of similarity. Table 1 represents exemplary a crisp and a fuzzy representation for five categories of habitat suitability (VL=very low, L=low, M=medium, H=high, VH=very high). The fuzzy representation of Table 1 assigns a membership of 0.5 if the simulated category is an adjacent category of the original category.

Table 1. Crisp and fuzzy representation of five categories for the habitat suitability index (HSI)

| Crisp representation of five categories of HSI | | | | | | | Fuzzy representation of five categories of HSI | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | VL | L | M | H | VH | | | VL | L | M | H | VH |
| VL | 1 | 0 | 0 | 0 | 0 | | VL | 1 | 0.5 | 0 | 0 | 0 |
| L | 0 | 1 | 0 | 0 | 0 | | L | 0.5 | 1 | 0.5 | 0 | 0 |
| M | 0 | 0 | 1 | 0 | 0 | | M | 0 | 0.5 | 1 | 0.5 | 0 |
| H | 0 | 0 | 0 | 1 | 0 | | H | 0 | 0 | 0.5 | 1 | 0.5 |
| VH | 0 | 0 | 0 | 0 | 1 | | VH | 0 | 0 | 0 | 0.5 | 1 |

The fuzziness of location considers to a lesser content also cells that are in close vicinity of the target cell. The influence of the neighboring cells can be expressed by different distance decay function (e.g. defined by radius, halving distance of variance; Figure 2). Mathematically, the contribution of the neighboring cells are combined by determining the fuzzy union of the predefined neighboring cells multiplied by their respective distance-based membership. According to Hagen [5], the appropriateness of each function as well as the size of the considered neighborhood depend on the nature of uncertainty, imprecision of input data and the acceptable tolerance for spatial errors.

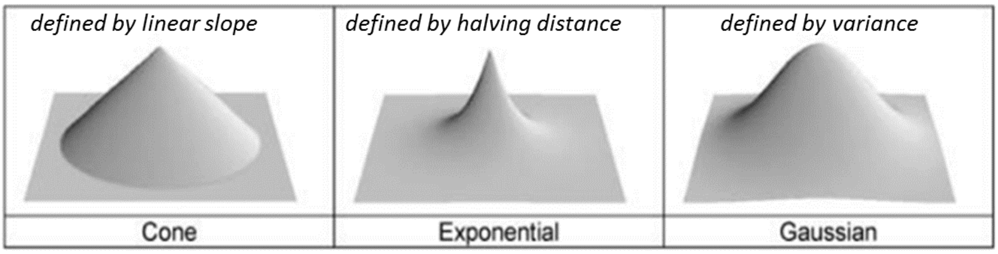


Figure 2. Exemplary distance decay functions implemented in the Map Comparison Kit [5].

## 3 RESULTS

In a first case study, the fuzziness of location is investigated to determine the influence of the distance decay functions on the comparison output. The model area includes a river length of approx. 1200 m with a raster size of 3.0 m. In the study-site, we applied the habitat model CASiMiR [6] to simulate the habitat suitability distribution for spawning graylings. Subsequently, we compared the resulting map of $HSI_{spawn}$ with areas where spawning is observed. Figure 3A represents the simulation results as well as the observed spawning areas while Figure 3B shows the output of map comparisons including a cell-by-cell comparison as well as the exponential decay function with three different halving distances (HD). In addition, the average similarity (AS) is given and the distance in meters of the origin cell to the cell ($d_{M0.5}$), where the membership becomes 0.5.

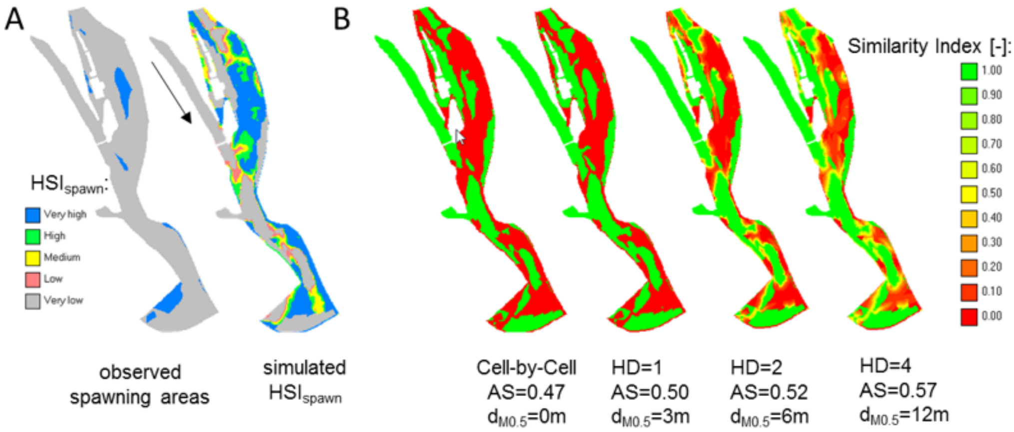


Figure 3. A: Simulated habitat suitability distribution and observed spawning areas. B: Output of map comparisons including cell-by-cell comparison as well as the fuzziness of location for three different halving distances of the exponential distance decay function.

Based on visual judgement, Figure 3 clearly indicates that the maps of observed spawning areas and simulated HSI do not have a high similarity. However the observed spawning areas are predominantly located in areas where $HSI_{spawn}$ is 'high' and 'very high', indicating a good agreement and most probably, the other areas of simulated high spawning habitat suitability are not used by grayling because of parameters that are not considered in the habitat model (e.g. biological interactions). A cell-by-cell comparison yields an AS of 0.47, which means that 47 % are equal and 53 % are unequal. Introducing the fuzziness in location by increasing halving distances of the exponential decay function the AS-values are slightly increasing to a value of 57 %, whereby the halving distance of 4 assigns a membership of 0.5 to the cells which have a distance of four cells to the origin cell. Given the raster size of 3.0 m, this corresponds to a real distance of 12.0 m. For this study site, no significant improvement related to the fuzzy map comparison can be achieved; however, the effect of fuzziness in location becomes clearly visible, especially because in Figure 3B, the results become more and more indistinct and blurred over the cell margins with increasing fuzziness.

In a second case study (length of 1600 m, raster size of 1.0 m), the fuzziness of category is investigated by comparing two HSI-maps, which are based on the same input data and habitat preferences but different combination methods (product vs. geometric mean) of parameter-specific suitability indices (SI). Therefore, we defined three matrices with different degrees of memberships regarding the adjacent categories, which represent a medium, high and an extreme level of fuzziness of category (Figure 4).

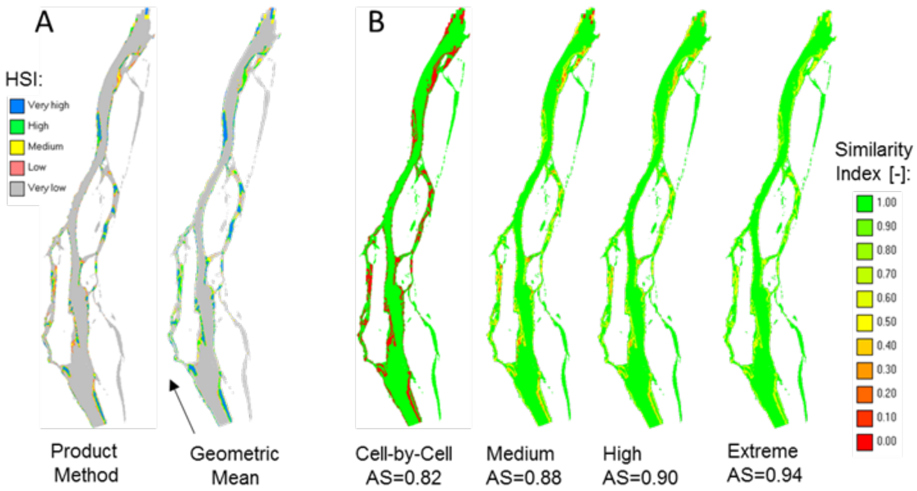


Figure 4. A: Simulated HSI-maps for two different combination methods of parameter-specific SI-values (product, geometric mean). B: Output of map comparisons including cell-by-cell comparison as well as the fuzziness of category for three different levels of fuzziness (medium, high, extreme).

In contrast to the first case study, the visual judgement of Figure 4A principally yields a good agreement between both maps, which is also represented by the cell-by-cell comparison (AS=0.82). However, the AS can be increased further by growing levels of fuzziness regarding the category (Figure 4B). The medium-level considers the adjacent category with a membership of 0.5 (see also Table 1) while the high-level assigns additionally a membership of 0.33 to categories, which deviate by two categories. Moreover, the extreme-level even assign a membership of 0.25 to categories with a deviation of three categories to the original category. However, it is questionable if it is correct when, e.g. the category ‘low’ is considered in a comparison, where the original cell is categorized by ‘very high’. To decide which level of fuzziness is appropriate to evaluate map comparisons best is one of the most challenging tasks when applying the fuzzy map comparison method.

## 4 CONCLUSION

The applied software provides a promising opportunity to investigate and to improve performance tests of habitat simulation tools. However, attention is required in defining the degree of fuzziness for both location and category because it represents a strong feature to increase similarities artificially, which might be beyond physical and biological means. Therefore, further investigations are highly recommended to gain additional knowledge on site-specific parameters and to gather data for future work on the evaluation of habitat model performances using the fuzzy comparison method.

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