Do habitat measurements in the vicinity of Atlantic salmon (*Salmo salar*) parr matter?

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Abstract

Atlantic salmon (*Salmo salar*) parr habitat characterization is usually performed by *in situ* measures of key environmental variables, taken at the exact fish location, or conversely, in large sampling sections, often ignoring variability in the immediate vicinity around individuals. These data may have a critical importance in development and validation of habitat preference models. The influences of seven increasing distances of measurements, the number of considered measures, and two depth of velocity measurement were tested in the calculations of HSI (Habitat Suitability Index) from a multiple-experts fuzzy model. The radius of 50 cm around the fish, an average measure of 6 measurements in the neighbouring environment and a velocity measured at 60% of the depth gave the highest HSI values. These results show some potential for the use of an intermediate study scale, between micro- and mesohabitat, and questions how the fish habitat conditions are currently measured.

Keywords: Fuzzy logic, Multiple-expert fuzzy modelling, Habitat model, Habitat measurement methods, Intermediate scale measurements, Habitat Suitability Index.

1 INTRODUCTION

In salmon habitat assessment, environmental measures characterizing this habitat are most often unique focal measurements taken at the exact location of the fish (e.g. Morantz et al., 1987; Guay et al., 2000), or a composite data from several measurements realized in large sampling section (e.g. Hedger et al., 2005). Atlantic salmon parr are territorial: they present agonistic behavior to defend a territory in order to maintain the best possible place to feed, shelter and grow (Gerking, 1953; Heland & Dumas, 1994; Höjesjö, Kaspersson, & Armstrong, 2015). The size of this territory varies according to factors such as fish size, age, habitat heterogeneity and food availability (Grant, Steingrimsson, Keeley, & Cunjak, 1998; Keeley & Grant, 1995; Lindeman, Grant, & Desjardins, 2015), centred on a "home rock" around which the parr moves (Guay et al., 2000). This behavior could interfere with the results of habitat models and characterization analyses, since the data (i.e. the measurements of environmental variables) collected at the focal location or in the whole section may not reflect the actual habitat being used by fish. In addition, depending on the methodology and the fishing gears used to sample fish, *in situ* measurements of habitat variables associated with fish presence can be done at different scales (Heggenes, 1990; Wildman & Neumann, 2003). For example, sampling techniques such as direct viewing by snorkeling (Flebbe & Dolloff, 1995) or detection by electronic tags can provide information on the exact location of the fish and allow the researcher to associate habitat variable measurements at the precise location of the fish. Alternatively, seining or electrofishing (Foldvik, Einum, & Finstad, 2016; Mäki-Petäys, Erkinaro, Niemelä, Huusko, & Muotka, 2004) do not allow this precision and the subsequent measurements of environmental conditions are related to a larger area of capture. Finally, the protocols used to describe salmon habitat are different: the water velocity can be measured at or near the bottom (e.g. Heggenes et al., 1995) or at a variable depths according to the total depth of the water column (e.g. Morantz et al., 1987). In addition, the habitat can be characterized by a single measurement per fish (e.g. Morantz et al., 1987) or up to 15 measurements in the entire reach (e.g. Hedger et al., 2005).

Yet, these uncertainties may have a critical importance in habitat modeling. Indeed, before being made available for managers, models have to be validated, i.e. they have to be tested with data not used for model development and calibration. During the validation process, they have to reach the required performance standards (Rykiel, 1996). In the specific case of habitat models, one validation process consists in confronting the modeled predictions of habitat quantity and suitability indices against field observations of presence or absence of fish (Fukuda & Hiramatsu, 2008; Mocq, St-Hilaire, & Cunjak, 2013; Mouton et al., 2008). Uncertainties in environmental data and approximation in habitat characterization may induce errors, distort the validation, and even affect the robustness of the model when the measures are used as input data.

We questioned the influence of these uncertainties in measured data in habitat models, and we investigated the impact of the scale at which measurements are taken by hypothesizing that this scale can affect the model results or the validation efficiency. We tested the hypothesis that focal measurements (i.e. at the exact location of the fish) may not be the best representation of habitat variables that determine (in part) fish presence, by using as a tool a previously developed fuzzy model for Atlantic salmon (*Salmo salar*) parr habitat (Mocq et al., 2013). Fuzzy logic is regularly used to model efficiently fish habitat (Muñoz-Mas et al., 2016) and this approach allows determining a scale that provides a better habitat description according to the expert system. In addition, the influences of the velocity in such a fuzzy system were assessed when it has been measured at the bottom or at 60% of total depth, which is used as an estimate of average velocity over the entire water column for shallow rivers. Finally, focusing on a study scale between micro- and mesohabitat, we varied the number of measurements in a close neighborhood around the individuals used to evaluate salmon habitat quality to highlight their impact in the model and determine which numbers provide the best results, with the objective of improving the usual method of sampling.

2 MATERIAL AND METHOD

2.1 Fuzzy model

To build the fuzzy logic Atlantic salmon parr rearing habitat model (Mocq et al., 2013), three of the most important variables defining salmon distribution and abundance, i.e. depth, velocity and mean substrate diameter (Armstrong, Kemp, Kennedy, Ladle, & Milner, 2003; Bardonnet & Baglinière, 2000; Heggenes, 1990) were chosen as input variables, and Habitat Suitability Index (HSI) as the output variable. Each variable domain was split into three categories defined by combinations of linear membership functions, which constitute the fuzzy sets. Then HSI consequences of each possible combination of every category of the three variables were determined with "If…Then…" fuzzy rules, i.e. 27 possible rules. A comprehensive presentation of the fuzzy method and model building is provided by Mocq et al. (2013).

Since the experts' geographic range of knowledge showed influences on the fuzzy model results (Mocq, St-Hilaire, & Cunjak, 2015), only those from eastern Canada were selected. Twenty experts defined individual fuzzy sets and fuzzy rules, which were integrated and treated with the fuzzy package FuzzyToolkitUoN in R (R Development Core Team, 2016). The Mamdani inference method was used (Mamdani, 1977; Shepard, 2005) to process data from fuzzy input sets to the fuzzy output set. The defuzzyfication (i.e. the transformation from the final fuzzy sets to a crisp number) was done by the commonly used method of centre of gravity (Jorde, Schneider, Peter, & Zoellner, 2001), providing an HSI value between 0 (representing an unsuitable habitat) and 1 (representing the most suitable habitat) for each expert.

2.2 Sampling campaign

2.2.1 Study sites

Environmental measurements were taken in three Canadian Atlantic salmon rivers (Fig.1): the Sainte-Marguerite River (Québec), the Little Southwest Miramichi River and its tributary, Catamaran Brook (New-Brunswick).

Catamaran Brook flows for 20.5 km for a drainage basin of 50 km² (Cunjak, Caissie, & El-Jabi, 1990) with a mean annual discharge of 0.6 $m^3 s^{-1}$ (Benyahya, Daigle, Caissie, Beveridge, & St-Hilaire, 2009). The Little Southwest Miramichi (Cunjak et al., 1990; Johnston, 1997) drains a 1340 km² basin with a mean annual discharge of 32.2 $m^3 s^{-1}$ (Benyahya et al., 2009). These streams are characterized as relatively pristine (Cunjak et al., 1993). Finally, the Sainte-Marguerite River is a 100 km-long river (Guay et al., 2000), with a catchment of 2100 km² and a mean annual discharge of 30.93 $m^3 s^{-1}$ (Benyahya et al., 2009). Wild Atlantic salmon populations are present in all three rivers.

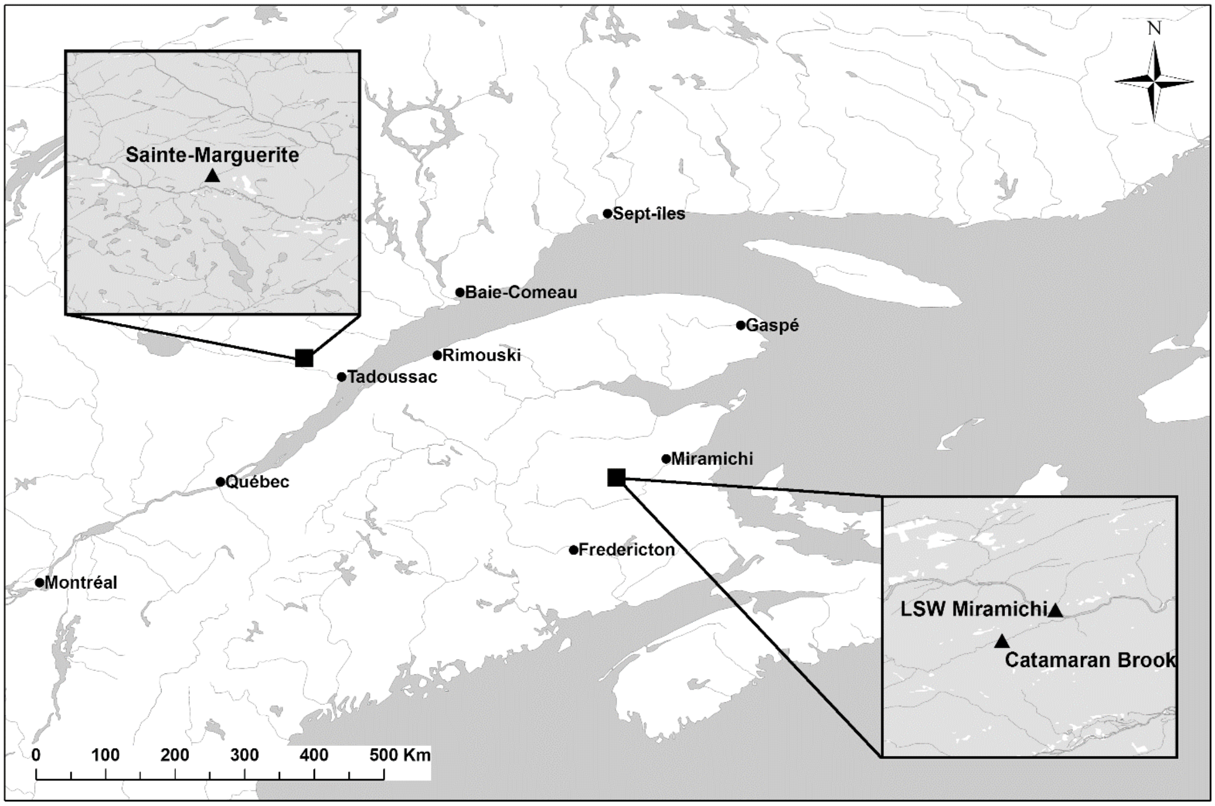

Figure 1: Localization map of the Sainte-Marguerite River (Québec), Little Southwest Miramichi River and its tributary, Catamaran Brook (New-Brunswick).

2.2.1 Sampling method

The sampling campaign took place in July 2012, at four sites in Catamaran Brook and two sites in Little Southwest Miramichi. Two sites were sampled in the Sainte-Marguerite River, in June and September of 2012. The considered reaches were sections of length 5 times larger than the width when the width was lower than 8 m. If the width was larger than 8m, a 6x25 m subsection along the banks was sampled.

The protocol was divided into three steps. First, salmon parr (1 and 2+ year-old) location was assessed by a snorkeling diver moving upstream in zigzag patterns, reaching the fish location from behind to avoid flight. Upon recognition, the diver waited motionless for a minimum of one minute to ensure that the fish position was not influenced by the observer. A painted stone was dropped onto the bottom as a position marker.

Environmental measurements were done for the whole reach, including in the vicinity of the spotted fish. The whole reach were assessed by measurements along transects, every 2 m, with nine measurements per transect, each measure constituting a coordinated node of a grid, dividing the section into cells. Depth was measured with a ruler, and velocity with an electronic flowmeter Flo-Mate model 2000 (Marsh-McBirney, inc.) during at least 2 min, at the bottom (i.e. the position of the parr on its home-rock) and at 60% of the depth in the water column (i.e. classical depth of velocity measurements). Substrate composition was assessed by evaluating the proportion of the different classes of grain size according to the modified Wenthworth scale (Schoeneberger, Wysocki, Benham, Soil Survey Staff, & Natural Resources Conservation Service, 2012) and a mean substrate size was calculated by weighting the diameter of each class by the evaluated proportion observed at the site.

Microhabitat measures were made at the precise position and in the vicinity of the located fish. Velocity and depth were measured, first at the exact location of the fish, then at distance of 10, 25 and 50 cm from it, representing respectively a circular area of 0.04, 0.2 and 0.79 m^2, for a total of 5 points around a circle for each radius (3 upstream, 2 downstream). The substrate was assessed by evaluating the proportion of the different classes of grain size, at the exact position of the fish first, then in a square of 10, 25 and 50 cm on each side always centered on the fish.

2.3 Data process and statistical analysis

First, for each measurement point, a mean Habitat Suitability Index (HSI) value was calculated through the fuzzy inference system of each expert, providing a spatial distribution of HSI. One HSI value was calculated for velocity measured at 60% of the total depth (V_{60}) and for velocity measured at the bottom (V_{bot}). These two sets of mean HSI values were compared with a Wilcoxon matched-pairs signed-ranks test. The variation between the two HSI values at a same point were calculated for each expert and then averaged to visualize the consequence on the differences of velocity measures on a map. The same process was repeated with environmental measures at the exact location of fish. Since the sampled sites presented low parr density, it was considered that the choice of location by the parr was made regarding habitat quality only (i.e. likely no density-dependence effect). The values of HSI were compared with a Wilcoxon matched-pairs test with correction for multiplicity. Our hypothesis was that a fish will choose a location not only because of the conditions at a focal location, but because of the conditions experienced in a short-range neighborhood around the focal location. Consequently, considering the neighboring environmental conditions of the fish position should improve the model results by better describing habitat at a fish location, highlighted by an increase of the mean HSI and/or a decrease of the variability, until a limit where the HSI mean should decrease and/or the variability should increase again.

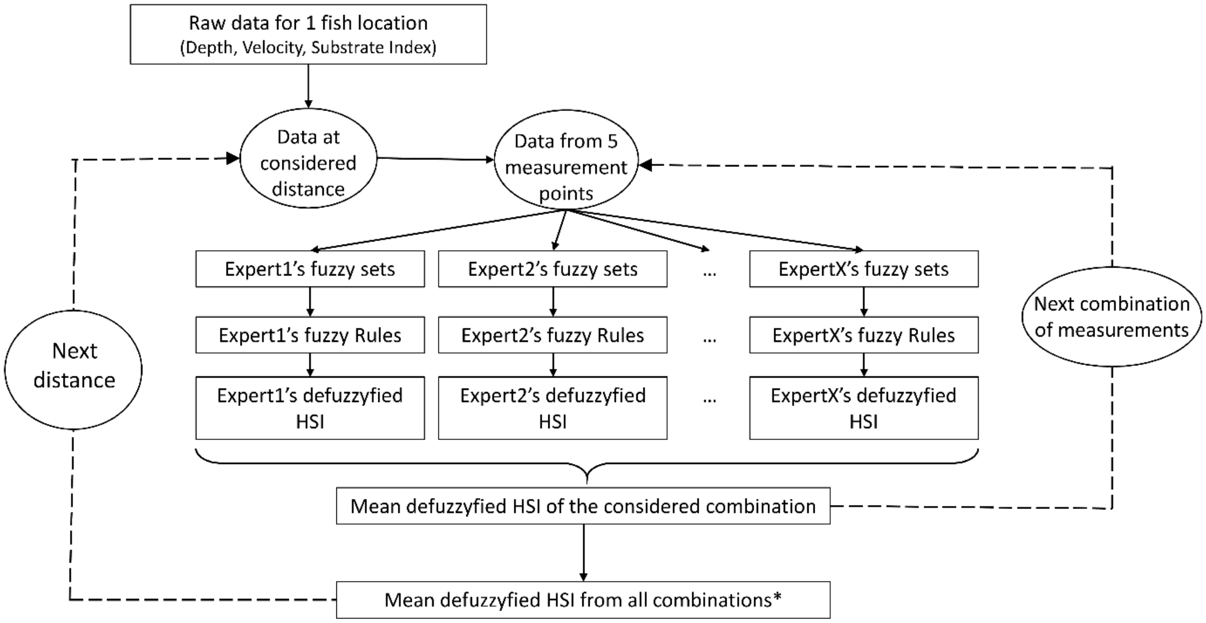

Figure 2: conceptual scheme of our study of impacts of increasing measurements distances on multiple-expert fuzzy models. (* except d310, half of combinations were performed)

The habitat quality was also assessed within an increasing area around the fish. The unique measure realized at the exact location of the fish provided the focal data, using a mean substrate size according to the proportion of different size classes, the velocity measured at 60% of the depth and the depth measured using a ruler with a 1cm precision. The integration of measures realized at three distances (i.e. 10, 25 and 50 cm) around the fish provided the data for the areas of 0.04, 0.2 and 0.79 m². Finally, 4, 11 and 30 m², represented by circles around the fish with respective approximate radii of 113, 190 and 310 cm, were assessed by integrating the measured data from the grid when they were located in the appropriate area. Then, for each distance and for each fish, mean HSI was calculated from the fuzzy sets and rules developed by each expert, for all of the combination of 5 measurements encompassed in the considered area (Fig. 2). The mean depth, velocity and substrate size of all considered measurements were used as input data in the fuzzy system. For the distance of 310 cm, half of the possible combinations of a set of 5 out of 16 measurements, randomly drawn, were used because of computational limitations, but representing a final 50 344 combinations, and 1,066,880 HSI values. The accuracy of each model was estimated with the kappa statistics (see for example McHugh, 2012), with a threshold of HSI at 0.5 beyond which the habitat is considered suitable. Since presenting the HSI values did not allow to visualize the variation of the HSI value for a same fish, the variation of value from the HSI value at the focal point, and the mean HSI value for the considered distance were calculated for each fish. The HSI values according to the distance, and then the variation with the focal HSI values were compared with a Friedman two-way analysis of variance, the non-parametric test corresponding to a repeat-measure ANOVA, with a *post hoc* analysis i.e. a Wilcoxon matched-pairs test with correction for multiplicity.

Finally, to evaluate the optimal number of environmental measurements, all measurements included in a radius of 25 cm were considered for each parr (i.e. 11 measures for most of them). All possible combinations of measures, including 1 to 11 measures, were averaged and a HSI value was calculated for each expert fuzzy system and each fish. The accuracy of each model was also estimated with the kappa statistics with a threshold of HSI at 0.5. The variation with the HSI at the focal position of the fish were calculated for each expert, and then averaged for each fish. The HSI variations were compared with a Friedman two-way analysis of variance with a *post hoc* analysis (Wilcoxon matched-pairs test with correction for multiplicity). The optimal number of measurements to characterize the salmon habitat was seen as the category providing the highest HSI associated with fish presence and/or the smallest variability.

3 RESULTS

On the 10 considered sites, a total of 1366 points were sampled, showing an overall HSI mean of 0.42 +/- 0.12 (range from 0.17 to 0.7) for the velocity measured at 60% of the depth, and an overall HSI mean of 0.48 +/-0.15 (range from 0.17 to 0.71) when velocity is measured at the bottom (Tab. 1, Fig.3).

Table 1: Mean, minimum and maximum of Habitat Suitability Index (HSI) values from multiple-experts fuzzy system, with velocity measured at 60% of the depth (V_{60}) and at the bottom (V_{bottom}), and the calculated variation at a same point, considering the entire reach of the station.

River	Site	Year	HSI V_{60}			HSI V_{bottom}			Variation		
			Mean	Min	Max	Mean	Min	Max	Mean	Min	Max
Catamaran	Div2	2012	0.35	0.17	0.59	0.37	0.17	0.66	-0.03	-0.27	0.05
Catamaran	Lor	2012	0.35	0.17	0.64	0.36	0.17	0.63	-0.01	-0.12	0.15
Catamaran	Moc	2012	0.38	0.18	0.66	0.42	0.18	0.67	-0.04	-0.25	0.16
Catamaran	Tom	2012	0.33	0.17	0.59	0.34	0.17	0.57	-0.01	-0.19	0.21
St-Marguerite	Smp	2012-06	0.51	0.29	0.69	0.59	0.31	0.71	-0.08	-0.29	0.15
St-Marguerite	Smp	2012-09	0.51	0.29	0.67	0.58	0.27	0.71	-0.07	-0.30	0.23
St-Marguerite	Smt	2012-06	0.39	0.19	0.70	0.48	0.19	0.68	-0.09	-0.25	0.13
St-Marguerite	Smt	2012-09	0.38	0.21	0.66	0.43	0.21	0.68	-0.05	-0.28	0.22
Miramichi	Alx	2012	0.53	0.30	0.69	0.65	0.30	0.71	-0.12	-0.31	0.03
Miramichi	Spm	2012	0.49	0.28	0.67	0.58	0.31	0.70	-0.09	-0.30	0.21

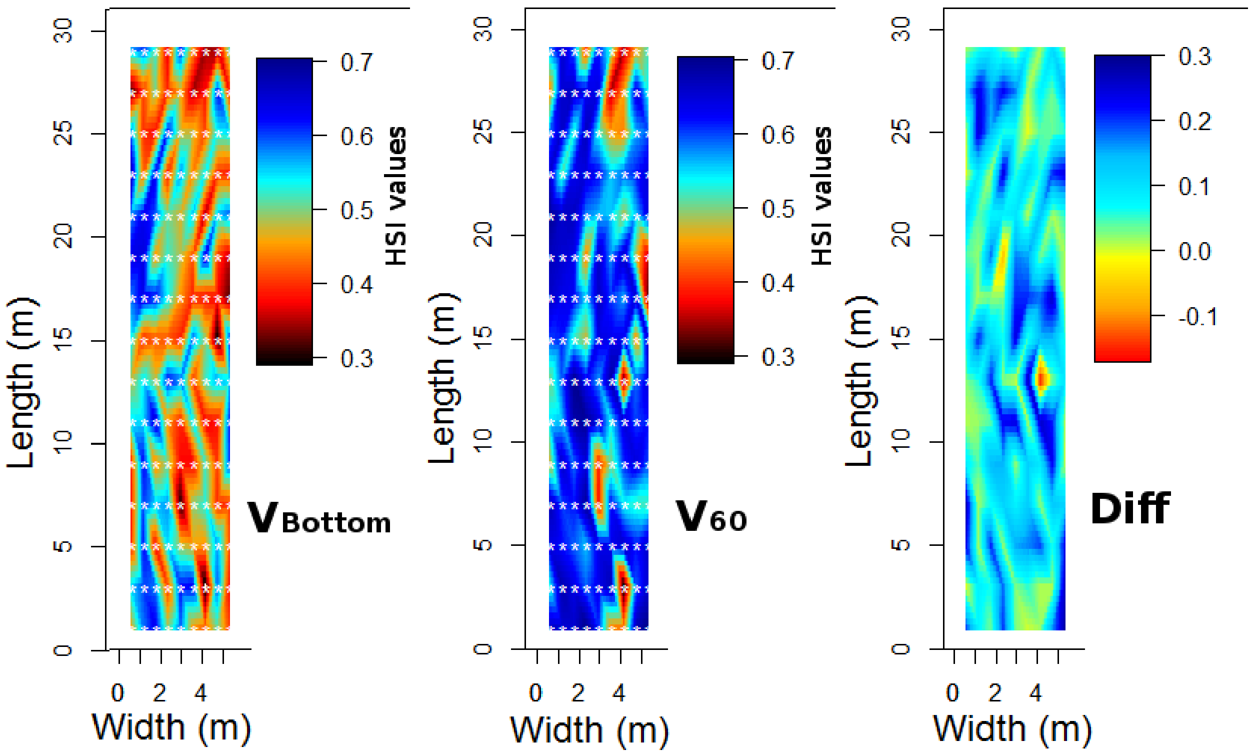

Figure 3: Map of HSI value distribution, after spline interpolation from measuring points (white stars), for velocity measured at the bottom (left panel) or at 60% of the depth in the water column (middle panel), and the difference between them (right panel), in the Miramichi River (Spm site).

The two sets of HSI were significantly different (Wilcoxon matched-pairs signed-ranks test with correction for multiplicity, *p-value* < 2.2e-16). The variations of HSI values were ranged from -0.30 to +0.23 (mean= -0.06 +/-0.09).

In the three rivers, 93 fish were observed. HSI were calculated at the focal location of the fish, using the velocity measured at the bottom, then at 60% of depth (Fig.4). The resulting HSI values were significantly higher (Wilcoxon matched-pairs signed-ranks test, *p-value* <0.001), when the velocity was measured at 60% of the depth (mean= 0.47 +/- 0.11) than at the bottom (mean= 0.42 +/- 0.1).

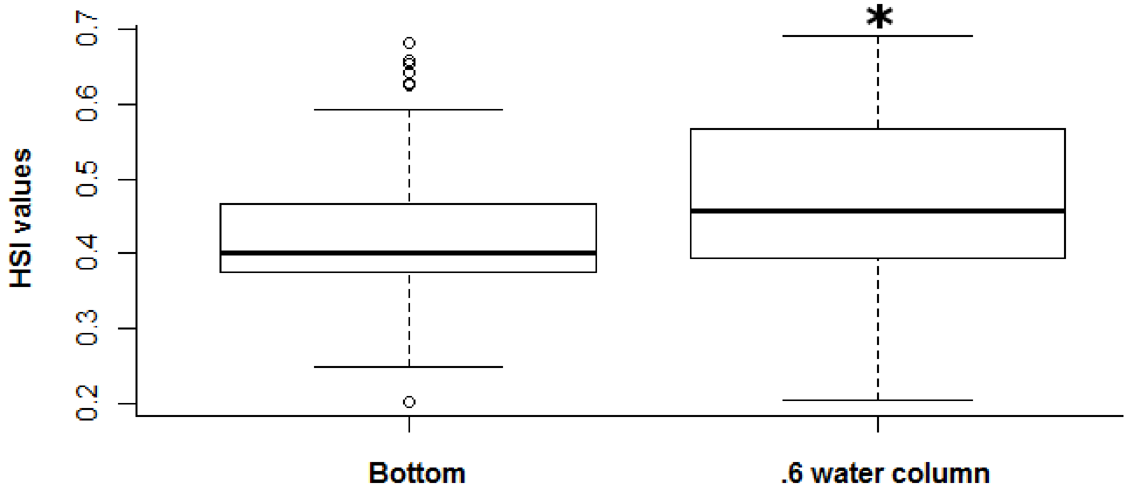

Figure 4: Distribution of HSI values with velocity measured at the bottom (left panel) or at 60% of the depth (right panel) at the exact fish location. Asterisks (*) indicate significant difference (Wilcoxon matched-pairs signed-ranks test, p-value <0.001).

Regarding the influence of increasing area of measures around the fish, 7 distances were tested: 0 (focal measure), 10, 25, 50, 113, 190 and 310 cm around the parr (Tab.2, Fig.5). The focal measures provided the lowest mean HSI and the largest variability (mean= 0.47 +/- 0.11). The HSI increased slowly until d50, and decreased afterward, while the variability decreased progressively. Regarding the variation of HSI by fish, the highest positive difference with the focal HSI value occurred at d50 (mean= $+3.92.10^{-2}$ +/- $6.35.10^{-2}$) and the highest kappa value is reached at the same distance (κ = 0.66 at d50; Tab.2). Friedman's test was significant for the HSI values and for the variations with the focal value (both *p-value* <0.01). The post hoc analysis found only a significant difference between d0 and all other distance (all *p-value* <0.01) but no other significant difference was found afterwards. The same analysis on the variation with the focal values highlighted significant differences between every distances (all *p-value* <0.05) but d113 and d190 (*p-value*= 0.28).

Table 2: mean values and standard deviation (SD) for HSI values, and for the variation from the focal HSI values for each parr, provided by a multiple-expert fuzzy system on every possible combination of 5 measures encompassed in seven increasing distances (0, 10, 25, 50, 113, 190 and 310 cm) around the considered parr.

Distance	**Mean HSI**	**SD HSI**	**Mean variation with focal values**	**SD variation with focal values**
d0	0.475	0.112	0	0
d10	0.499	0.106	0.024	0.058
d25	0.506	0.105	0.031	0.062
d50	0.514	0.099	0.039	0.064
d113	0.514	0.095	0.039	0.07
d190	0.514	0.096	0.039	0.08
d310	0.512	0.096	0.037	0.082

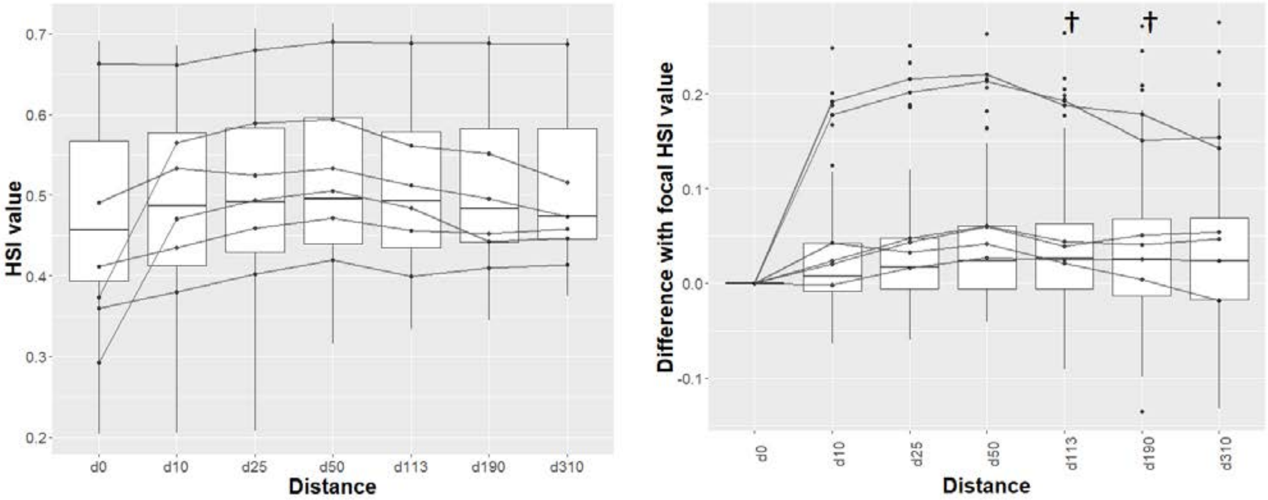

Figure 5: Distribution of HSI values calculated with a multiple-experts fuzzy model (left panel) and the variation of this HSI values with the focal HSI value for each parr (right panel), according to the distance inside which measures were considered as input data for the model; the HSI values (lines) of a selection of 6 (out of 93) different fish are provided. Asterisks (*) indicate a significant difference with the other categories. Daggers (†) indicate non-significant difference between the two categories, all other differences are significant (both post hoc Wilcoxon matched-pairs signed-ranks test).

For the number of measurements to include in the models, the HSI provided by the different categories of included measures were averaged for each fish and for each expert. All HSI calculated showed an increase compared with the value calculated from the focal position 0*. The maximum is reached with 11 measures but the Cohen's kappa was the highest with 6 measures (κ = 0.66), providing 94% of the maximum improvement of HSI values (Tab. 3, Fig. 6). The variations of HSI values between categories were significantly different from each other (Friedman rank sum test, *p-value* < 0.01). Only the categories of 9, 10 and 11 measures showed significant differences with each other (Wilcoxon matched-pairs signed-ranks test, *p-value* <0.01 for these three categories, *p-value* >=0.42 for the other combinations).

Table 3: Means and standard deviations of differences in values of calculated HIS, between focal environmental measures of Salmon parr location (0*) and averaged HSI from every combination of measures, including from 1 to 11 measures.

Number of included measures	0*	1	2	3	4	5	6	7	8	9	10	11
Mean	0	0.023	0.03	0.032	0.037	0.034	0.033	0.033	0.033	0.031	0.032	0.034
SD	0	0.07	0.073	0.072	0.07	0.072	0.073	0.073	0.073	0.069	0.068	0.066

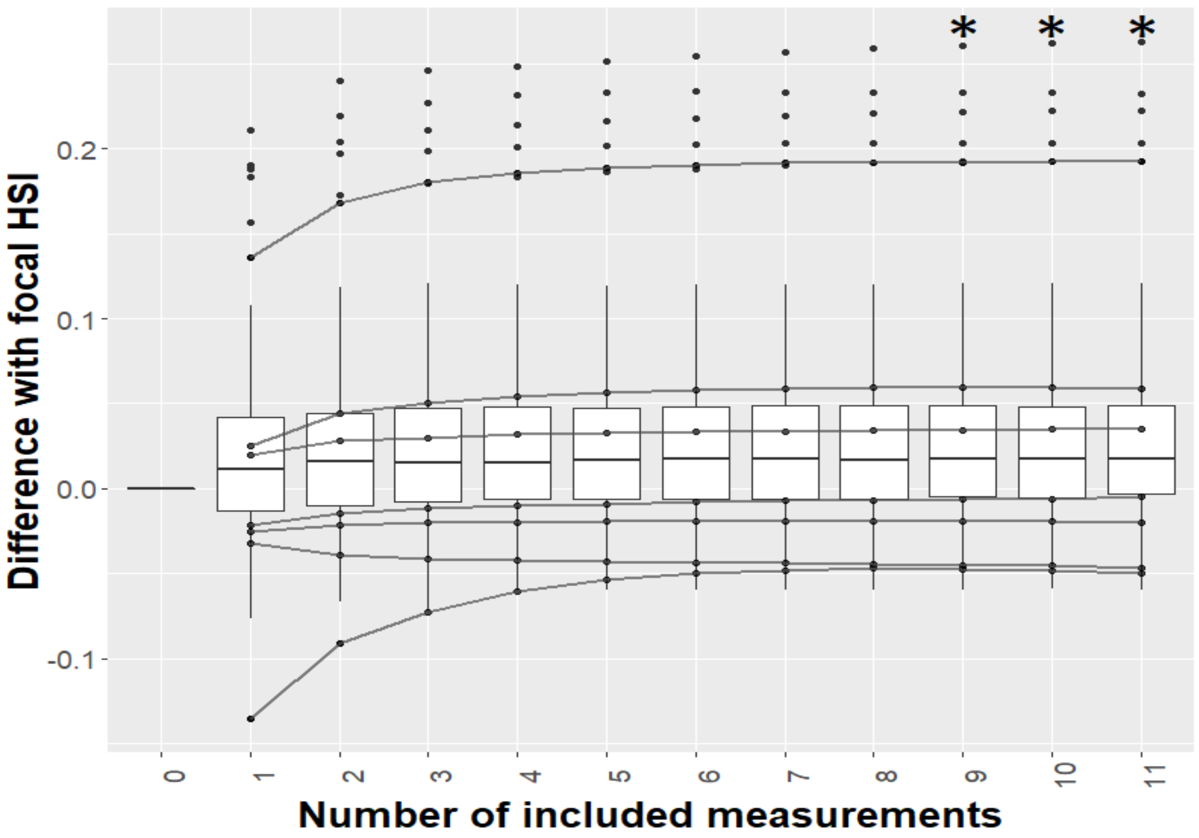

Figure 6: Differences in values of calculated HSI, between focal environmental measures of salmon parr location (0*) and averaged HSI from every combination of measures, including 1 to 11 measures; the differences in HSI values (lines) of a selection of 7 (out of 93) different fish are provided. Asterisks (*) indicate categories with no significant differences from each other (post hoc Wilcoxon matched-pairs signed-ranks test).

4 DISCUSSION

Highlighting and calculating the radial distance from the fish defining a circle in which measurements could be taken to describe accurately the physical habitat is one possible way to improve habitat characterization and subsequent habitat modeling. Seven different distances were tested for each presence. The null distance, i.e. the focal measure taken at the exact location of the fish, gave globally the lowest HSI values and the highest variability. This is potentially explained by the fact that only one measurement of each habitat variable may introduce an important bias: assuming the fact that the parr may chose a suboptimal focal location with good vicinity, if the exact location did not present good conditions for the fish, the error is not attenuated by other measurements. Consequently, despite the geographic proximity of their measures, the multiple-measures 10 cm-distance and the unique focal measure showed significant differences in their calculated HSI, the 10 cm-distance providing a slightly better HSI than focal measurements. Then, increasing the distance improved the model performance: for a same fish, the HSI calculated by the fuzzy system reached a peak at a distance of 50 cm, which corresponded with an area of 0.79 m^2, consistent with previous assessment of parr territory sizes (Keeley & Grant, 1995; Lindeman et al., 2015). Beyond this distance, the calculated HSI values tend to remain constant, the loss of variability in HSI values being the sign of a homogenization of the measures at a large scale instead of a model improvement, as proved by the large variability of HSI values at large distance.

Our protocol gave the opportunity to explore the influence of the location of the velocity measurements in an expert fuzzy system. As expected, the data highlighted the fact that the velocities at the bottom were slower than at 60%, because of frictions with the substrate, and sometimes even counter-currents were observed. Near the bottom, parr can save some energy while having access to the drifting food, the habitat quality should be consequently higher there than further up in the water column. The HSI values were slightly lower when the velocities were measured at the bottom than at 60% of total depth. In addition, with the measurements taken at the fish location, our result showed an improvement of the model with higher HSI when the velocity is measured at 60% of the depth. Thus, having better calculated HSI at 60% of the depth instead of at the bottom for a benthic fish is unexpected and raises some questions. It is unclear if the experts unconsciously referred to the velocity in the middle of the water column when they built their memberships functions and rules, or if they consider the 60%-depth velocity is more representative of the velocity associated with the drifting food.

It is usual, when characterizing salmon habitat, to take one measure of velocity and depth, and an assessment of the substrate at the exact location of the fish. Our results showed that the values of HSI provided by one measure at the exact location of the fish were generally lower than several measures realized in its direct environment. The average highest HSI value was obtained when all the measurements of each habitat variable, at randomly selected locations (within a radius of 25 cm), were aggregated, but 6 measurements provided the best model. More than 6 measurements improved marginally the model outputs and the extra time and efforts required is not warranted in this case. However, a fixed number of measurements to describe the environmental conditions cannot be applicable to every circumstance and should be adapted to local habitat complexity. In addition, our results exhibit a snapshot of habitat suitability, for a short time period and the integration of flow dynamics would be important to model adequately the salmon habitat (Boavida, Harby, Clarke, & Heggenes, 2017). Nevertheless, our study shows a clear difference in the models outputs, highlighting the needs to take into consideration multiple measurements in a close range around the individuals.

Our results suggest that the best description of the parr rearing habitat during summer diurnal period to be used in the fuzzy logic model described by Mocq et al. (2013) is reached by taking into consideration the neighboring conditions, i.e. measuring variables at 50 cm from the fish and adding them to calculate a mean value. In addition, this multiple-points sampling protocol could improve the models. Moreover, the fuzzy model is based on expert knowledge and it is possible that they defined the fuzzy sets and rules using characteristics of parr habitat that include all or a part of its territory instead of only its home-rock, as our results indicate. Our hypothesis about the model efficiency was that a high calculated HSI for a presence indicated that habitat description used in the calculations was accurate and consequently, led to a more efficient model. However, parr were frequently present in habitats with calculated HSI under 0.5, while the reaches presented large bands of good quality. Field observations indicate that, in the three sampled rivers, densities extended from 0.5 to 13.5 ind/100 m², were too low to force some parr to use poor-quality habitat. Therefore, density dependence-related biases are not the likely cause of presence of fish in relatively poor habitat. This observation can more likely be explained by expert's unsure or ill-translated knowledge in the fuzzy sets and rules. These biases are found in the fuzzy sets and rules definition: the unsure or ill-defined knowledge could be represented in fuzzy logic by an important overlap between successive categories or by membership functions limits irrelevant with ecological reality. Indeed, accurate codification of the expert knowledge is an important obstacle. The difficulties could come from the expert (unwanted forgetting of information, difficulty of expression or abstraction, fear of personal knowledge disclosure and use; Chevrie and Guély, 1998, Drescher et al., 2013), or from the method (poor ergonomics of the worksheet used to collect data, lack of precision in words or concepts description; Knol et al., 2010). In addition, the growth of the parr evolves quickly in few months, especially for the youngest parr, modifying their habitat preferences and complicating the definition of the related fuzzy sets. Finally, another explanation could be related with the physical factors that were not included in the model: indeed, the habitat selection by parr is under the influences of multiple factors (Armstrong et al., 2003), generally of lesser importance than the three selected variables but sufficiently important to modify substantially the habitat selection of some of the fish.

This study is linked to the problematic study of scale, i.e. the spatial and temporal dimension of a process or an entity (Lewis et al., 1996). Considering the Atlantic salmon (*Salmo salar*) physical habitat, some studies work at the microhabitat scale, measuring environmental physical variables in the vicinity of the fish, on the order of the cm² (Armstrong et al., 2003; Heggenes et al., 1995; Heggenes, Bagliniere, & Cunjak, 1999). By contrast, other studies are concerned with the mesohabitat scale, from m² to some tens of m², equivalent to Channel Morphological Units (CMU, e.g. riffle, glide, pool; Folt et al., 1998). For the habitat characterization, the mesohabitat is too large to precisely describe salmon needs and preferences, while the microhabitat neglects environmental elements which could influence the selection and the occupation of the habitat by the fish (Shirvell, 1994). An intermediate scale, considering the exact location of the fish and its close environment as potential used habitat, could be useful to describe more precisely the habitat and improve the model predictions. Moreover, lots of scientific studies and protocols about fish habitat are based, for their field data, on the measures of environmental variables at the exact location of the fish: our results suggest a change in this protocol may be needed, in order to improve the habitat description.

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