FUNCTIONAL HABITAT CHRONOLOGY ANALYSIS: INTEGRATING LIFE STAGES HABITAT REQUIREMENTS AND HABITAT CONNECTIVITY FOR ESTIMATING RIVER PRODUCTION POTENTIAL

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The functional habitat chronology approach we present is based on the idea that the value of a complementary habitat decreases to zero if it is too far to be reached by an individual or if access is precluded by an impassable obstacle. Applying this principle chronologically throughout the life history of a fish therefore only keeps a chain of successive suitable habitat patches that are connected to each other based on the mobility of the fish at the time that the movement is required. This approach is intended to provide improved estimates of production units in a river. In this presentation, the usefulness of the approach is illustrated using an example from Atlantic salmon (*Salmo salar*) rivers of the province of Québec (Canada).

1 INTRODUCTION

In order to complete their life cycle, fish need to access an orderly sequence of different habitat types whose characteristics fulfil the requirements associated to particular life functions or life stages. Heterogeneity of physical habitat is therefore essential to create a mosaic of complementary habitats. Connectivity between these habitats is also required for a fish to freely move between them in the appropriate chronological order. The functional habitat chronology approach we present is based on the idea that the value of a complementary habitat decreases with distance and becomes zero if it is too far to be reached by an individual or if access is precluded by an impassable obstacle. Applying this principle chronologically throughout the life history of a fish produces a chain of successive suitable habitat patches connected to each other based on the mobility of the fish at the time the movement is required.

In this study, we suggest a spatially explicit approach to be used by stream managers and practitioners to integrate habitat chronology for the estimation of the carrying capacity of rivers. The usefulness of the approach is illustrated using an example from Atlantic salmon (*Salmo salar*) rivers of the province of Québec (Canada). First, we quantify and map the contrasted accessibility of functional habitats. Second, we test the hypothesis that juvenile (fry and older) densities are positively correlated to the modelled habitat accessibility.

2 MATERIALS AND METHODS

2.1 Study site and field data

This study was carried out on the Matapédia river system, in Gaspésie, Québec, Canada. The study area consist of a 67 km segment of the Matapédia river, and two tributaries, Assémetquagan and Milnikek, which extend on both West and East sides of the main river respectively. Juvenile Atlantic salmon densities (0+, 1+, 2+) were sampled repeatedly by Fisheries and Oceans Canada at eight locations once a year during the summer from 2001 to 2012 in 100m^2 parcels.

Substrate and reach types (rapids, riffles, channel, meanders, pools) were visually identified and mapped using a GPS at the scale of morphohydrological units. This classification and associated juvenile salmon preference curves are used by the Québec Wildlife Services as inputs in a mesohabitat quality model to estimate salmon rivers productive areas [1].

2.2 Defining functional habitats

Four types of Atlantic salmon functional habitats were defined: 1) Pool habitats, where adults gather before spawning, were directly extracted from the field database. 2) Spawning habitats, 3) fry habitats and 4) parr habitats were defined as areas where suitability values, ranging from 0 to 1, were higher than 0.7. Used suitability indices were obtained from the literature for parr [1] and from expert opinion for spawning and fry.

2.3 Functional habitat connectivity modeling

Connectivity between functional habitats was modeled in terms of probability of access with a least-cost path approach using the custom freeware Anaqualand 2.0. For each particular functional habitat, the workflow consists in 1) creating “instream distance raster maps” for both upstream and downstream directions, in which each pixel expresses the shortest instream distance to the closest target functional habitat. These distances maps are then converted to accessibility maps using an inverse probability function

$$p = e^{-Dist/\alpha} \qquad (1)$$

where p expresses habitat accessibility ranging from 0 to 1, *Dist* the instream distance and α a mobility coefficient. For every functional habitat, α varied with directionality up/downstream and with associated life stage mobility based on values reported in the literature as follows: 1) Pools -> spawning (adult, up: α=1000m, down = α=1000m, [2], spawning -> fry (fry, up: 50 m, down= 300m [3], fry -> parr (parr, up: 1000m, down: 1000m (unpublished data). To obtain connectivity between functional habitats, probability of access were sampled in ‘previous functional habitat patches’. For instance, probability to access spawning habitats from pools was obtained by crossing spawning habitat accessibility maps to binary pool habitat maps. The resulting “probability to access spawning habitats from pool” map was reclassified as a binary map, where pool pixels presenting values higher than a threshold of 0.7 were considered “connected to spawning”. This process was repeated in a hierarchical manner to examine habitat connectivity through life stage. The resulting maps were then used to estimate areas (m^2) of connected habitat.

Table 1. Binary habitat connectivity raster maps produced for the Matapedia river system.

Habitat connectivity levels	Binary habitat maps
Spawning habitats	
S all	Total spawning habitats
S-Po	Spawning connected to pool habitats
Fry habitats	
F all	Total fry habitats
F-S	Fry connected to spawning habitats
F-S-Po	Fry connected to spawning connected to pool habitats
Parr habitats	
Parr all	Total Parr habitats
Pa-F	Parr connected to fry habitats
Pa-F-S	Parr connected to fry connected to spawning habitats
Pa-F-S-Po	Parr connected to fry connected to spawning connected to pools

2.4 Connectivity vs juvenile density

To examine the relationship between connectivity (accessibility) and juvenile Atlantic salmon density, for each age class (yoy, 1+ and 2+), densities were standardized in order to obtain a z-score for each sampling site, representing a relative value integrating the twelve years of data. Partial least square correlations between connectivity and density were conducted in order to control a possible collinear effect of habitat quality.

3 RESULTS

Figure 1 shows the effect of considering habitat connectivity on the reduction of the amount of habitat effectively available for salmon on the Matapedia river. It is apparent that adding levels of connectivity considerably reduces the amount of habitat effectively available to a salmon at a particular life stage.

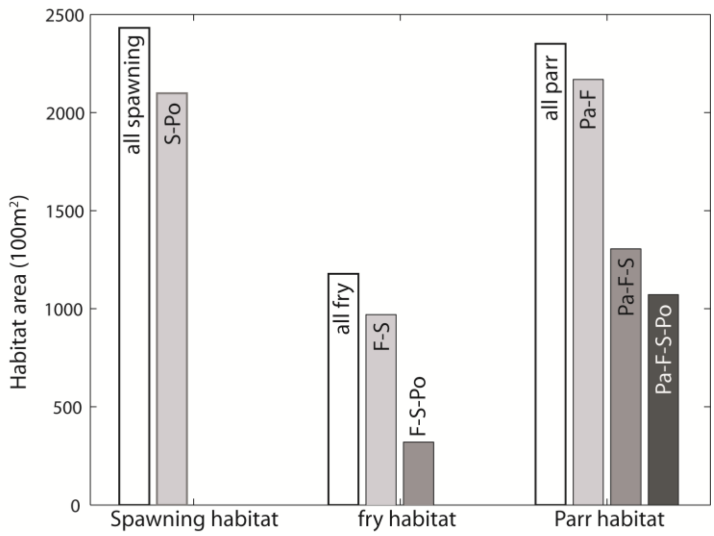

Figure 1. Areas of connected spawning, nursery and parr habitat (connexion established at a probability of access > 0.70). White: total habitat area, light grey: connected to previous functional habitat, dark grey: connected to two previous functional habitats, black: connected to three previous functional habitats. See Table 1 for variable definitions.

Statistical analysis indicates a strong and significant effect of habitat connectivity on juvenile densities (F-S-Po: R^2=0.617, p=0.038, Pa1+-F-S-Po: R^2=0.743, p=0.013), Pa2+-F-S-Po: R^2=0.624, p=0.034). Interestingly, these relationships become non significant when spawning habitats are not connected to holding pool habitats.

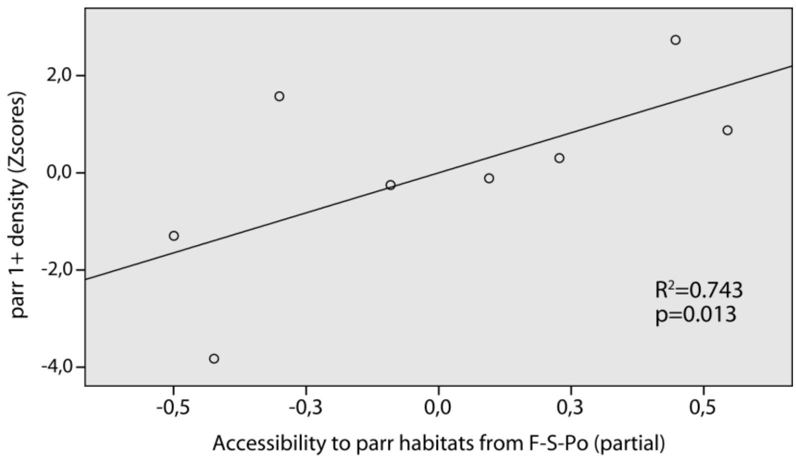

Figure 2. Partial least square correlation between standardized parr (1+) density between 2001 and 2012 and modeled probability of access to parr habitats from fry habitats connected to spawning connected to pools, while controlling for habitat quality.

4 DISCUSSION AND CONCLUSIONS

The functional habitat chronology approach presented here shows a great potential to improve habitat model predictions and estimates of carrying capacity by integrating habitat connectivity. Modelling and mapping the relative accessibility to contrasting habitats needed through the life-cycle of a fish might be valuable to better design habitat management plans. For instance, identifying good quality, but inaccessible habitats might be important to prioritize restoration actions, especially when the habitat availability for a specific life stage results in a bottleneck that determines the carrying capacity. Furthermore, our functional chronology approach presents the advantage of being relatively simple and interoperable with GIS, which makes it accessible to many wildlife managers and practitioners, as opposed to other more complex and theoretical life cycle approaches such as individual-based modelling. Despite being promising, the relationships between fish density and connectivity presented here are based on a relatively small sample size and more data is required in order to validate the significance of the approach for Atlantic salmon.

5 ACKNOWLEDGMENTS, APPENDICES, AND REFERENCES

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