HABITAT USE AND MOVEMENT PATTERNS OF ATLANTIC SALMON PARR (*SALMO SALAR*) DURING PEAK FLOW VARIATIONS

ISABEL BOAVIDA
CERIS, Instituto Superior Técnico, Univiersidade de Lisboa
Lisbon, Portugal

ATLE HARBY
CEDREN, SINTEF Energy Research
Trondheim, Norway

KEITH CLARKE
Department of Fisheries and Oceans, Science, Oceans and Environment Branch
St. John's, Newfoundland, Canada

JAN HEGGENES
Telemark University College
Bø, Norway

Depending on timing, frequency, duration, and magnitude; peak flows may directly impact native stream fishes, e.g. stranding, downstream displacement, obstruction of migration, and reduced spawning and rearing success. Here detailed movements of 13 radio tagged Atlantic salmon (*Salmo salar*) parr were studied during a eight-day period with experimental manipulations of flow, in a by-pass section of the Mandal River, southern Norway. Fish positions were recorded 4 to 12 times per day, before and after every flow change and at dawn, mid-day, dusk and night, depending on the flow variations. The main objective was to assess to what extent fish movements were influenced by water flow changes, temperatures, and light. Results indicate that fish movements correlated significantly with discharge alterations and diel variations, but not with the studied water temperatures.

1 INTRODUCTION

In regulated rivers, hydropeaking or similar rapid flow changes, may adversely affect the hydrologic regime and river hydraulics. Corresponding non-natural and rapid changes in ecological conditions of the affected river reach are likely to challenge the resilience of, and induce stress in, native fish over all life-stages. Previous studies in North-American and European rivers have documented numerous biological impacts of rapid flow fluctuations [1],[2].

Peak flows are often rapid (seconds and minutes), severe, frequent occur at non-natural times without natural warning cues, and may be erratic. This flow increase concerns about the ability and possibility of fish to respond adequately to the quickly changing environment. An organisms' potential for immediate adaptive responses depends on behavioral adjustments, i.e. ability to respond rapidly by local movements and habitat shifts [3].

Despite the growing awareness of hydropeaking impacts on fish biota, behavioral responses are, however, understudied and still uncertain. Will fish react to flow changes by moving laterally to more suitable local habitats during increase and thereafter 'recolonize' abandoned habitats during flow decrease? Is there a time-lag? Are temperatures and diurnal light conditions important? Will fish move longer longitudinal distances to other habitats resulting in redistribution? Or will fish simply seek out short-term refuges in suitable substrate rendering them susceptible to stranding [4]. Moreover, are highly territorial species, such as salmonids, more vulnerable to hydropeaking effects owing to reluctance to abandon territories?

To study relations between territorial salmon movements and systematic experimental discharge alterations, we used radio telemetry in a 720 m-long study section of a river where flow could be manipulated within the range of 1.5 to 10 m^3s. The main objective was to assess to what extent fish movements were influenced by magnitude and speed of water flow changes, temperatures, and light.

2 MATERIAL AND METHODS

This study was conducted in a 6 km bypass river section of Laudal power plant in the Mandal River, Southern Norway (catchment area c. 1800 km^2, mean annual flow 88 m^3/s), where the flow could be freely manipulated between 1.5 and 10 m^3/s by adjusting a gate in the intake reservoir for the power plant. The flow in the bypass section would normally vary between 1,5 and 3 m^3/s. A 720 m long reach that covers a range of habitats, was selected for experimental study. A concrete weir divide the study site into two distinct reaches with contrasting habitats: an upstream pool and a downstream diverse habitat reach, with a typical pool-riffle-run sequence.

Wild salmon parr were caught locally on the study site by back-pack electro shocking, and a miniature radio transmitter was surgically implanted in the body cavity. Mean total parr length before implant was 12,8 ± 0,9 cm, and mean weight 19,4 ± 3,4 g. Fish were re-introduced to the river at their previous capture site and left to acclimate for 4-5 days on high flow (> 70 m^3/s), before manipulation of flow started. Fish positions were recorded manually 4 to 12 times per day, depending on experimental flow and duration, but at a minimum before and after every flow change and at dawn, mid-day, dusk and night. The flow was manipulated between 1.5 and 10 m^3/s in order to simulate different hydropeaking conditions, from 9 May to 16 May (8 days). During the first three days of experiments, discharge was systematically manipulated step-wise from 1.5 to 10 m^3/s, then left stable for 1-2 hours, and finally decreased step-wise (same protocol) to 1.5 m^3/s. The discharge was then left at 1.5 m^3/s for two days, before three days of replicated rapid systematic manipulation from 1.5 to 10 m^3/s was implemented. Transient water temperatures were recorded every 10 minutes.

Study site riverbed topography was surveyed in a total of *c.* 4000 dispersed topographic points. Water surface elevation and flow velocity were recorded at three different discharges (i.e. 1.5, 7 and 10 m^3/s) along different stratified cross-sections in the downstream reach and randomly in points in the upstream study-reach. The two-dimensional flow model River2D [5] was used. Depth and water flow measurements were used to calibrate the model bed roughness and to establish the boundary conditions, specifically the water surface elevation at the downstream and upstream cross sections. Upon calibration, the model was run for the manipulated discharges (i.e. 1.5, 7 and 10 m^3/s). All fish locations from the tracking data were plotted in a Geographic Information System to quantify fish spatial distributions, habitat use, home range and movements. Total distance moved was calculated as the Eucledian distance between fish locations. This corresponds to estimated minimum distance traveled by the fish as not all movements are expected to be unidirectional. Minimum mean movement velocity was calculated for each fish by dividing minimum distance moved by number of hours between relocations. Fish home ranges were estimated by the Minimum Convex Poligon (MCP) method with 100 percent of fixes. Furthermore, the Fulton's condition factor k was calculated for each fish [6]. Changes in discharge were categorized as: SAI (slow increase), SAD (Slow decrease), I (increase), D (decrease), and S (stable). The diel light conditions were recorded as binary data: light or dark. Temperature measurements were categorized as L: 6-8 ºC; M: 8-10 ºC; H: 10-12 ºC for further analyses.

3 RESULTS

A total of 13 salmon were tagged and released in the study area. Overall, and based on patterns in the movement frequency distributions, tagged fish could be divided into three main groups (Table 1): (I) salmon parr that did not relocate during all the experiments (*i.e.* 283; 431). (II) Parr that traveled longer, directional distances (*i.e.* 154; 303; 311) with correspondingly large home ranges (*c.* MCP>4000 m^2). (III) Parr that used a defined home range in the stream moving in all directions (*i.e.* eight individuals), with variable home ranges ranging from 215 to 2686 m^2, but skewed towards smaller MCP (median=1015 m^2). Also fish 283; 431; 202; 294 and 272 used the upstream part of the reach while the others used the downstream part. Fish total length and weight were significantly correlated (Spearman ρ: 0.594; p=0.025). Home ranges, calculated as MCP, for the salmon parr ranged overall from 1 to 6467 m^2. Home ranges used by fish in the upstream pool part of the reach were all substantially larger than in the downstream pool-riffle-run lower part (range: 2148-2686 m^2 and 215-1422. m^2, respectively). Average time between relocations was 3h20. Movements distances were strongly skewed towards many short (*e.g.* fish from group I and III) and few but long movements (*e.g.* fish from group II), ranging from 1 to 890 m of total distance. Average distance moved per hour for individual fish over the tracking period ranged from 4.3 to 17.9 m/h. There were no significant relationships between fish movements, expressed as either home range, total distance and mean movement velocity, and fish weight or length. Fulton's condition factor was, however, positively correlated with fish total movement distance (Spearman ρ: 0.651; p=0.0298). Total fish movement distances were significantly longer in the upstream pool (*i.e.* 283; 431; 202; 294; 272) compared to the downstream pool-riffle-run (*i.e.* 331; 343; 812; 789; 772; 311; 154; 303) (p<0.001; Mann-Whitney U test).

Fish inhabiting the upstream pool tended to move more and with larger home ranges. No significant differences were found with respect to mean movement velocities between the upstream pool and the downstream reach.

Flow manipulations clearly affected salmon parr movements. There was a significant association between fish movements and the five different flow situations ($\chi 2$: 12.91; p=0.0117). During slow variations in flow (i.e. SI and SD), fish tended to move longer distances (Figure 1). Considering the three categories for temperature (i.e. L, M and H) fish movements did not differ significantly with temperatures ($\chi 2$: 5.49, p>0.05). Fish movements differed, however, between dark and light conditions ($\chi 2$: 6.13; p=0.0133). The parr tended to move longer distances in light conditions.

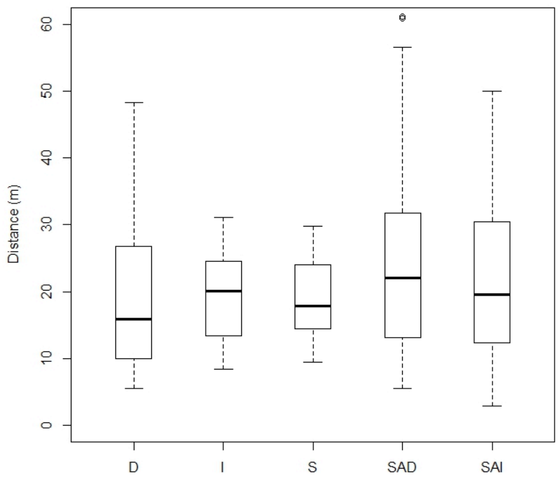

Figure 1. Boxplots of fish movement distance for the five different discharge situations; D (decrease), I (increase), S (stable), SAI (slow increase), and SAD (slow decrease).

Table 1. Fish characteristics and movement patterns

	Fish id	TL (cm)	WT (g)	K factor	NL	TD (m)	MCP (m^2)	Vel. (m/h)
I	283	13.1	19	0.85	1	0	1.0	-
	431	12.6	18	0.90	1	0	1.0	-
II	311	12.9	15	0.70	22	1225.3	18008.4	17.9 (14.4)
	154	13.6	19	0.76	11	526.3	6467.3	16.3 (28.7)
	303	13.9	18	0.67	23	890.0	4172.5	10.4 (10.7)
III	202	13.2	19	0.83	21	439.7	2686.0	8.6 (7.5)
	294	13.5	21	0.85	20	534.6	2147.5	9.3 (5.2)
	272	13.8	21	0.80	23	580.3	2268.6	8.2 (4.6)
	331	13.1	21	0.93	24	688.5	1421.89	10.2 (6.8)
	343	11.2	17	1.21	19	409.9	376.43	6.7 (3.3)
	812	12.0	19	1.10	32	434.7	608.5	4.3 (3.1)
	789	11.5	16	1.05	22	441.4	568.6	6.7 (4.9)
	772	13.8	29	1.10	18	288.0	215.4	5.1 (2.2)

*Mean values are given for depth and velocity followed by standard deviation

*TL – Total Length; WT – Weight Total; K factor – Fulton's condition factor; MCP – Minimum Convex Polygon (100% percent of fixes); TD – Total Distance.

4 CONCLUSION

In conclusion, Atlantic salmon parr exhibited a wide individual variation in movement behaviors. Overall, the thirteen telemetry tagged parr could be pooled into three main groups: fish that did not move during all the experiments; fish that traveled longer directional distances; and fish that used a defined area in the stream, but moving in all directions. In our study some individuals displayed strong site fidelity (Group I, two parr), while others were more mobile moving in all directions Group III, eight parr), exhibiting little or no site fidelity. Fish inhabiting the upper part of the reach (*i.e.* pool) tended to move more resulting in larger home ranges. Highly territorial species, such as salmonids, may be suspected to be less inclined to move and thus more vulnerable to hydropeaking effects owing to reluctance to abandon territories. There was limited immediate evidence of this in the present study. However, we do not know how potential breakdown of social organization may affect populations.

Movement distances were strongly skewed towards many short movements. This tendency may be explained as a movement behavior response to peak flows, when fish seek for suitable habitat downstream where river reach is less perturbed by the peak wave; or when fish lose their swimming capacity (downstream displacement – e.g. [7]. Flow manipulations and diel variations clearly affected salmon parr movements, with more movements in the dark and slow flow manipulations. As for variations in temperatures, no relation with parr movements was found, but studied temperature range was limited.

5 ACKNOWLEDGMENTS

The authors would like to thank MSc students Torben Ott and Eduard Stephenson from University of Stuttgart, Germany and Curtis Pennel from Department of Fisheries and Oceans, St. John's, Canada for extensive field work. Ana Adeva Bustos, Ph D student at NTNU, Trondheim, helped establishing GIS analysis. This study would not have been possible without the support and practical assistance by Svein Haugland at Agder Energi, Norway. The data collection and initial analysis were performed under the "EFFEKT-project", The Research Council of Norway Grant no 117776. Further analysiswere performed with funding from Science and Technology Foundation (SFRH/BPD/90832/2012) and The Research Council of Norway Grant no 193818.

REFERENCES

[1] Saltveit SJ, Halleraker JH, Arnekleiv JV, Harby A (2001) Field experiments on stranding in juvenile Atlantic salmon (Salmo salar) and brown trout (Salmo truta) during rapid flow decreases caused by hydropeaking. Regul Rivers Res Manag 609–622.

[2] Scruton DA, Ollerhead LMN, Clarke KD, et al (2003) The behavioural response of juvenile Atlantic salmon (Salmo salar) and brook trout (Salvelinus fontinalis) to experimental hydropeaking on a Newfoundland (Canada) river. River Res Appl 19:577–587.

[3] Berland G, Nickelsen T, Heggenes J, et al (2004) Movements of wild atlantic salmon parr in relation to peaking flows below a hydropower station. River Res Appl 20:957–966.

[4] Halleraker JH, Saltveit SJ, Harby A, et al (2003) Factors influencing stranding of wild juvenile brown trout (Salmo trutta) during rapid and frequent flow decreases in an artificial stream. River Res Appl 19:589–603.

[5] Steffler P (2000) Software River2D. Two Dimensional Depth Averaged Finite Element Hydrodynamic Model.

[6] Fulton TW (1904) The rate of growth of fishes. 22nd Annu Rep Fish Board Scotl 3:141–241.

[7] Flodmark LEW, Forseth T, L'Abee-Lund JH, Vollestad L a. (2006) Behaviour and growth of juvenile brown trout exposed to fluctuating flow. Ecol Freshw Fish 15:57–65.