FISH RESPONSES TO ARTIFICIAL FLOW AND WATER TEMPERATURE VARIABILITY IN A LARGE RIVER (RHÔNE, FRANCE)

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Understanding fine scale behavioural responses of fish to changes in abiotic characteristics of habitat, such as flow variability, is an interesting innovative issue to improve river management in highly disturbed aquatic environments. For example, in the Rhône River (France), important hydrology and thermal contrasts are mainly explicated by the succession of dams and nuclear power plants. The main aim of our study was to describe fish behaviour in term of movements and habitat use as responses to habitat variability due to the production of peaking electricity and temperature heterogeneity (natural or due to a nuclear power plant release). Fixed telemetry system (accuracy of few square meters; Hydroacoustic Technology Inc.) enabled to define individual fish behavior during different short habitat variability configuration (flow increase, flow decrease, temperature increase....). We then recorded at a local scale continuous movements of n=61 fish during short term (lower than day) habitat variability. The study was conducted in a 2 km long river stretch, from July to September 2009. Abiotic conditions (temperature, depth, velocity or substrate) were simulated (with an accuracy comparable with fish positioning accuracy) every where at any time (i.e. for any discharge) using a hydraulic 2D model calibrated and validated for the whole discharge range observed during the experiment. Three main species were represented : two native cyprinids, chub (*Squalius cephalus*) and barbel (*Barbus barbus*), and an invasive species, wels catfish (*Silurus glanis*). Fish mobility and habitat use were studied to describe changes in behavior associated with changes of abiotic conditions. The separate effects of each environmental factors (discharge, temperature, photoperiod) and their interactions on fish behavioral responses were studied. Finally, variability of fish habitat preferences were estimated to refine understanding of observed behaviors. The different results highlighted the advantages and limitations of the telemetry acoustic system in a large river to address fish displacement in response to discharge and temperature variability. They also emphasized the necessity of a 2D hydrodynamic model to understand fish behaviour.

1 INTRODUCTION

The results of the working group 'Rhône Thermie - Phase III' (EDF Drire, Water Agency, Diren, Univ. Lyon I, Aralep, Cemagref Aix and Lyon; Carrel *et al.* 2006 [1]) clearly illustrated the need to take into account the spatial and temporal variability of flow conditions, habitat and temperature to study the variability of the structure of fish communities of the Rhone.

Simulation techniques of fish habitat versus flow are frequently used tools within management expertise (e.g. definition of minimum flow regime) but much less frequently to study the relationship between environmental characteristics (e.g. availability of habitat) and fish behaviour.

Thus the objectives of the study presented here were 1) to accurately characterize the spatial and temporal variations in living conditions of aquatic communities of the Rhone (habitat and temperature) and 2) to analyze the behavioral responses of fish subjected to simultaneous changes and contrasting habitat and water temperature. In this context, it is likely that fish are compelled to adapt their behaviour and their habitat selection in this changing environment. In order to test this hypothesis, a fixed acoustic telemetry survey was performed in the Rhône River during summer 2009 in front of the Bugey nuclear power plant (NPP) which released warmed water within the river.

2 MATERIAL AND METHODS

The experiment took place from 3 July to 29 September 2009 in a sector of the French Upper- Rhone (45° 47’ N; 5° 16’ E) located upstream of the confluence with the Ain River in the longest section not bypassed by a canal for hydroelectricity production (Figure 1). The study site was 1 730 m long and 156 m wide on average (SD=32.4 m; min=113.1 m; max=235.7 m), for a total surface area of 270 273 m² at an average annual flow rate of 473 $m^3.s^{-1}$ in 2009. At this average flow rate, the mean water column velocity was from 0 to 1.7 $m.s^{-1}$ for an average depth of 2.8 m (SD=1.4 m; max=8.7 m). The Bugey NPP, located on the right bank of the site, takes in water upstream (~ 100 $m^3.s^{-1}$) to cool the reactors and discharges the heated water (from 8 to 10°C warmer) using two outlets of ~ 10 $m^3.s^{-1}$ and ~ 90 $m^3.s^{-1}$.

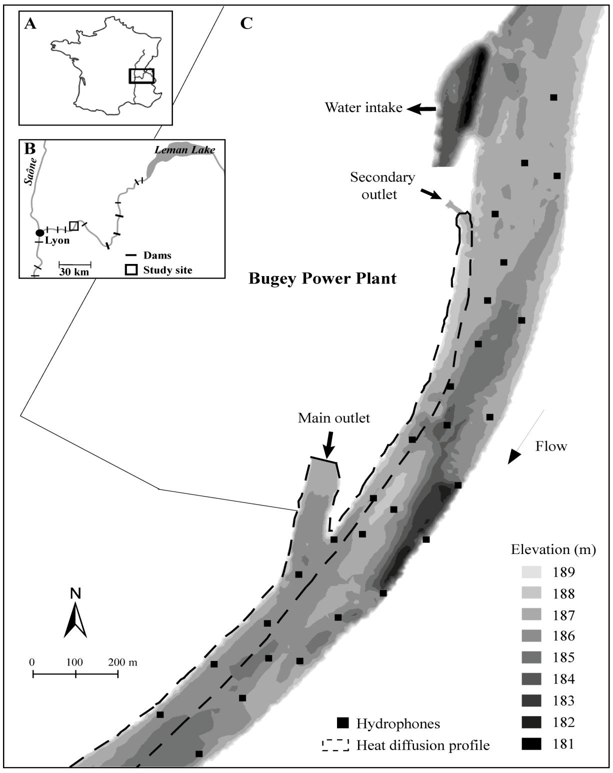

Figure 1. Location of the study site in the Upper-Rhone in Middle East France (A), in between Lyon and Leman Lake (B). Transverse bars on the Rhone on map B are dams. Map C presents elevation recorded in the study site (filled contour) in front of the Bugey NPP with the location of the 28 hydrophones deployed. The heat diffusion profile (dashed line) generates a transversal thermal heterogeneity downstream of both outlets (for 465 $m^3.s^{-1}$).

In June 2009, following the reproduction period of the species studied, an initial total of 94 fish belonging to 8 species were captured by electric fishing and net fishing over the entire site, and placed in stabilisation tanks for a minimum period of one hour. By using the technique described by Ovidio *et al.* (2009) [2], we implanted acoustic tags (307 KHz; pulse rate ~ 3 sec.) in the intra peritoneal cavity of the fish. In our experiment, we tracked the fish in two dimensions only (i.e. plane) since the low average depth of the river did not permit vertical localization. The fish were monitored by using 28 fixed hydrophones (Hydroacoustic Technology Inc., Seattle, Wash.) installed at predefined positions chosen to optimize the tracking into the entire study site. The installation procedure of the hydrophones in the river has been described by Bergé *et al.* (in press) [3] who analyzed the accuracy of the system under the same listening conditions as the present study. A positional error less than 4 m was found in the channel (detection efficiency of 50 %) and less than 8 meters along the banks (detection efficiency of 20 %; Bergé *et al* (in press) [3]).

A two-dimensional mapping was used to characterize abiotic conditions prevailing in the study site. This choice results from the following considerations: 1) the preference models of fish habitat are defined in terms of average speeds on the water column, 2) there is no vertical stratification of water temperature; 3) the fish are likely to move both laterally and longitudinally relative to the watercourse, and 4) a three-dimensional hydrodynamic modeling approach would not have provided more information, while proving more complex implement and validate. Geometric discretization of the study site was conducted in the form of an irregular mesh of triangular elements, considering the bathymetric configuration of the study site. A high density of points of bathymetry to suggest that, given the techniques used to collect, differences between measured values and observed values are the order of a few centimeters (Pella et al., 2008 [4]). Characterization of substrate conditions prevailing at the right of each node of the mesh was established from a mapping of the spatial distribution of the substrate (comments and photos) within the study site. Process for calibration and validation, records of water levels versus flow were made at gauging stations located right on the banks along the study reach. Furthermore, longitudinal profiles of free surface elevation for different stabilized flow rates (7 readings between 190 and 1300 $m^3.s^{-1}$) was observed between the upstream and downstream of the study site. The results of hydrodynamic simulations are used to characterize, for each node of the mesh, the mean flow velocity and depth depending on the prevailing discharge passing through the section under consideration. Hydrodynamic conditions simulated were used as inputs, with the operating conditions of the Bugey NPP, to simulate the spatial distribution of water temperature.

Behavioural responses of fish were investigated through the individual mobility during selected phases of flow (increase, decrease and stability), during main circadian phases (morning, day, twilight and night) and during water temperature changes (imposed by the rapid transition of deep cold waters from the Leman Lake discharged within the river). Mobility and activity of fish were particularly studied to determine the amount of movement associated with a change of abiotic conditions. The separate effects of each environmental factors on behavioral responses of fish were studied and interactions between factors were analyzed to highlight potential synergistic or antagonistic effects. Finally, to describe habitat selection implemented by the species and by the individuals during environmental changes, we developed habitat preference curves (depth, flow velocity, substrate and temperature). These curves were used as indicators of fish habitat selection in changing habitat availabilities.

3 RESULTS

From 3 July to 29 September 5 517 610 fish locations were recorded. Sixty one fish mainly belonging to three species, barbel (*Barbus barbus*), chub (*Squalius cephalus*) and wels catfish (*Silurus glanis*), were located.

The hourly gradient of the maximum flow rate observed was 79 $m^3.s^{-1}$ for rising flow rate phases and -62 $m^3.s^{-1}$ for falling flow rate phases (Figure 2). The rising flow rate phases were mainly observed during the day (86% of rising flow rate hours), whereas the falling flow rate phases were mainly observed at night (65% of falling flow rate hours). For static hours, we observed a larger number of diurnal hours, which is consistent with the longer diurnal period during summer. During monitoring, three cold drops were observed from 6 July and 12 September (Figure 2), with a maximum fall of 4.9°C in 6 days, observed during the first event.

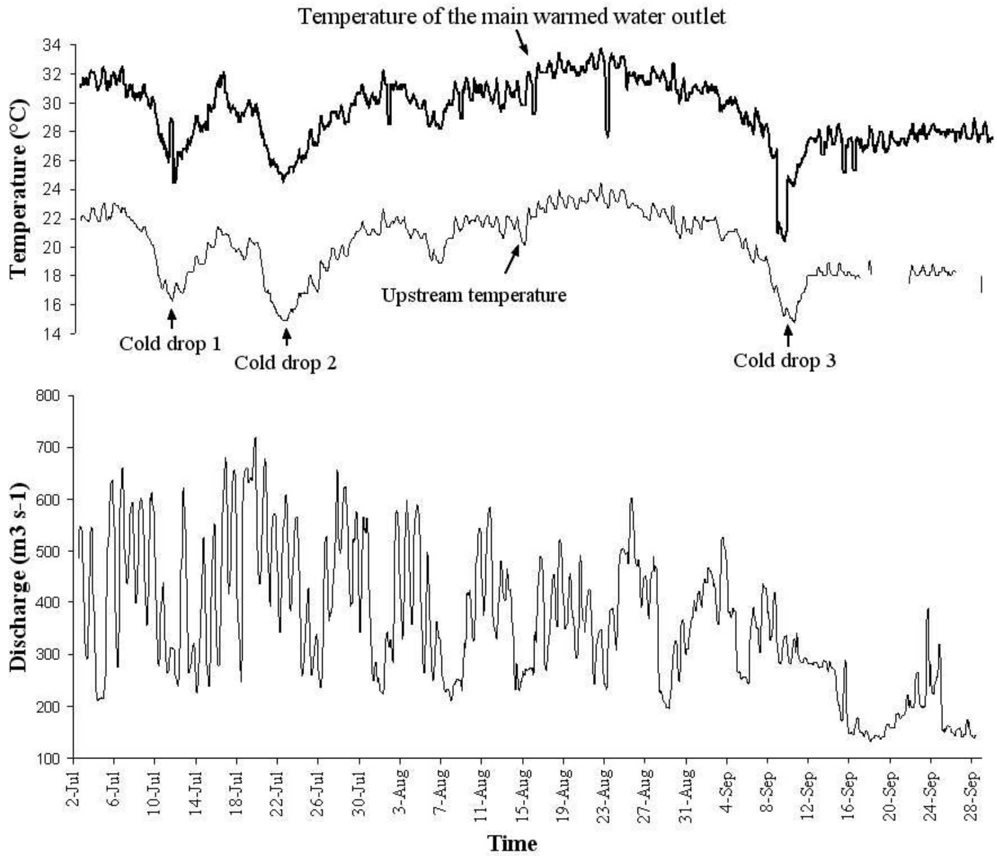

Figure 2. Water discharge and water temperature variations recorded from the 3 July 2009 to the 29 September 2009. Three cold drops were recorded during the study and the lack of temperature data are explained by the dewatering of the thermometers.

The validated hydrodynamic model simulated water levels very close to observed water levels (maximum difference of a few centimetres between observed and simulated values) and flow velocities with a transverse distribution and modules very close to observations. The simulations of temperature immediately downstream of the NPP have an accuracy estimated at 0.5 ° C. Then it was possible to simulate thermal and hydraulic characteristics at any point of the segment for any discharge (Capra et al., 2011 [5]).

The experiment of 2009 showed that the wels catfish used predominantly (65% of the time) heated waters downstream of the discharges from the Bugey NPP, but also in areas of water not heated. Instead the barbel and the chub used very rarely heated water bodies (<10%). The three species mainly used habitats located along the banks, with incursions by barbel in the channel. Barbel and chub mainly used areas located on the left bank, although barbel frequented several areas near the right bank.

For the three species, individual movement was mainly linked to the different circadian phases rather than to variations of flow rate in spite of the considerable frequency and amplitude of flow. The total distances travelled by the barbel are influenced by the environmental combinations (discharge x circadian) recorded during the monitoring. Barbel mainly moved during twilight and to a lesser extant during the morning whereas the smallest movements were recorded during the day and the night. Chub moved least at night and more during the morning and during twilight. Distance travelled by wels catfish was higher at night and less during the day. For the three species, in the different groups of circadian phases, no effect of flow rate on fish displacements was observed.

Finally, fish habitat preferences seemed not so variable among different circadian phases whereas the preferences appear to change between low flow conditions and high flow conditions. An important inter-individuals variation of habitat preferences was observed depending on habitat variable and depending on species.

4 DISCUSSION

The fixed acoustic telemetry system used in this study was a very useful tool to increase our knowledge on fish - habitat relationships. Despite technical difficulties during its deployment in such a large fast flowing river, this equipment offered the possibility of obtaining large amounts of fish locations with very good accuracy.

A 2D hydrodynamic model is also fundamental to simulate habitat conditions anywhere into the study site for the whole range of observed discharges. But a high accuracy of the 2D model means much time and much attention for field sampling, for calibration and for validation of the model.

The crossing of hydrodynamic simulations and recording of the fish locations gave us the opportunity to know more precisely the modes of fish habitat selection in configurations of large fluctuations (e.g. hydropeaking) of habitat conditions in the Rhone River.

The adults of the studied species are not necessarily those most sensitive to fluctuations in flow recorded in the Rhône River at Bugey. They seemed to retain a type of activity guided primarily by photoperiod, as in streams not subject to hydropeaking. This is probably related to the diversity and the availability of the habitat, even at low flow, and to their mobility (particularly in comparison with the early life stages).

We conclude that the influence of flow rate was weak on the adult stage of these three species compared to the importance of photoperiod and water temperature and that wels catfish appear to be the species most generally ecologically adapted to such disturbed environments.

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