Déterminants de la structure spatio-temporelle de l'assemblage piscicole d'une grande rivière méditerranéenne régulée : stochasticité environnementale *vs* régulation du débit

Drivers of the spatial-temporal patterns of fish assemblage in a large regulated, Mediterranean river: environmental stochasticity *vs* flow regulation

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RÉSUMÉ

La gestion durable des ressources en eau en région méditerranéenne est un défi majeur pour les années à venir. La Durance est une rivière fortement régulée utilisée pour la production hydroélectrique, mais aussi pour des usages agricoles, récréatifs, industriels et domestiques. Les gestionnaires d'ouvrages hydroélectriques s'efforcent d'atténuer les impacts des altérations hydrologiques en expérimentant différents niveaux de débit réservé dans les sections court-circuitées, associés à des suivis d'indicateurs physiques et biologiques. Sur la base d'échantillonnages piscicoles réalisés entre 1991 et 2010 sur des sites témoin ainsi que sur des sites soumis à régulation, nous avons analysé les relations entre la variabilité de la structure de l'assemblage piscicole et des variables environnementales clés (débit, température, habitat physique) partiellement dépendantes du fonctionnement des ouvrages. Les analyses ont montré que l'assemblage était alternativement dominé par des sous-ensembles d'espèces, et que cette structure résultait principalement d'événements hydrologiques majeurs (crues). Les réponses fonctionnelles étaient pertinentes, avec par exemple une augmentation des proportions d'individus rhéophiles et lithophiles lorsque les débits sont élevés durant la période de reproduction. Cette approche multi-sites et pluriannuelle apporte un éclairage sur le fonctionnement de l'assemblage piscicole d'une grande rivière soumise à régulation

ABSTRACT

Sustainably managing water resources in Mediterranean regions is a major challenge for the coming years. The Durance River (south-eastern France) is a highly regulated river whose water serves for hydropower production, agricultural, recreational, industrial, and domestic purposes. Powerplant managers strive to mitigate the deleterious impacts of flow alterations by experimenting with different levels of minimum flow increases in by-passed sections, and monitoring relevant physical and biological parameters. Using fish data collected during 1991-2010 on control and regulated sites along the Medium-Durance, we investigated the relationships between changes in fish assemblage structure and key environmental variables (flow, temperature, and physical habitat) that are partly affected by the operation of hydropower plants. Analyses showed that assemblages through time were alternatively dominated by a subset of species, and that this structure mostly depended on 'extreme' events, such as major floods. Functional responses were consistent with expectations, with e.g., rheophilic and lithophilic species being favoured by high flows during the spawning season. Our multiple site and year approach helped us better understand the functioning of fish communities in a large regulated system.

MOTS CLES

Durance River, fish assemblage, Instream flow, water ressource management.

1 INTRODUCTION

The Durance is a highly regulated, Mediterranean river flowing from the Alps to the Rhône River in South-Eastern France. Regulation consists in a series of dams and by-passed sections, with the main part of the water flowing into canals parallel to the main by-passed channel. Despite high anthropogenic pressures, the Durance River still is a highly dynamic, alluvial river. Under the European Water Framework Directive and French legal incitations, powerplant managers changed flow management rules so as to be less harmful for the aquatic ecosystem. Experiments of minimum flow (MF) increases were performed on the Sainte-Tulle hydroelectric scheme, with a shift from 1/40th (3.6 $m^3.s^{-1}$) of the mean annual flow (MAF; 144 $m^3.s^{-1}$) before 11/2007 to a seasonally modulated 1/20th (7.2 $m^3.s^{-1}$) or 1/14th (10 $m^3.s^{-1}$) MAF thereafter. Actually, tributaries flowing into the by-passed sections may significantly increase the minimum flow and originate peak floods (**Fig. 1**). We analysed the relationships between fish assemblage structure and flow variability between 2005 and 2010 for three sites, including one control site (D0, no minimum flow change) and two sites where the minimum flow has been increased in November 2007 (D1 & D2).

2 MATERIAL & METHODS

Fish were sampled annually in late summer by electrofishing, in 22-26 independent habitat units of several square meters per site (see Lamouroux *et al.* 1999). Daily flow time series for the control site (D0), and for D1 and D2 were described using 11 variables reflecting median, high, and low flow levels, and the magnitude and duration of floods. Variables were computed for three 'biological periods': reproduction (March-June), growth (July-October), and winter (November-February).

Fish (species proportions) and flow variables were separately analysed using within-sites normalized Principal Component Analysis (PCAs). Results are presented with projection of species traits. Pearson's *r* quantified the relationships between fish and flow PCAs axes, used as synthetic variables. ANCOVA were used to test for the robustness of fish-flow relationships across sites. Complementary, longer-term fish and flow data collected since 1991 on site D1 were used to check whether the fish-flow relationships revealed for 2005-2010 could be robust at a larger temporal scale.

3 RESULTS & DISCUSSION

The shift in flow management rules occurred in November 2007. The hydrograph (**Fig. 1**) clearly displayed two hydrological periods that matched the pre- and post- minimum flow increase. Between 2005 and 2007, the flow level was low, very stable, without major flood. The period 2008-2010 was characterised by a higher flow level, higher variability, and three major floods with Q_{max} > 600 $m^3.s^{-1}$.

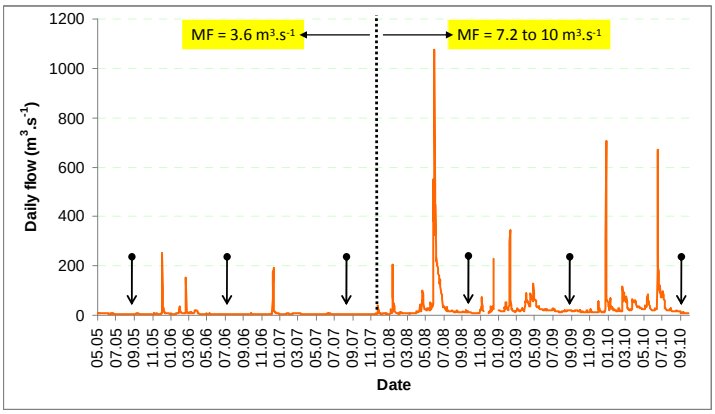

Fig. 1: Hydrograph of the by-passed Durance River (Ste-Tulle hydroelectric scheme) at D1 and D2 section. The dotted black line indicates the shift in flow management rules. Black arrows indicate the fish sampling operations.

The fish PCA (**Fig. 2A**) mainly discriminated the barbel (*Barbus barbus*, BAF), chub (*Leuciscus cephalus*, CHE), and the South-west European nase (*Parachondrostoma toxostoma*, TOX), that dominated the assemblage in years 2008 and 2010 (**Fig. 2B**), from the nase (*Chondrostoma nasus*, HOT), stone loach (*Barbatula barbatula*, LOF), and minnow (*Phoxinus phoxinus*, VAI), very abundant in years 2007 and 2009. The fish assemblage structure was significantly correlated with the flow pattern during the reproduction period (r = -0.80; p < 0.005). Years with a high flow level and floods during the reproduction period (**Fig. 2C**) are characterized by a high proportion of species (**Fig. 1A**) which are rheophilic (Rh), lithophilic (L), and that have a large size (T3).

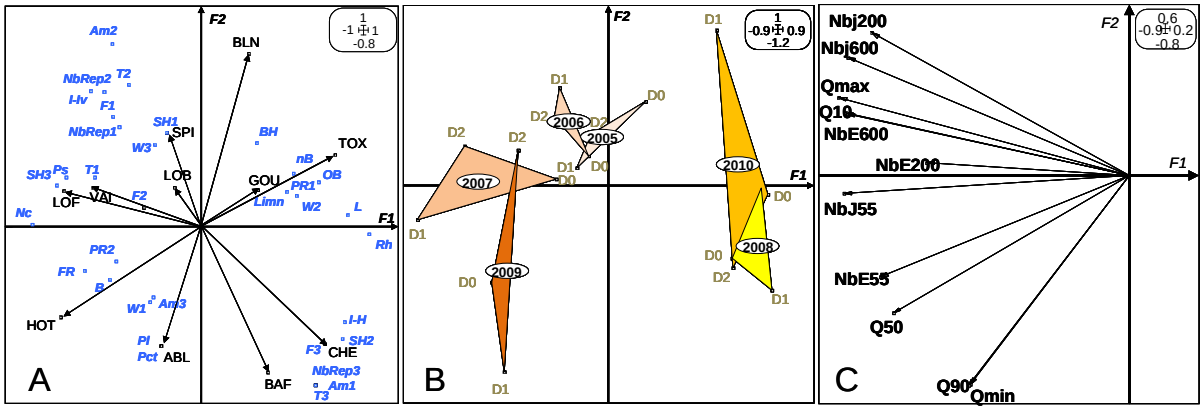

Fig. 2: Relationships between fish assemblage structure and flow variability. F1xF2 within-sites normalized PCA factorial plane A) of species, with species traits projected as supplementary individuals; B) of sites grouped by year; C) of flow variables during the reproduction period.

Quantifying the relationships by directly looking at the proportions of species *vs* a representative variable of $F1_{hydro}$ (daily peak flow Q_{max}) showed that the proportion of the assemblage TOX,CHE,BAF increased significantly with the peak flow value during the reproduction period (**Fig. 3**: ANCOVA, r^2 = 61.2%, $p < 0.001$), similarly in the three sites ($p_i = 0.97$). Using longer-term data on D1 confirmed this trend ($n = 14$, $r^2 = 0.44$, $p = 0.009$). Conversely, proportions of LOT+VAI+HOT significantly decreased (**Fig. 3**: $r^2 = 66.2\%$, $p < 0.001$), similarly in the three sites ($p_i = 0.38$).

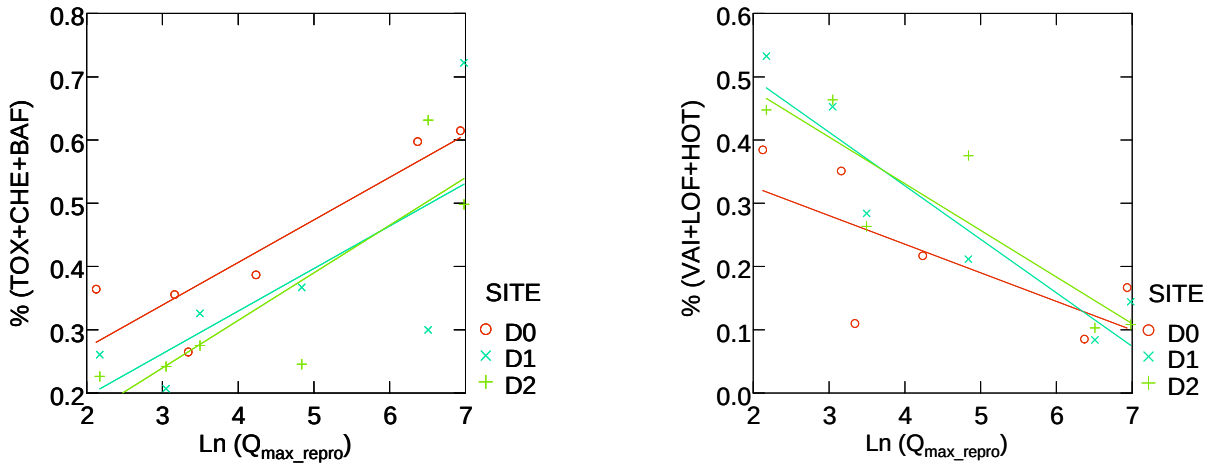

Fig. 3: Relationships between species' guild proportions and the peak flow value during the reproduction period, for the three sites.

4 CONCLUSION

The fish assemblage structure across years significantly depended on the flow pattern, but only during the reproduction period. Responses were consistent with previous findings (Cattanéo *et al*. 2001), and similar in all three sites. The potential effects of the shift in flow management rules were confounded by those of the natural hydrological variability, which appeared to be a main driver of the fish assemblage dynamics in this system. This analysis is planned to be extended in adding fish data collected upstream and downstream on controls and by-passed sections.

LIST OF REFERENCES

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