Comparison of two fine sediment release strategies from a large hydroelectric dam (Verbois dam, Rhône River, Switzerland) on the fish community

Comparaison de deux stratégies de gestion des sédiments fins d'un grand barrage hydroélectrique (barrage de Verbois, Rhône, Suisse) sur la communauté piscicole

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RÉSUMÉ

Les chasses de barrage sont des opérations couramment pratiquées pour évacuer les sédiments fins, mais peu d'études ont évalué quantitativement les impacts écologiques associés, et encore moins ont comparé les impacts de différentes stratégies de gestion. Nous avons analysé et comparé les impacts piscicoles des chasses de 2012 et 2016 de la retenue de Verbois (13 Mm^3, Rhône, Suisse), correspondant à deux stratégies différentes de relargage des sédiments fins. Les impacts ont été évalués pour la communauté piscicole de la retenue par hydroacoustique, et à l'échelle individuelle par radiotélémétrie à l'aval du barrage. L'abaissement complet du réservoir en 2012 a induit une baisse de 57 % de la densité acoustique, sans recolonisation durant les 16 mois suivants. L'abaissement partiel de 2016 n'a pas modifié la densité entre les campagnes d'avant et d'après chasse. La survie apparente totale est identique pour les deux opérations, soit 73.8 % en 2012 et 72.7 % en 2016. Les individus ont dévalé d'environ 1.5 km durant les opérations, sans différence entre 2012 et 2016. Nous avons conclu que la chasse de 2016 avait moins d'impacts piscicoles, ces impacts étant essentiellement comportementaux. Le contrôle de la concentration en sédiments fins à l'aval du barrage et l'abaissement partiel de la retenue ont permis aux poissons de résister à la perturbation, et représentent des éléments clés pour réduire les impacts de la gestion sédimentaire.

ABSTRACT

Fine sediment flushings from reservoirs are common management practices worldwide, but few studies report quantitative evaluations of their ecological impacts, and even fewer compared impacts of different sediment management strategies. We analysed and compared impacts on the fish community of the 2012 and 2016 drawdown flushings of the Verbois reservoir (13 Mm^3, Rhône River, Switzerland), which corresponded to two distinct strategies of releasing fine sediment. Impacts on fish were investigated at the community scale within the reservoir by means of hydroacoustics, and at the individual scale for representative species using radio-telemetry. The total reservoir emptying of the 2012 flushing resulted in a 57% decrease in fish density, with no recolonization process during the 16 following months, while the partial emptying of the 2016 flushing did not modify fish density between the pre- and post-flushing periods. Overall apparent survival was similar for the two flushing events, i.e. 73.8 % and 72.7 % in 2012 and 2016, respectively. Fish moved downstream during the sediment release for *ca* 1.5 km, approximately the same distance for the two flushing events. We concluded that the 2016 flushing had fewer impacts on fish, with mainly behavioural impacts. The control of the sediment concentration downstream of the dam and the partial emptying of the reservoir allowed fish to withstand the disturbance, and are key elements to mitigate impacts on the fish community.

MOTS CLES

Gestion sédimentaire, hydroacoustique, impacts piscicoles, retenue hydroélectrique, télémétrie

1 INTRODUCTION

Sediment flushings of hydropower reservoirs are commonly performed to maintain water resource uses and ecosystem services (Kondolf *et al*. 2014), but may have strong ecological impacts, especially on fish. However, despite the worldwide scope of this issue, very few studies report quantitative *in situ* evaluations of sediment flushing from dams, and even fewer compared impacts of different sediment management strategies.

On the Swiss Rhône River, the Verbois reservoir (13 Mm^3) traps massive amounts of fine sediment carried by the Arve River, whose confluence is 8 km upstream to the dam. From 1968 to 2003, sediment aggradation has been managed by drawdown flushing every three years, with a complete emptying of the reservoir. This management strategy resulted in significant ecological impacts, mainly on fish. Impacts were not restricted on a local scale, but concerned the whole upper-Rhône River until Lyon (Roux 1984). The growing discontent from civil society, nature conservancy organizations, fishermen associations and water management authorities led dam operators to consider alternative, less harmful sediment release strategies. Sediment flushings were then stopped until 2012, and a new management strategy was operated in 2016.

This study aimed to compare *in situ* ecological impacts on fish resulting from two distinct sediment management strategies. Effects of the 2012 and 2016 flushing events were investigated within the Verbois reservoir at the community scale, and below the dam at the individual scale.

2 MATERIAL AND METHODS

2.1 The 2012 and 2016 flushing events

Both events mainly differed according to their duration, the magnitude of the reservoir emptying and the control of the suspended sediment concentration (SSC) downstream of the dam. The 2012 event took place in June after a period of 9 years without flushing, lasted 13 days, and totally emptied the reservoir. It released an estimated volume of 3.2 Mm^3 of fine sediment, with no control of the SSC downstream to the dam (mean = 11 $g.L^{-1}$; max = 48 $g.L^{-1}$). The 2016 event corresponded to a new sediment management strategy which combines sediment flushing from the dam with a partial emptying of the reservoir and controlled SSC downstream, dam gates opening during floods and localized dredging. It was operated in late May, lasted 9 days, and released 1.3 Mm^3 of fine sediment with a mean controlled SSC downstream of 3.28 $g.L^{-1}$ (max = 11 $g.L^{-1}$).

2.2 Impact monitoring on fish

A series of hydroacoustic surveys conducted just before and after flushings allowed to assess fish density changes within the reservoir, as well as the size distribution of fish composing the community. Hydroacoustics surveys were also performed during years without flushing to analyse the seasonal variability in fish density independent of sediment management operations. Differences between surveys were tested by non-parametric Krukall-Wallis tests.

The behaviour of individual fish (displacement distances) and apparent survival rates for representative species (*Salmo trutta*, *Barbus barbus*, *Squalius cephalus*) were analysed by means of a capture-mark-recapture approach using radiotelemetry. Tracking sessions were performed before, during, and after each flushing event. The overall apparent survival rate Φ was calculated as the proportion of marked fish that remained alive in the study area at the end of the flushing. A Cormack-Jolly-Seber (CJS) mark-recapture model was used to assess daily apparent survival rates and to test for potential effects of species, flushing event, and their interaction.

3 RESULTS

The acoustic density (a proxy for fish density) in the Verbois reservoir significantly decreased by 57% between the pre- and post-flushing periods in 2012, and no recolonization process occurred during the 16 following months. In 2016, the acoustic density did not differ between the pre- and post-flushing periods. A high proportion of small fish (length < 10 cm) was observed during the 2016 autumn sampling, suggesting a good reproduction success.

The overall apparent survival rate Φ of marked fish was similar for the two flushing events, i.e. 73.8 % and 72.7 % in 2012 and 2016 respectively, but differed between species ($\Phi_{barbel} = \Phi_{chub} > \Phi_{trout}$). CJS mark-recapture models indicated that the daily apparent survival rate significantly decreased during the both flushings, but differently: while fish movements were mainly observed during the first three days of the flushing in 2012, which corresponded to the highest SSC, movements occurred throughout the 2016 flushing event. Fish moved downstream during the sediment release, approximately the same distance for the two flushing events (i.e., about 1.5 km, depending on species).

Table 1: Summary of the operational characteristics of the 2012 and 2016 flushing events, and impacts on fish.

	Flushing event	
	2012	**2016**
Operational characteristics		
Reservoir emptying	complete	partial
Period	9-21 June	21-30 May
Duration (days)	13	9
Mean (peak) SSC ($mg.l^{-1}$)	11 (48)	3.3 (11)
Metrics for fish impact assessment		
Acoustic density (S_A, $m^2.ha^{-1}$) after / before flushing	↘	→
Return of S_A to pre-flushing level (resilience)	no	yes
Displacement distances of marked fish below the dam (km)	< 1.5	< 1.5
Overall apparent survival rate φ of marked fish (%)	73.8%	72.7%
Observed mortality along the riverbanks	high	very low

4 DISCUSSION

We showed that the fish community within the reservoir was better able to cope with the flushing event when the emptying was partial. This maintained a higher volume of habitat in the reservoir, and generated lower water velocities which allowed the less rheophilic species to withstand these conditions. We observed that the behaviour of fish, as measured by the distance travelled downstream to the dam during the flushing, was similar for both events despite very distinct mean and peak SSC. However, the 2016 event did not lead to massive fish mortality as observed along the riverbank in 2012. This suggested that a mean SSC of a few $g.l^{-1}$ (3.3 $g.l^{-1}$ in 2016) may be tolerated for the duration of the sluicing provided the peak SSC is controlled.

Overall, we concluded that the 2016 flushing had fewer impacts on the fish community, with mainly behavioural impacts. The control of the SSC downstream of the dam and the partial emptying of the reservoir allowed fish to withstand the disturbance, and are key elements to mitigate impacts on the fish community. Further investigations should emphasize on the best compromise between the SSC and the duration of the flushing, and should attempt to better evaluate the optimal recurrence time between flushing events (Grimardias *et al.* 2017).

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