Protecting fish from entering turbines: the efficiency of a low-sloping rack for downstream migration of Atlantic salmon smolts

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ABSTRACT. – In April 2015, the efficiency of a system of low-sloping rack and bypass has been assessed for Atlantic salmon smolts at the small hydroelectric plant (HEP) of Auterrive on the Gave d'Oloron River (France ; turbine discharge: 7.8 $m^3.s^{-1}$; rack inclination: 26° relative to the horizontal ; bar spacing: 20 mm ; bypass discharge: 0.5 $m^3.s^{-1}$). 239 hatchery smolts (mean length 185 mm) were PIT-tagged and released 100 m upstream the HEP, in 5 groups at different times of the day. Their passages downstream the HEP by the bypass and as well by the fishpass for upstream migration were monitored with RFID antennae. On average 80.7% of smolts migrated through the HEP bypass and 3.8% of smolts descended through the fishpass. In total, 84.5% (min-max: 75.5–91.9%) of smolts migrated downstream the HEP via safe routes. 50% of them did it in less than 23 minutes since their release and 75% of them did it in less than 2 hours. Fish migration time was similar for afternoon, evening and night releases (median times between 19 and 21min), but was significantly longer when the fishes were released in the morning (median migration time: 3hours 17min). Our findings give credence to the recommended design criteria for low-sloping racks, which is the main solution implemented in France for small HEPs.

Key-words: fish protection system, hydroelectric, downstream passage, Salmonids

Eviter l'entrainement des poissons dans les turbines : efficacité d'un plan de grille incliné pour les smolts de saumon atlantique

RÉSUMÉ. – En avril 2015, l'efficacité d'un système de plan de grille incliné et d'exutoires de dévalaison a été évaluée pour les smolts de saumon atlantique à la centrale d'Auterrive sur le Gave d'Oloron (France, débit turbiné : 7.8 $m^3.s^{-1}$; inclinaison du plan de grille : 26° par rapport à l'horizontale ; espacement libre entre barreaux : 20 mm ; débit des exutoires : 0.5 $m^3.s^{-1}$). 239 smolts d'élevage (longueur moyenne 185 mm) ont été marqués avec des PIT tag et déversés dans le canal d'amenée 100 m en amont de la centrale, en 5 lots à différents moments de la journée. Leurs passages par les exutoires, ainsi que par la passe à poissons pour la montaison ont été suivis avec des antennes RFID. En moyenne 80.7% des smolts ont dévalé par le dispositif de dévalaison et 3.8% ont emprunté la passe à poissons. Au total, 84.5% (min-max : 75.5–91.9%) des poissons ont dévalé par une voie saine. La moitié des smolts a mis moins de 23 minutes depuis leur lâcher pour franchir l'ouvrage et 75% a mis moins de 2 heures. Les temps de passage ont été similaires entre les lots relâchés l'après-midi, le soir et la nuit (durées médianes entre 19 et 21 min), mais ont été significativement plus longs pour les poissons relâchés le matin (durée médiane de 3H et 17 min). Les résultats de cette étude apportent du crédit aux critères de conception des prises d'eau équipées de plan de grille inclinés, configuration aujourd'hui largement privilégiée en France.

Mots-clés : protection des poissons, hydroélectricité, dévalaison, Salmonidés

I. INTRODUCTION

Fish downstream migration through hydroelectric installations is a major concern because turbine entrainment is a significant source of immediate and/or delayed mortality for several endangered migrating fish species [see Travade and Larinier, 2006; Gomes and Larinier, 2008; Larinier, 2008 for study review]. A wide variety of fish protection systems have been developed including low-sloping racks with bypass (Figure 1). In France, the ONEMA (Office National de l'Eau et des Milieux Aquatiques) recommends: (1) low bar spacing (≤ 25 mm for salmon and sea trout smolts, ≤ 15-20 mm for silver eels), (2) a normal velocity ≤ 0.5 $m.s^{-1}$, (3) an inclination angle relative to the horizontal ≤ 26° to guide fish to the top of the rack; and (4) several criteria for the entrance's design, including dimensions, spacing and entrance velocity which allow to define the bypass discharge based on the intake characteristics of the hydroelectric plant (HEP) [see Courret and Larinier, 2008; Courret *et al.*, 2015 for more details]. Previous hydraulic studies [Raynal *et al.*, 2012; 2013] have confirmed satisfactory conditions for energy production (acceptable head-loss) and for fish (good guidance, no risk for impingement). However, the biological efficiency of systems meeting all these criteria remains to be tested *in situ*, what is the main objective of this study.

II. MATERIEL AND METHODS

In April 2015, we studied the efficiency of the fish protection system for Atlantic salmon smolts at the small hydroelectric plant (HEP) of Auterrive on the Gave d'Oloron River. This HEP (maximum intake capacity of 9.5 m^3s^{-1}) is equipped with a fishpass for upstream migration and a low-sloping rack with a bypass for downstream migration. The rack in front of the turbine (Figure 1) is inclined at 26° with a 20 mm bar spacing (6 m of width, 5.5 m of submerged length) and has two bypass entrances at the top: one on the right side (0.5 m of width) and the other in the middle (0.7 m) of the rack, both fed with total discharge of 0.5 m^3s^{-1}. 239 hatchery PIT-tagged salmon smolts (mean body size 185 mm) were released in five groups in the intake channel, 100 meters upstream of the HEP, at different times of day: morning, afternoon, evening, night (Table 1). Their downstream passages were monitored with four RFID antennae: one in the right-side bypass entrance, two in the bypass (near the exit), and one in the fishpass. During the study, the mean intake discharge of the HEP was 7.8 m^3s^{-1} and the total discharge in the bypass was 0.5 m^3s^{-1} (6.4%). The proportion of successfully migrating fishes (through the bypass and the fishpass) and the migration time (difference between the time of the last detection in the bypass and the time of fish release) have been computed.

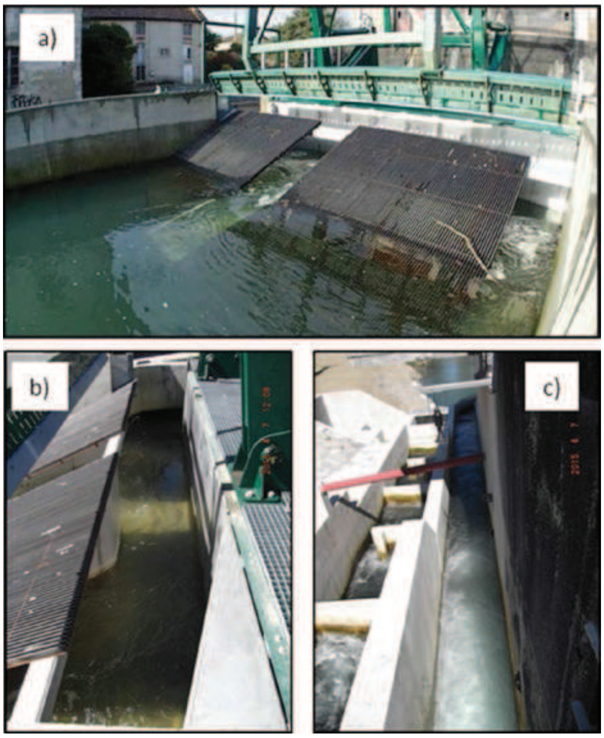

Figure 1 : *a) The view of submerged studied low-sloping rack with two entrances, b) bypass immediately after the entrances, c) the following bypass channel and the fishpass (left side of the photo) of the Auterrive HEP.*

III. RESULTS

On average 80.7% (min-max: 75.5–89.2%) of smolts migrated through the bypass, and 3.8% of smolts (0–6.4%) descended through the fishpass (Table 1). In total, 84.5% (min-max: 75.5–91.9%) of released smolts successfully crossed the HEP using these two migration passes. No difference in passage success was observed among different releasing moments, but an influence of fish storage duration is suspected (the efficiency decreases slightly with study time, Table 1).

Table 1 : Proportion of individuals detected (or not) in the bypass or the fishpass of the Auterrive HEP.

	Number of individuals	Time of release		Proportion of individuals (%)			
					detected in		bypass + fishpass
				undetected	bypass	fishpass	
group 1	37	07/04/2015	20:20	8,1	89,2	2,7	91,9
group 2	59	08/04/2015	14:48	11,9	84,7	3,4	88,1
group 3	47	09/04/2015	21:21	17,0	76,6	6,4	83,0
group 4	49	09/04/2015	23:28	24,5	75,5	0,0	75,5
group 5	47	10/04/2015	10:25	14,9	78,7	6,4	85,1
weighted average				15,5	80,7	3,8	84,5

Table 2 : Migration time of individuals detected in the bypass of the Auterrive HEP.

	Number of individuals	Time of release	Min.	1Quartile	Median	3Quartile	Max.
group 1	33	evening	0:11:03	0:14:59	0:18:47	0:23:12	0:58:55
group 2	50	afternoon	0:07:47	0:13:53	0:18:29	0:31:51	46:13:00
group 3	36	night	0:12:49	0:15:05	0:20:04	0:39:47	5:46:54
group 4	37	night	0:11:50	0:15:33	0:21:36	0:54:26	47:00:00
group 5	37	morning	0:12:43	2:28:12	3:17:00	6:37:06	54:18:34
all groups	193		0:07:47	0:15:33	0:22:24	1:51:50	54:18:34

First fishes were detected in the proximity of rack entrances 7 minutes after their release. 50% of smolts passing through the bypass did it in less than 23 minutes since their release and 75% of them did it in less than 2 hours (Table 2). Fish migration time was similar for afternoon, evening and night releases (median migration times between 19 and 21min), but was significantly longer when the fishes were released in the morning (median migration time: 3hours 17min, Table 2).

IV. DISCUSSION

Fish-guidance of studied low-sloping rack is considered quite satisfactory because first fishes were detected in the proximity of the bypass entrances very quickly after their release and migration times were overall short (Table 2). However, during the study we observed some fishes approaching the entrances but not entering immediately. Instead, fishes hesitated and spent more time upstream the rack before finally entering, either by bypass, fishpass or probably passing through the rack and turbine (for not detected fishes). The velocity acceleration and higher hydraulic turbulence in the bypass entrances may explain fishes' hesitation. Reducing this velocity variation and hydraulic turbulence should improve the overall efficiency of this fish protection system. However, we also observed a preferential incoming flow on the right bank (unexpected during the project) leading to the creation of the recirculation zone at the top of the rack along the left bank. The fish spent time in this zone without bypass entrance and it could be detrimental to the bypass attractiveness and overall efficiency. Based on this finding and in addition to the general criteria, a particular attention should be paid to the position of the bypass entrances in order to fully adapt it to the site-specific flow organization.

On average, we detected 84.5% of released smolts successfully crossing the HEP (Table 1). We hypothesize that remaining undetected 15.5% passed through the rack and the turbine (fish width being inferior to the bar spacing in our study). They could also swim upstream in the intake channel up to the river and avoid the passage through the HEP. In this case, we should adjust the number of tested fish for the efficiency computation (by deleting upstream migrating fish) but it is not possible (the number of upstream migrating fish is unknown in our study). For this reason, we present the efficiency results as a minimum value.

75% of individuals detected in the bypass successfully crossed the HEP in less than 2 hours (Table 2) and in less than 1 hour if we exclude the group released on the morning. We state that this migration time, representing the migration delay, is very low.

V. CONCLUSIONS

In conclusion, despite some points to improve and given that the measured efficiency is a minimum value, we found the efficiency of the HEP low-sloping rack to be satisfactory compared to previous studies of trashracks with bypasses [Larinier and Travade, 2002; Travade and Larinier, 2006]. Estimated fish mortality on the Auterrive HEP equipped with the Kaplan turbine is 5.2% [Anonymous, 2002] and the installation of the low-sloping rack (and the fishpass) on this site (with 84.5% passage efficiency) reduced the fish mortality to 0.8%. We conclude that such fish protection devices implemented at catchment scale should decrease significantly the cumulative impact of HEPs on Atlantic salmon populations. Our findings give credence to the recommended design criteria for low-sloping racks [Courret and Larinier, 2008; Raynal *et al.,* 2012; 2013; Courret *et al.*, 2015], which is the main solution implemented in France for small HEPs. However, additional studies are needed to evaluate different types of rack configurations, on bigger HEPs and including other migratory fish species, especially silver eels.

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