Field test for mortality of eel after passage through the newly developed turbine of Pentair Fairbanks Nijhuis and FishFlow Innovations

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Summary

Mortality of fish during passage of hydropower turbines is a worldwide problem especially for migratory fish species. In this study we test a new type of turbine by Pentair Fairbanks Nijhuis/FishFlow Innovations that was purposely developed to be fish-friendly. In a controlled experiment we exposed groups of European eel Anguilla Anguilla to passage through this new turbine and compared direct and delayed mortality of these groups to control groups of eels that received a similar handling and treatment except for the passage of the turbine. A Pentair Fairbanks Nijhuis/FishFlow Innovations turbine (diameter of 0.80 m and three blades that are more curved and rounded than traditional Kaplan-type turbines) was installed alongside pumping station Leeghwater at Buitenkaag, the Netherlands. Six trials were carried out with two different treatments of turbine passage (the guide vanes open at an angle and fully opened) and a control, all in Duplo with ca. 79 eels per trial. After the experiment eels per duplo group were stored together in a large pontoon and checked after 96 h for delayed mortality. No direct mortality was found, nor any abnormal swimming behaviour or severe injuries. The frequency of occurrence of minor injuries showed no differences between control groups and treatment groups. Delayed mortality after 96 hours was limited to 0.9 % of all groups combined, and were found in the controls group compartment (n=2) as in one of the treatments compartment (n=2), indicating that these were not linked to turbine passage but most likely were due to the catching, handling and transport of the eels. This first test showed that this new type of turbine appears to be very promising as an alternative for existing turbines in reducing and perhaps even avoiding fish damage during turbine passage.

Samenvatting

Sterfte van vis tijdens het passeren van turbines in waterkrachtcentrales is een wereldwijd probleem, met name voor migrerende vissoorten. In deze studie testen we een nieuw type turbine die is ontwikkeld om visvriendelijk te zijn door Pentair Fairbanks Nijhuis/FishFlow Innovations. In een gecontroleerd experiment zijn groepen Europese paling Anquilla anquilla gedwongen blootgesteld aan passage via deze nieuwe turbine en zijn de directe en vertraagde sterfte van deze groepen vergeleken met controle groepen paling die afgezien van turbine passage een gelijke behandeling hebben gehad. Een Pentair Fairbanks Nijhuis/FishFlow Innovations turbine (diameter 0.8 m en drie bladen die ronder zijn dan van conventionele Kaplan turbines) is geïnstalleerd bij gemaal Leeghwater te Buitenkaag, Nederland. Zes trials werden uitgevoerd met twee verschillende standen van de leidschoepen (gedeeltelijk open en volledig open) en een controlegroep, elk in duplo met ca. 79 palingen per trial. Na het experiment werden de palingen van de duplo trials gecombineerd per groep ondergebracht in een groot ponton en na 96 uur werd de vertraagde sterfte bepaald. Er is geen directe sterfte gevonden, evenals abnormaal zwemgedrag of ernstige verwondingen. Het voorkomen van kleinere verwondingen vertoonde geen verschil tussen de verschillende groepen. Vertraagde sterfte was 0.9 % na 96 uur gemiddeld over alle groepen, en werden zowel aangetroffen in de controle groep (n=2) als in één van beide behandelde groepen (n=2), hetgeen suggereert dat deze niet gerelateerd is aan turbine passage, maar zeer waarschijnlijk als gevolg van het vangen, hanteren en transporteren van de paling. Deze eerste test laat zien dat dit nieuwe type turbine een veelbelovende techniek is om vissterfte in turbines te verminderen of zelfs weg te nemen.

1. Introduction

An important environmental issue for hydroelectric power production is mortality of fish passing the turbines (Coutant & Whitney 2000). Especially diadromous fish populations such as salmonids or eel are affected by mortality due to passage through single or series of hydropower plants (Winter et al. 2006, Winter et al. 2007). A variety of mitigation measures to minimize turbine-induced mortality have been tested and implemented world-wide. This mitigation measures usually involves a combination of a bypass construction and deflection or guidance systems blocking the turbine intake. These mitigations typically lower the overall mortality rate to some extent, but complete prevention of mortality is not reached with the exception of inclined screens (Reuter et al. 2001), which are costly and debris sensitive.

The most effective way of preventing fish mortality in turbines is to develop turbines that allow passage without any injury (Cada 2001). Most efforts so far included adaptations and adjustments to already existing designs, rather than newly designing fish friendly turbines (e.g. Becker et al. (2009).

In this study we test a new type of turbine by Pentair Fairbanks Nijhuis/FishFlow Innovations that was purposely developed to be fish-friendly. Because the European eel *Anguilla anguilla* is in strong decline (Dekker 2003) and eel is especially vulnerable for hydropower mortality due to its life history and long body lengths when migrating downstream to sea (Calles et al. 2010), this species was selected as test fish for this study. In a controlled experiment we exposed groups of eel to passage through the new turbine and compared direct and delayed mortality of these groups to control groups of eels that received a similar handling and treatment except for the passage of the turbine.

2. Assignment

Initially also an experiment with the fish species carp *Cyprinus carpio*, tench *Tinca tinca* and perch *Perca fluviatilis* was intended, but because only a very limited or too large sized individuals were available, this experiment was limited to determining the effect of the tested turbine on eel.

3. Materials and Methods

Study site

A Pentair Fairbanks Nijhuis/FishFlow Innovations fish-friendly turbine was installed alongside pumping station Leeghwater at Buitenkaag, the Netherlands. The turbine has a diameter of 0.80 m and three blades that are more curved and rounded than traditional Kaplan-type turbines. Water head at this location was 5.5 m on average. Turbine rotation frequency was 250-280 rpm. Water velocity within the turbine was 4.5 m.s⁻¹. A trash rack with 10 cm between bars at the entrance prevented debris from entering the pipe with the turbine (with a 10 m upstream section from the turbine to the trash rack and a 4.2 m downstream section from the turbine to the exit of the pipe). Just after the water inlet an additional upward directed opening was present in the pipe.

Experimental set-up

To test whether the turbine causes mortality of eel, a controlled experiment was carried out in duplo with two different treatments of turbine passage and a control, i.e. 3 different groups of eel subdivided over 6 trials. The two 'treatments' that were tested were; passage through the turbine with 1) the guide vanes fully open and 2) the guide vanes open at an angle of 30 degrees. The treatments were randomly allocated to the 6 trials. The eels of the four 'treatment' trials were inserted in the upward directed opening in the inlet pipe of the turbine. The eels of the two control trials were inserted at the outlet pipe

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of the turbine. The outlet of the turbine pipe exit downstream of the pumping station was enclosed by a net with 20 mm meshes that covered an 3 by 10 m area, and 2 water depth. This allowed the eel to be collected after each trial.

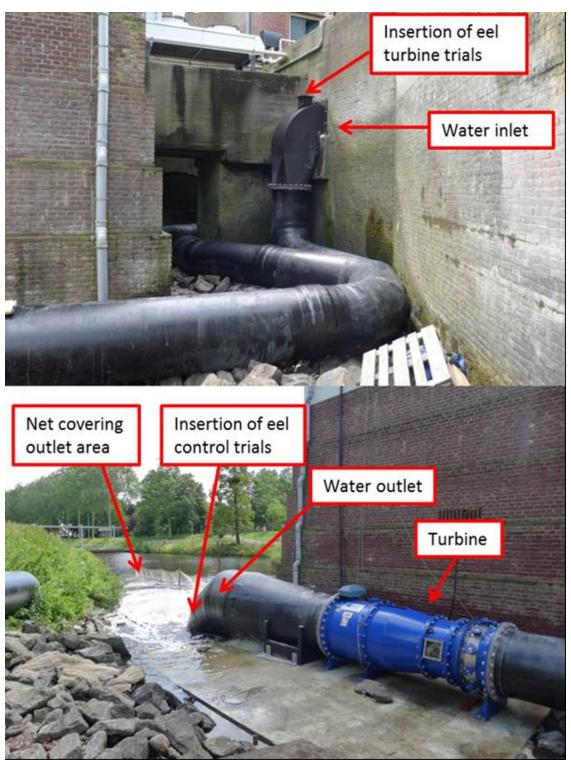


Figure 1. Overview of the pipe-construction with the turbine from the upstream water inlet (top panel) to the downstream water outlet (bottom panel). The location where the eels were inserted for the different trials, the net covering the outlet area and the position of the turbine are indicated.

Test fish and measurements

For this experiment we used eels that were delivered by an aquaculture company and eels that were wild caught. The wild caught eels were collected by electrofishing the day before the experiment was conducted (August 2nd 2012). Both wild caught eels (ranging 37-84 cm in length) and eels from aquaculture (ranging 28-55 cm in length) were transported with a van with tanks aerated with oxygen. The eels of different origin were evenly distributed over the 6 trial groups: 53 eels from aquaculture and 26 wild caught eels, making 79 eels in each of the 6 trial groups. For logistical reasons and to minimize stress due to the handling of the eel the sorting procedure was carried out as quickly as possible and as a result miscounting by one or two might have occurred for some of the trial groups.

After each trial, the eels were collected from the net. Because the eels from aquaculture had pale greyish dorsal and white ventral sides and the wild caught eel had dark olive-brownish dorsal and yellow ventral sides, for each of the checked eels the origin could be determined. For each eel, total length was measured (cm), state (alive-death) and eventual type of visible injuries were determined. All visible injuries were noted by type and typical examples photographed. In addition, each eel was checked for swimming behaviour (normal sinuous movement and activity – abnormal swimming behaviour with indications for spinal injuries) in a tank.

Because some internal injuries might remain undetected we also determined delayed mortality after 96 h. For this, a pontoon with three large compartments (3,2 m by 2 m and 0,6 m depth) and in open connection with surface water was placed in the waterway upstream from the turbine. The duplo trials for each of the 3 groups (i.e. 2 different treatments and 1 control) were combined per group and stored in each of the three compartments. Thus, delayed mortality could only be determined per group and not be separated by trial.



Photo: Overview of the net covering the outlet area (left), recovering the eel after a trial (top right panel), and during the turbine in operation (bottom right panel).

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Data treatment

During the course of the experiment it became apparent that starting from trial 3 less eel were recovered than were inserted for each of the trials. Whereas in trial 1 and 2 assumingly all inserted eel were recovered, respectively 80 and 79 eels, in the three trials thereafter fewer eel were recovered, i.e. 73 in trial 3, 70 in trial 4 and 64 in trial 5. Because the water current flowing into the net was relatively strong and a few eel were observed to escape through a small tear in the net after trial 5 (which was then repaired), it was assumed that all missing eel had escaped after leaving the outlet. However, when after the last trial the net was completely removed and emptied, more eels than were inserted were recovered, i.e. 93 in trial 6. Thus, at least some eel inserted during a previous trial were included in trial 6, and to a lesser extend this possibly also applies to trial 4 and 5. Total number of eels inserted was 474 eels, assuming 79 on average per trial, whereas in total 458 eel were recovered after the trials. This suggests that during trial 3, 4 and 5 about 16 eel have escaped, and that for trial 4, 5 and 6 at least about 14 eels (93 minus 79) have been assigned to the results of a later trial than the trial during which they were inserted.

4. Results

None of the trials showed direct mortality for eel (table 1). All eel showed normal sinuous swimming behaviour and no indications for spinal injuries were found. Mean lengths and fraction of wild caught eel versus eel from aquaculture were similar between trials and groups.

Table 1. Summary of the results of the field-test for the Pentair Fairbanks Nijhuis/FishFlow Innovations turbine. Two trials were performed for each of the three groups; i.e. two treatment groups (with guide vanes fully open and at an angle of 30°) and a control where eel did not pass through the turbine but received similar handling. For each trial, the order in which they were carried out, the number of eels recovered after the trial, different

length parameters, direct mortality, swimming behaviour and delayed mortality are given.

Group	Control		Turbine, guide vane 30°		Turbine, guide vane open	
Trial order	3	5	2	4	1	6
N eels recovered after trial	73	63	79	70	80	93
Fraction wild caught eel	0.64	0.73	0.71	0.69	0.70	0.71
Mean length ± st.dev. (cm)	42.0±9.1	40.7±8.3	40.6±8.0	40.3±7.5	41.3±9.4	42.8±10.6
Length range (cm)	32-75	31-64	31-76	28-60	31-75	31-84
Direct mortality %	0 %	0 %	0 %	0 %	0 %	0 %
Normal swimming % *	100 %	100 %	100 %	100 %	100 %	100 %
Mortality after 96 h %, _(n; length of death eel)**	1.5 % (n=2; 32, 36 cm)		0 %		1.2 % (n=2; 35, 57 cm)	

^{*} Sinuous swimming with no indications for spinal injuries

No severely injured eel were found during the experiment. Part of the eels checked after each of the trials showed minor injuries (Figure 2). The most frequent occurring minor injuries were minor skin damages (19-39 % per trial), such as scratches, and nose damage (16-34%), mostly reddish tips of the upper or lower jaw. Tail damage (4-13%) and small blood stains in fins (4-21%) were less abundant but found in each trial. More rarely found type of injuries were infection of the underjaw (0-4%), all in eel from aquaculture, local bruises on the skin (0-4%), i.e. a reddish stain on the skin, and some bleeding from a gill (0-2%). No apparent differences were found between the treatment trials and control trials, with perhaps the exception of the bleeding of a gill. The four eel in which this was observed all originated from treatment groups, but the frequency in which this occurred was very low (on average 1.3 % in the treatment trials).

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^{**} For the delayed mortality the two Duplo trials per group were stored in one compartment

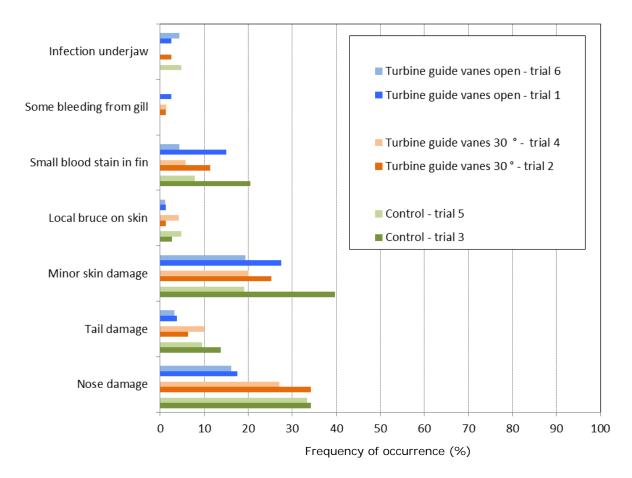


Figure 2. Overview of the frequency of occurrence of the observed minor injuries after each of the trials.

After 96 hour in storage in a three compartments of a large pontoon, four eels out of 458 (0.9 %) had died. Two in the compartment with the control trials, two in the compartment with the turbine and guide vane fully open group and none in the compartment with the turbine and guide vanes at 30° (table 1). The lengths of the four dead eels did not match the lengths of the four eels that showed some bleeding from a gill (37 and 60 cm after trial 1, 40 cm after trial 2 and 36 cm after trial 4). Two eels with bruises were found and they were well alive after 96 hours.

There was no statistical evidence that delayed mortality rates were dependent upon treatment (p=0.47; Fisher's exact test), with the observed numbers of deaths and recovered eels as given in table 1 (2 deaths out of 63+73=136 for Control; 0 deaths out of 79+70=149 for guide vane 30° ; 2 deaths out of 173 for guide vane open). As explained above, there is a small chance that the two deaths in the control group (trial 5) originated from the 'guide vane 30° ' treatment group (trial 4). If the two deaths from the Control group are re-allocated, there is also no evidence that mortality rates were dependent upon treatment (p=0.56; Fisher's exact test; 0 deaths out of 63+73-2=134 for Control; 2 deaths out of 79+70+2=151 for guide vane 30° ; 2 deaths out of 173 for guide vane open). In the unlikely event that all four observed mortalities were from the treatment groups (2 deaths each in the for guide vane 30° and guide vane open groups), point estimates and 95% confidence intervals of mortality rates for each of the two groups are: 1.32% (0.27%-4.13%) for treatment group vane 30° , and 1.16% (0.24%-3.62%). However, these estimates are conservative, because there is no evidence of an effect of treatment on death rate.

5. Discussion

The results of this study suggest that newly developed fish friendly turbine from Pentair Fairbanks Nijhuis/FishFlow Innovations indeed allows safe passage for eel. No direct mortality was found, nor any abnormal swimming behaviour or severe injuries. The frequency of occurrence of minor injuries showed no differences between control groups and treatment groups. Moreover, most of these injuries, particulairly with infections, appeared to be inflicted during periods before the experiment was carried out, Delayed mortality after 96 hours was limited to 0.9 % of all groups combined, and were found in both the controls group compartment (n=2) as in one of the treatments compartment (n=2), whereas the other treatment compartment showed no mortality (n=0), indicating that these four deaths were not linked to turbine passage, but most likely the result of multiple catching, handling, storing and transporting the eels.

Some eels were assigned to a following trial during trials 4 to 6, however, this does not affect the conclusion that no direct mortality occurred, or abnormal swimming behaviour was found because this was found for no eel throughout the entire experiment. For the delayed morality, it cannot be excluded that the two eels that were found dead after 96 hours in the control compartment originated from a trial with turbine passage. But then no mortality should have occurred in the majority of the treatment group that were caught directly after passage and no mortality should have occurred in the control group, whereas both delayed deaths occurred in the smaller number of eels that were assigned to the wrong group. This highly unlikely scenario would result in an estimate of 1.3 % delayed mortality for the tested turbine. However, it is much more likely that the delayed mortality of these four eels is linked to the stress, several times catching, storing, handling and transporting of the eel. This is supported by the fact that two eel were found to have died before conducting the experiment. Also the type of minor injuries found appear more linked to other factors than turbine passage. Also, the four eel that were found to show some bleeding from the gill, did not match with the lengths of the eels that showed delayed mortality. And therefore the conclusion that turbine passage did not result in direct or delayed mortality for eels seems justified.

In short, this new type of turbine appears to be very promising as an alternative for existing turbines in reducing and perhaps even avoiding fish damage during turbine passage.

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6. Quality Assurance

IMARES utilises an ISO 9001: 2008 certified quality management system (certificate number: 57846-2009-AQ-NLD-RvA). This certificate is valid until 15 December 2012. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025: 2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

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The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

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