ICES CM 2006/J:24

Just go with the flow?
How individual behaviour and river discharge affects silver eel mortality in the river Meuse

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Abstract- The European eel, *Anguilla anguilla,* population shows a strong decline over the past decades. Fisheries and hydropower induced mortality during the downstream migration of silver eels presumably play an important role. River discharge is assumed to play an important role in the onset of migration. This study therefore focuses on the effects of river flow on mortality of downstream migrating silver eel. Furthermore, the impact of individual behaviour on mortality is discussed. To quantify the impact of hydropower and fisheries on silver eel mortality, radio-telemetry experiments were performed in the river Meuse in 2002-2006. A total of 300 silver eels were surgically implanted with Nedap-transponders. This experiment distinguishes between individuals entering the turbine and individuals passing over the adjacent weir. Furthermore, the timing of migration and passage behaviour near detection stations was determined. Mortality rates caused by hydropower stations depended on the number of eel passing the weir/HPS and the water flux through the turbines. Observed behavioral factors, such as hesitation and avoidance of individual eels in front of a hydropower station are discussed. Furthermore, river discharge influences fisheries mortality by affecting the migration route of silver eel in the downstream area. Fishing intensity, and therefore fishery mortality, differs between the routes. The effect of river discharge and individual behaviour on fisheries and hydropower mortality will be discussed in a management context.

Keywords: migration, individual behaviour, river discharge, radio telemetry, hydropower, fishery, silver eel

Introduction

European eel is a catadromous species that migrates during the larval phase from the Sargasso Sea to freshwater basins in Europe and most likely return as adults to their natal grounds to spawn. The European eel population, however, shows a strong decline over the past decades. Among many other factors, fisheries and hydropower induced mortality during the downstream migration of silver eels are thought to play an important role. Recent studies showed that one cohort suffers between 14-23 % mortality due to hydropower turbine passage, 23-27% fisheries induced mortality and for the remaining 17-30% of the silver eels that ‘disappeared’ during downstream migration, fate was unknown (natural mortality/experimental induced mortality/tag loss or failure/resident eels) (Winter *et al.*, 2004).

The downstream migration is time dependent and generally takes places during a couple of weeks in autumn. River discharge is assumed to play an important role in the onset of migration. This study therefore specifically aimed to identify the effects of river discharge on silver eel mortality during the downstream run. River discharge affects HPS-mortality in two ways; 1) by the fraction eel passing the weir/HPS and 2) by mortality rates within turbine. However, hesitation and avoidance behaviour of individual eels in front of a hydropower station (Winter *et al.*, 2004) might to affect the mortality rates by increasing the number of eel which escape from entering the HPS. River discharge also affects fishery mortality by influencing the migration route in downstream area. In order to protect the species efficiently, management is important.

Materials & Methods

Study area

This study was performed in the Dutch part of the river Meuse in which two hydropower stations (HPS) are located (figure xx.xx). Fisheries in the River Meuse are most abundant in the downstream sections of the Rivers Meuse and Rhine, usually with large fykenets. In the upstream Dutch section of the River Meuse, fisheries are performed with electrofishing, more extensive fykenet-fishing and anchored stow nets at two locations, directly downstream HPS 1 and HPS 2.

Fish telemetry

To quantify the impact of hydropower and fisheries on silver eel mortality, radio-telemetry experiments were performed in the river Meuse in 2002-2006. A total of 300 silver eels (length >64 cm) were surgically implanted with Nedap-transponders; 150 in 2002 and 150 in 2004 (Winter *et al.*, 2004). The tag with a label with instructions should easily be discovered while preparing the caught eels for consumption. A clearly readable reward of 30€ was put on recovering a tag to maximise the return rate. In total 15 fixed detection stations (Nedap Trail-System®) in the river Meuse were used, each covering the entire river width, including all outlets to sea (figure 1.). At the two hydropower stations, detection stations covered the entrance of the turbines. This allowed distinguishing passage through turbines from passage over adjacent weirs (figure 2.). Furthermore, the timing of migration and passage behaviour near detection stations was determined.

Distribution of silver eels in relation to river discharge

Whether eel are divided conform the river flow was assessed by comparison between the observed fraction of eel passing the weir/turbine and the estimated fraction of eel passing the weir/turbine. The estimation was made by means of the fraction of river flows through the turbines and over the weir. Unfortunately only data of flow rates in the turbine versus weir was available for a short period in 2004.

Fisheries mortality versus river discharge

Fisheries mortality is indicated by the number of returned transponders by fisherman (commercial and recreational). Since eel seems to divide conform the river flow, river discharge in the downstream area indicates the most likely way eel will follow during their downstream migration. Fisheries mortality differs between migration routes in the downstream area (pers. comm.).

HPS mortality management

Within this study HPS mortality is discussed for one of the two HPS stations situated in the Dutch part of the river Meuse. Only for Linne HPS the required data was available. Observed HPS mortality was indicate to eel that were detected by the entrance station just upstream from the HPS but not downstream at station Linnedorp, and that were not recovered by the anchor stow nets.

However, HPS mortality can also be estimated by the number of eel entering the HPS and the mortality change within the HPS. Hadderingh & Bakker (1998) investigated turbine related mortality at Linne HPS. They demonstrated that flow rates turned out to be a responsible factor for the level of mortality. This is probably due to the relative small openings between the blades of both the guide vanes and the runner blades at low discharges. Bruijs *et al* (2003) found an inverse relationship between mortality and turbine flow at Linne HPS (figure 3; relation 2002: $Mort = 2.8 * Flow^{-0.6888}$).

Flow rates in the turbines are highly dependent on HPS management. The Linne HPS has four, horizontal, Kaplan-bulb turbines (ref). Turbines are automatically switched on/off at certain levels of river discharge (table 1.) (KEMA, 2004). The flux is thereby equally divided over the total number of working/running turbines. Management by increasing respectively decreasing river discharges varies. The maximum HPS flux is 500 m3/s and the station keeps on running up to a river flux of 800 m3/s, above that all turbines are switched off. The remaining flow is sent over the weir. Data of flow rates through the turbines were available for a just a short period (month-month 2004, including some blank dates). Estimation of turbine flow rates for the whole experimental period are made by means of river flow rates at Eisden in relation to HPS management. To validate the use of estimated turbine flow rates, results from the observed flow rates were compared to results of the estimated flow rates for the same time interval. Finally, estimated eel mortality is calculated at an daily level by the total number of eel detected at the HPS in relation to mortality change as indicated by turbine flow rates (figure 3.). Data is aggregated to total mortality rates per period.

Behaviour

Eel passage of the river stations was characterized by usually only one or a series of detections with two minutes intervals, whereas the passage of the detection stations near HPS showed a different pattern (Winter et al., 2004). Besides eel that were once detected, one group showed recurrence with intervals above 2 minutes, varying from several hours to several weeks. Another group showed stationary behaviour indicated by a series of detections with two minute intervals. This avoidance and hesitation behaviour in front of a HPS might be the explanatory factor for the difference between the observed and the estimated mortality at HPS Linne. Eel showing odd behaviour might seek for alternative ways to pass the HPS, for example by migration through the fish passage or over the weir. Four scenarios for escapement of eel near the HPS are developed:

1) all that show recurrence behaviour at HPS Linne will use the fish passage or weir
2) all fish that show stationary behaviour at HPS Linne will use the fish passage or weir
3) all fish that show either recurrence or stationary behaviour at HPS Linne will use the fish passage or weir
4) all fish that show either recurrence or stationary behaviour and show more that 3 detection at HPS Linne will use the fish passage or weir

For each scenario three parameters are calculated; number of eel passing the HPS, number of eel detected at Linnedorp and the estimated number of eel at Linnedorp. When behaviour aspects explain the difference in mortality rates the estimated and the observed number of eel at Linnedorp should be equal. For each scenario the goodness of fit was calculated (100%= best explanatory scenario).

Results & Discussion

Distribution of silver eels in relation to river discharge
Both cohorts (2002 & 2004) start their downstream migration in autumn when the river flow increases (figure 4.). In both years a steep migration peak was observed, although the 2002-peak was steeper than the one in 2004. In general the peak is followed by a more gradual pattern. When approaching weir and HPS barriers eel are divided over the different routes in accordance to the river flow (table 2).

In the downstream area the river Meuse splits into two branches. The division of river discharge over the two branches is highly dependent on management. During times with high discharge, river flow will be via route 1 (Haringvliet), while in times with low river discharge water will be guided via route 2 (Nieuwe waterweg). This can clearly been seen in figure 5: in 2002 discharge was high and water flew via route 1 while 2004 was a fairly dry year and water was guided through route 2.

Fisheries Mortality
Comparing fisheries mortality of the two cohorts in the downstream area shows a lower mortality for the 2004-cohort. Because eel follow the main stream (table 2.), the migration routes in both year varied (table 3.). Fisheries intensity is higher in Haringvliet (route 1) and so ´dry´ years eel face less fisheries mortality (table 3.).

HPS
The average number of detections per detection station is higher for HPS Linne compared to other river stations (respectively 8.1 and 2.6). This was observed in both year. This indicates avoidance and hesitation behaviour.

In total 157 eel were detected at the detection station just upstream from the HPS entrance, and 141 of them were detected at Linnedorp. Based on mortality rates in the HPS it was estimated that only 130 individuals would survive. Eel seems to have a better survival than predicted by theoretical models. Avoidance and hesitation behaviour in front of a HPS might be a explanatory factor for the difference between the observed and the estimated mortality at HPS Linne. Out of the 157 eels detected at the entrance of HPS Linne, 55% were once detected, 26% showed recurrence and 20% showed stationary detections. Table 5a&b give an overview of observed and estimated number of detected eel at HPS Linne and Linnedorp for all scenarios. None of the behavioural scenarios give a good explanation for the higher survival of eel, which indicates that the difference is not caused by behaviour but by other factors. Not all eels that are injured by turbine blades when passing hydropower stations, suffer instantaneous mortality (Hadderingh & Bakker, 1998; Bruijs *et al.*, 2003). In this study such delayed mortality was not taken into account. Eel suffering from lethal injuries might still pass detection station Linnedorp but die in one of the following river stretches. Since HPS mortality is related to fish length (figure 3; Haddering & Bakker, 1998) an under estimation could haven been made by using the mortality-formula of 2002. This formula is based on individuals with an average length of 64.4 cm, while the test fish for this experiment had an average length higher than 65 cm.

Management implications

Most of the eel migration takes place during a couple of weeks in autumn when the river discharge starts to increase (figure 3). Fisheries and mortality are both factors of considerable importance determining the fraction of silver eel that successfully pass the Dutch section of the river Meuse (Winter et al., 2003). Thus in order to protect the species, management measures could be implemented. This study showed that eel behave differently (recurrence and stationary) in front of a hydropower station, however, this behaviour does not seems to directly increase their survival rates (table 5). This might, however, set possibilities for fish guiding systems.

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Figures

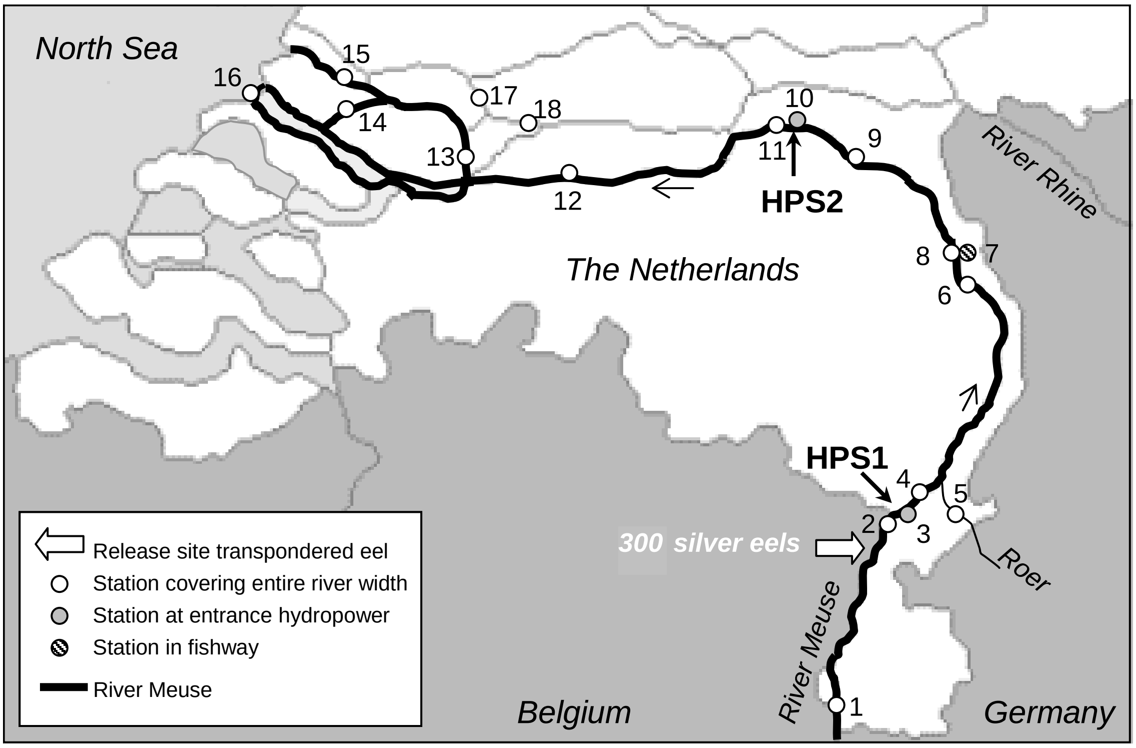

Figure 1. Map of the study area with the location of the different detection stations along the course of the River Meuse. The location of the two hydropower sations is shown (HPS1 and 2). The small arrows indicate flow direction of the river.

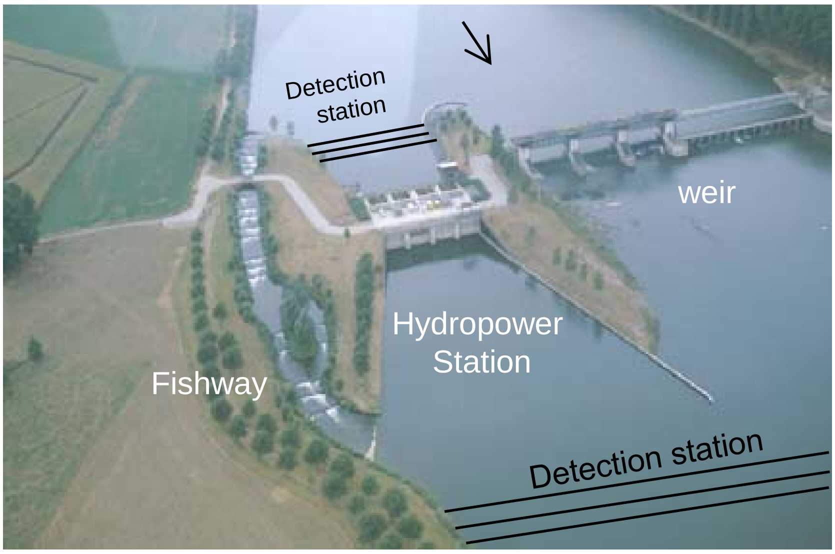

Figure 2. Overview at hydropower station HPS1 (Fig 1.). The location of the detection stations at the entrance of the turbines and downstream at the bottom of the entire river width is shown schematically. A similar situation is present at HPS2. The arrow indicates river flow direction.

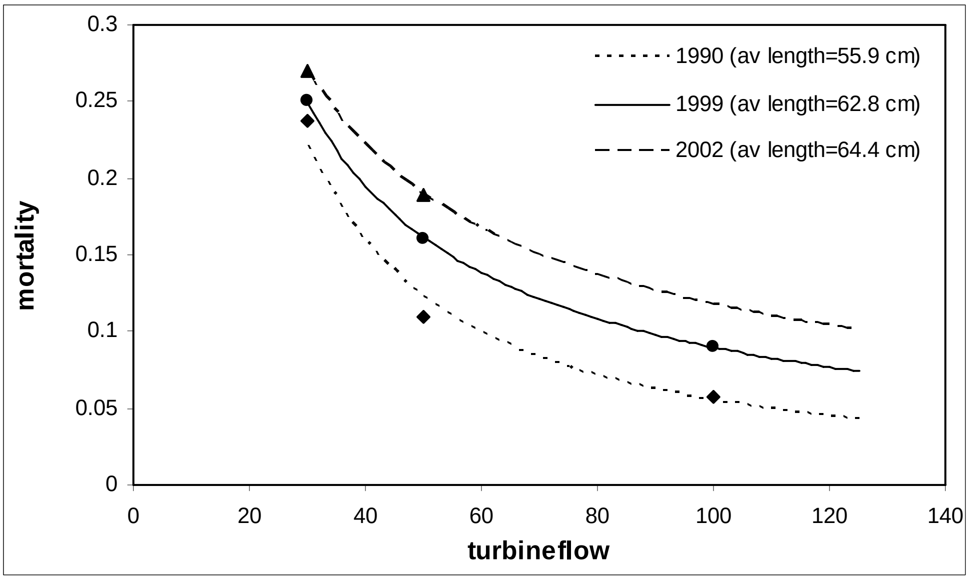

Figure 3. Percentage of eel mortality at different turbine flows at Linne Hydropower station *(based on: Bruijs et al., 2003).*

Table 1. Management of HPS Linne in relation to river discharge (*Based on; Kema, 2004*)

Number of turbines running	River discharge by switching on turbines	River discharge by switching off turbines	Turbine flux	Flux over Weir	Flux through fish passage
0	0-30	0-30	0	River flux	5
1	30-69.5	30-62.4	River flux/1	0	5
2	69.5-144.4	62.4-102	River flux/2	0	5
3	144.4-158.4	102-144	River flux/3	0	5
4	158.4-500	144-500	River flux/4	0	5
4	500-800	500-800	500	River flux - 500	5
0	>800	>800	0	River flux	5

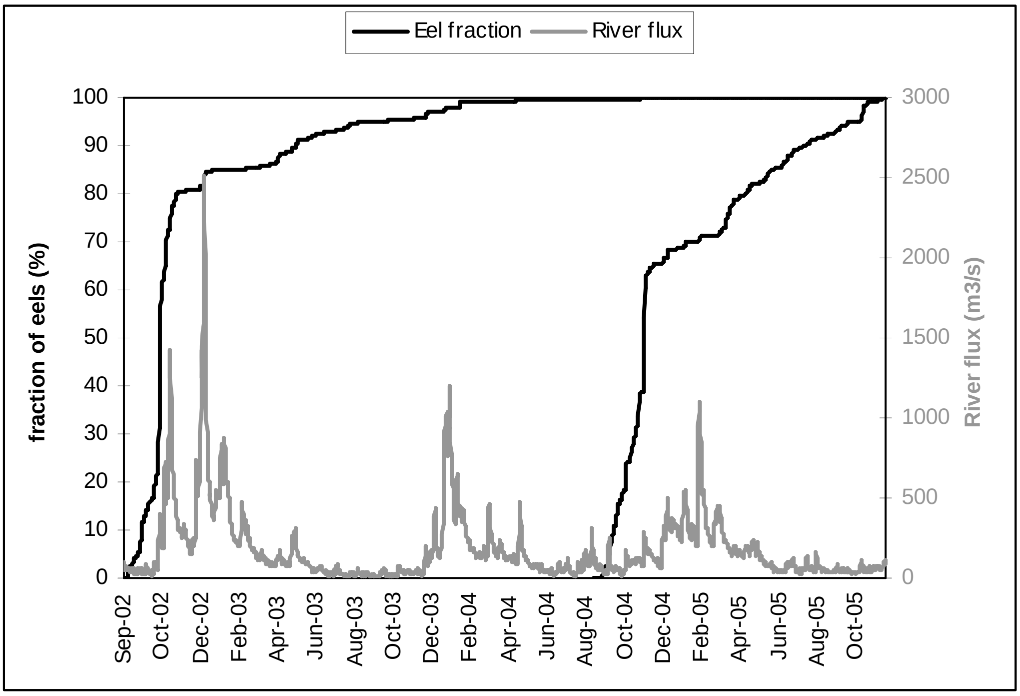

Figure 4. River discharge in relation to eel migration. Cumulative percentage of eel passage of transpondered eels by all detection stations.

Tabel 2. Division of silver eels approaching the weir and HPS at Linne that select the entrance of the HPS and that select the weir or fish passage as observed from the transponder experiment and compared to as estimated from the discharge through the turbine and over the weir and fish passage at the time of approach. These results indicate that silver eels are distributed over the different routes according to the relative discharge of each of the routes.

	HPS	Weir + Fish passage
Number of eel – observed	40	7
Number of eel – estimation	39.3	7.7

Figuur 5 – River discharge at Haringvliet (sea entrance) in 2002 and 2004. This figure clearly shows that discharge in autumn 2004 was much lower than in 2002.

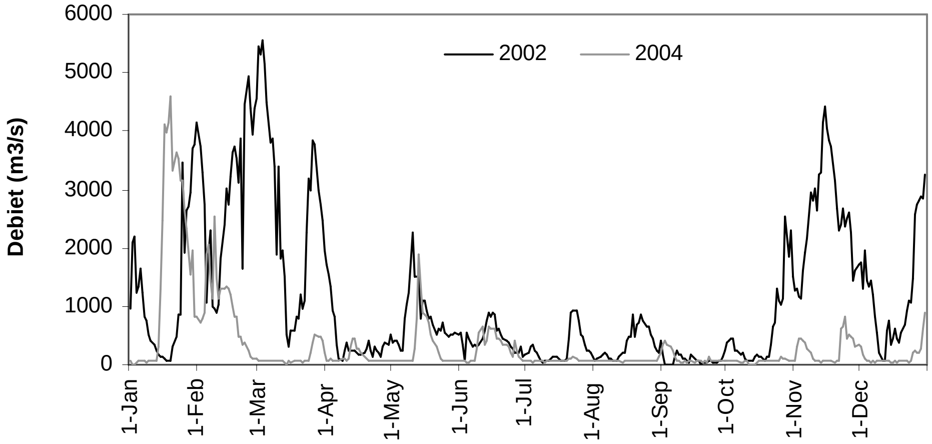

Table 3. Number of eel reaching the North Sea by the two different braches in the downstream area of the river Meuse. Fisheries mortality is indicated by the number between brackets

	Total	Route 1: Haringvliet	Route 2: Oude Maas
Batch 2002	41 (8)	27 (8)	14 (0)
Batch 2004	30 (0)	6 (0)	24 (0)
Total	71 (0)	33 (8)	38 (0)

Table 4. Average number of detections per eel for the detection stations (all river stations are averaged in one variable “other river stations” except for Stevensweert (release site) and Linnedorp, which are the river stations where settlement behaviour causes high number of detection per individuals)

Station	2002	2004	Average
HPS Linne	6.9	9.3	8.1
Other river stations	3.3	1.9	2.6

Table 5a Number of observed and estimated eel at HPS Linne and Linnedorp. Based on observed flow data through turbines at HPS Linne (selective period)

	Scenario				
	Base line	Recurrence	Stationary	Stationary + Recurrence	Stationary + Recurrence + >3 detections
HPS Linne	55	52	46	43	50
Observed- Linnedorp	53	50	44	41	48
Estimation- Linnedorp	46	43	38	36	41
Fit (%)	86	87	87	87	86

Table 5b. Number of observed and estimated eel at HPS Linne and Linnedorp. Based on estimated flow data through turbines at HPS Linne (whole experimental period)

	Scenario				
	Base line	Recurrence	Stationary	Stationary + Recurrence	Stationary + Recurrence + >3 detections
HPS Linne	157	146	122	111	136
Observed- Linnedorp	141	130	108	97	121
Estimation- Linnedorp	130	122	102	93	114
Fit (%)	92	93	94	96	94