Research on downstream migration of salmon smolts (tagging/tracking), from the tributary Roer into the river Meuse and the North Sea

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Summary

As part of the recovery plan of Atlantic salmon, smolts are being released into the tributaries of the rivers Rhine and Meuse. The percentage of adult salmon which return in the tributaries of the Rhine is estimated at 1% of the number of salmon smolts released. The percentage of returning smolts in the river Meuse is much lower than 1%. For the conservation of a salmon population at least 3% of the smolts must return. One possible cause is the loss of smolts during their downstream migration. To gain insight into the migratory behaviour of smolts in the catchment area of the Meuse, and particularly in the tributary Roer at the ECI hydro power plant in the town Roermond, the Royal Dutch Angling Organisation (Sportvisserij Nederland) has contracted VisAdvies BV to carry out research on downstream migration of smolts. The study took place during the period from March 2010 until May 2011. In both years, 100 smolts were equipped with a remote detectable internal tag (transponder) and released in the tributary Roer. The fish could be tracked using the NedAp Telemetry System, from the tributary Roer, via the Meuse into the North Sea.

In 2010 and 2011, 88% and 65% of the tagged smolts was observed on at least one detection station; 56% and 55% reached the Meuse; and 2% and 3% reached the North Sea. All fish left the freshwater via the sea lock Haringvlietdam.

The mortality of smolts appears to be mainly caused by predation from predatory fish and birds. In the stretch on the river Meuse between the town Lith and the North Sea, mortality also occurred due to damage suffered from passage through the hydro power plant at Lith (immediate and postponed mortality – fish damaged in the hydropower plant). Because in both years smolts hardly passed via the weir, a comparison between the effect of passage through the hydro power plant or via the weir, is not possible. The discharge of the Meuse appears to affect the behaviour of smolts near the inlet of the hydro power plant at Lith. In 2010 (high discharge) and 2011 (low discharge) smolts were on average 1.5 and 29 times observed at the inlet of the hydro power plant.

The sea lock Haringvlietdam prevents a natural fresh-salt transition in the original estuary (the lakes Haringvliet and Hollands Diep). This is probably a major influence on the orientation of the smolts in the area. Disorientation and delay in migration can pose an increased risk of predation.

The fish guidance system and the smolts bypass at the ECI hydro power plant seem to work well. Based on both the catches in the smolts bypass and near the hydro power plant, and registrations of smolts at the upstream NedAp tracking station, it appears that the smolts managed to pass the hydro power plant using the fish guidance system.

1 Introduction

1.1 General

With the aim of reintroducing salmon into the rivers, salmon eggs and young salmon of various life stages have been released since 1984 into tributaries of the Meuse (in the Ardennes and the tributary Roer in the Eifel region) and the Rhine (e.g. in the Sieg and Ahr).

During their stay in the river the young salmon gets an imprint of the characteristic smell of the river, and after spending 1-3 years at sea, they return as adult salmon. The return rate of adult salmon is very low. The percentage of smolts that return in the tributaries of the Rhine as adult salmon is estimated to be 1% (Rhein 2020 Lachs, 2004). For the conservation of a salmon population at least 3% of the smolts must return (MUNLV - NRW (2006). The number of returning adult salmon in the Meuse is lower than that of the Rhine. In 2004, a few adult salmons have been observed that found their way through the Meuse and moved into Belgium.

Possible causes for the low return rates are:
- stocking a too small number of smolts;
- mortality of smolts during their downstream migration in the tributary Roer (predation, hydropower, etc.);
- high mortality at sea at feeding grounds, because of by catch in commercial fishing;
- high mortality of returning adult salmons in the tidal river area, because of by catch in commercial fishing;
- and the impact of weir and sluice buildings in the river system.

With the focus on loss of smolts during their downstream migrating, there are indications that these are caught by commercial fishermen in Lake IJssel (Hartgers & Van Willigen, 2000). Also post-smolts are taken in coastal waters in the Haringvliet in May and June (Vriese & Wiegerinck, 1991).

So far there is limited knowledge on the downstream migration patterns of smolts in the river Meuse, the losses during the migration and the number of fish that successfully reach the North sea. Little or no knowledge is available about the downstream migration of smolts in the tributary Roer. In 2009-2011 studies were conducted on the migration of smolts in the river Meuse, using the NedAp Trail System ®. In these studies 13%, 5% and 0% of the tagged smolts reached the North Sea. It is also proven that smolts passing a hydro power plant downstream show a higher mortality than smolts that pass the weir downstream (Kemper et al, 2010).

In the Rhine several studies were conducted on the downstream migration of smolts (Vriese, Laar & Break, 2006, 2007; Spierts et al, 2008, 2009, 2010). The results of the survey carried out in 2011 are not yet available. The research in 2006 was a pilot study in which the options were explored for implantation with NedAp transponders. In the following years, extensive studies have been conducted on the migration of smolts in the Rhine. The proportion of marked smolts which may have reached the

North Sea in 2007, 2008, 2009 and 2010, was respectively 46%, 18%, 12.5% and 28%. The losses on the Meuse are clearly larger. Presence of dams and hydro power plants play an important role. In the study area in the river Rhine these were not present. In addition, the discharge varies greatly between the two rivers, which may affect the chances for smolts to reach the North Sea. In 2010 a new detection station was installed in the water ways Nieuwe Waterweg and the Hartel Kanaal. Previously it was assumed that smolts reached the North sea after they were registered at the stations in the waterway Oude Meuse, de Noord, or in the Lek.

The ECI hydropower station at Roermond formed an important obstacle to the downstream migrating smolts. Nowadays the hydro power plant is equipped with a fish guidance system, a so called "wedge wire screen" which consists of very small apertures in the duckweed fence before the turbines, and in front of that three diversions over the hydro power plant. These three are: the smolts bypass, a bypass going under the barrier (the eel bypass) and the fish ladder.
Most recently it has been established that the survival of smolts in the Meuse, that pass the hydro-power plants in Linne and Lith is significantly worse than has hitherto been assumed (Kemper et al, 2010). An important question in the present study is to what extent the fish guidance system in the tributary Roer at the ECI hydro power plant is successful in redirecting downstream migrating salmon smolts. This research can be an initial evaluation of the functioning of this system.

In order to increase knowledge of the migratory behaviour of smolts in the catchment area of the Meuse, and especially in the tributary Roer at the ECI hydro power plant in the town Roermond, the Royal Dutch Angling Organisation commissioned VisAdvies BV to carry out research on downstream migration of farmed salmon smolts during the period from March 2010 until May 2011.

1.2 Objectives

The objectives of the study are:

1. evaluating the performance of the fish guidance system for downstream migrating salmon smolts in the tributary Roer at the ECI hydro power plant in Roermond;
2. gaining insight into the migratory behaviour of smolts (route, timing, migration rate, delay, etc.) in the Roer and the Meuse;
3. determining factors that influence migration;
4. quantifying the mortality of smolts during their downstream migration, and the final escapement to the sea;
5. comparing migration data from different years, to investigate the discharge in the Meuse and its impact on the successful migration of smolts to the sea;
6. comparing the differences between the migration from both the river Berwijn (in Belgium) and the river Roer, both tributaries of the Meuse.

2 Materials and methods

2.1 Test area

The locations of the stations of the detection NEDAP TRAIL System ® in the Rhine / Meuse system are shown in figure 2.1 and table 2.1.

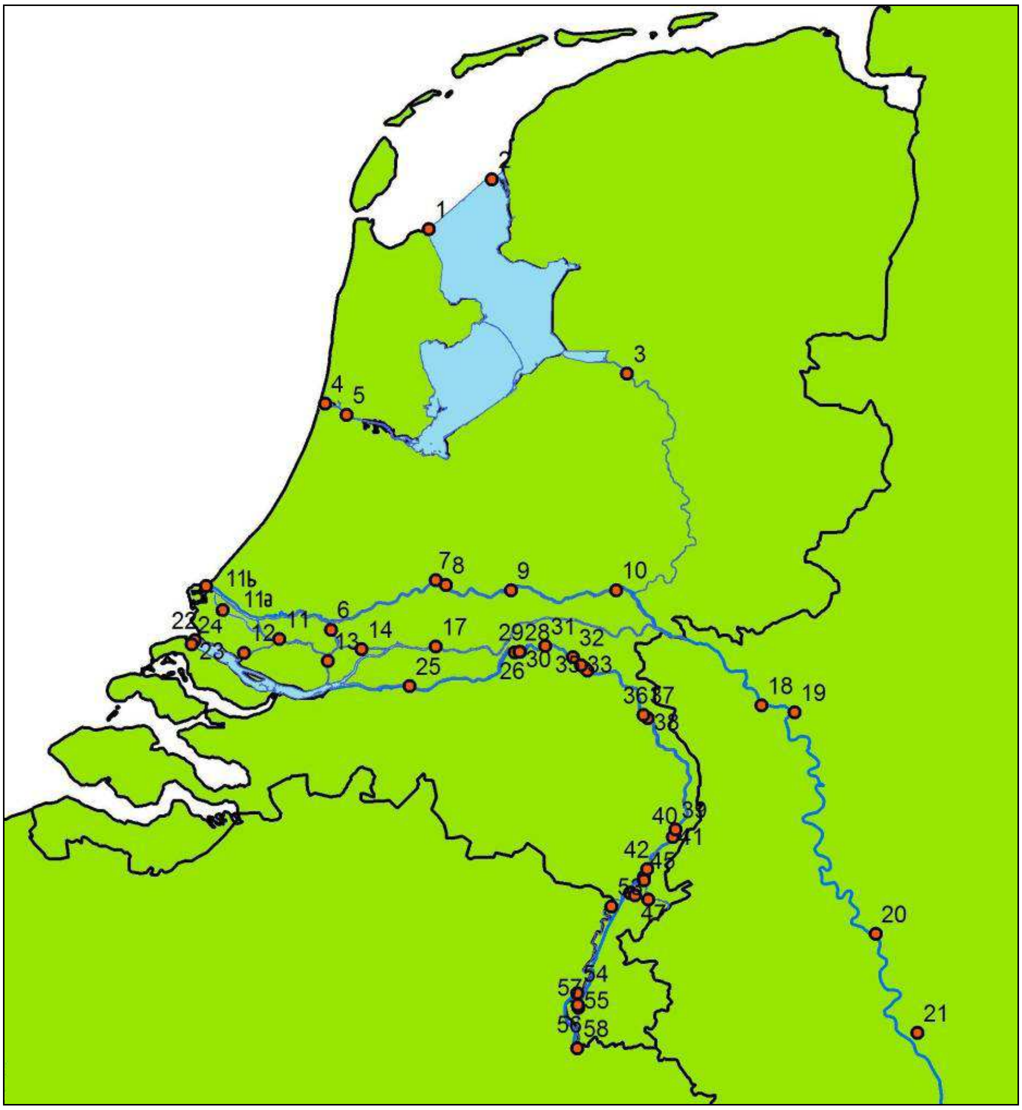


figure 2.1 *Schematic representation of the locations of the various detection stations in the Rhine / Meuse system (situation June 1, 2010).*

table 2.1 *Overview of detection stations in the Rhine / Meuse Rivers System and the lower river area (Dutch: Beneden rivierengebied). Ben: bottom; Bov: top; Be: Belgium.*

nr	naam	nr	naam
1	IJsselmeer_Den Oever	**31**	Maas_Megen
2	IJsselmeer_Kornwerderzand	**32**	Maas_Niftrik_Loonsewaard
3	IJssel_Kampen	**33**	Maas_Balgoij
4	NZK_IJmuiden_gemaal	**34**	Maas_Grave_vispass.
5	NZK_Velsen	**35**	Maas_Grave_bov
6	De Noord_Kinderdijk	**36**	Maas_Sambeek_ben_stu
7	Lek_Nieuwegein	**37**	Maas_Sambeek_vispass
8	Nederrijn_Hagestein	**38**	Maas_Afferden
9	Nederrijn_Maurik	**39**	Maas_Steyl
10	Nederrijn_Arnhem	**40**	Maas_Belfeld_vispass.
11	Oude Maas_Spijkenisse	**41**	Maas_Belfeld_bov
11a	Hartelkanaal_Europoort	**42**	Maas_Buggenum
11b	Nieuwe Waterweg_Europoort	**43**	Maas_Linne_vishevel
12	Spui_Zuidland	**44**	Maas_Roermond_vispass.
13	Dordtsche Kil_s'Gravendeel	**45**	Maas_Roermond_bov
14	Ben Merwerde_Sliedrecht	**45a**	Roer Roermond_ECI_bov
17	Waal_Brakel	**46**	Roer_Sint_Odiliënberg
18	Rijn_Xanten	**47**	Maas_Linne_dorp
19	Lippe_Wesel	**48**	Maas_Linne_vispass.
20	Wupper_Burrig	**49**	Maas_Linne_wkc_ben
21	Sieg_Menden	**50**	Maas_Linne_stuw_ben
22	Haringvliet_Stellendam_noord	**51**	Maas_Linne_wkc_bov
23	Haringvliet_Stellendam_zuid	**52**	Maas_Linne_stuw_bov
24	HV_Stellendam_scheep	**53**	Grensmaas_Stevensweert
25	Bergsche Maas_Cap. Veer	**54**	Grensmaas_Itteren
26	Maas_Lith_dorp	**55**	(vervallen)
27	Maas_Lith_vispass.	**56**	Grensmaas_Bharen_vis
28	Maas_Alphen_wkc_ben	**57**	Maas_Maastricht
29	Maas_Lith_stuw_ben	**58**	Berwijn_Moelingen
30	Maas_Alphen_wkc_bov		

2.2 Material

2.2.1 NEDAP Trail system®

We used the NedAp Trail System ® (Bij de Vaate & Breukelaar, 2001). The method is based on inductive coupling between an antenna and a ferrite rod antenna in the transponder. The antenna is positioned on the bottom of the river / canal, from shore to shore. This telemetry system can be used in rivers, canals and estuaries. For the transmission of signals, a narrow band low frequency (33.25 kHz) was chosen resulting in a high-sensitivity receiver with low probability of interference from radio signals and other disturbances. The choice of frequency was based on the consideration that the link between the transponder and antenna on the river bed acts as a transformer (inductive coupling). This means that no radio signals are transmitted and therefore no interference occurs with radio use.
Every four seconds the transmission station (detection station) sends out an interrogation signal, with which the transponder antenna that passes, will be activated. The transponder responds by transmitting an unique signal, which is then decoded and

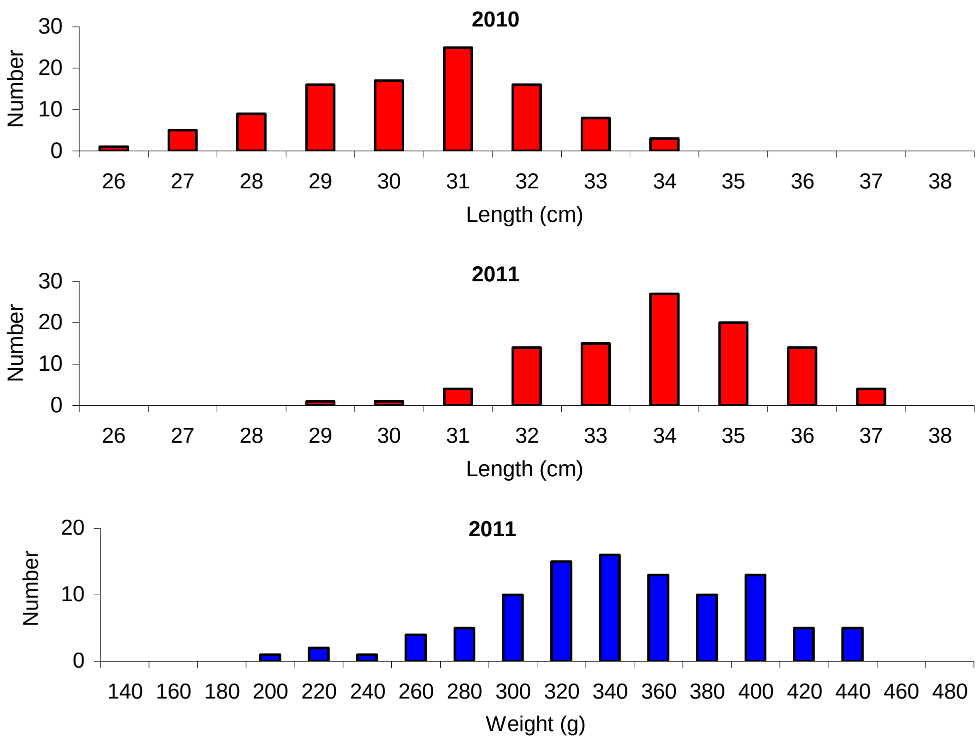
recorded by a microprocessor. This unit is connected to a modem. Sending a transponder signal lasts two periods of 8 seconds each, separated by 8 seconds silence. In each broadcast period of 8 seconds, the unique code of the transponder is transmitted 32 times. In a single transmission period, the transponder can be recognized up to 64 times. After the complete transmission cycle of 24 seconds, the transponder is turned off for 2 minutes, to prevent the batteries from running down, in case a fish decides to stop over the antenna.

From field tests it became clear that the signal exchange between a transponder and a detection station still fully operates under the following conditions (Bij de Vaate en Breukelaar, 2001):

- at an antenna length of 550 m from the detection station;
- at a depth of 15 m;
- if the transponder passes the detection station at a speed of at least 5-6 $m.sec^{-1}$ (the cruising speed of a tagged fish, including the flow of the river).

2.2.2 Salmon smolts

The study needed the approval of the Animal Experiments Committee (Dutch: Dieren Experimenten Commissie - DEC). The test plan was submitted and received a positive recommendation (Appendix II). For the study, 200 smolts were tagged, 100 in 2010 (30,4 ± 1,8 cm TL) and 100 in 2011 (34,0 ± 1,6 cm TL, figure 2.2). The average weight in both years was 238 ± 46 g and 354 ± 53 g. A complete overview of the fish data is shown in Appendix I. In addition, in both years 2010 and 2011 an equal number of smolts without transponders was released at the same time and on the same location where the tagged smolts were released.



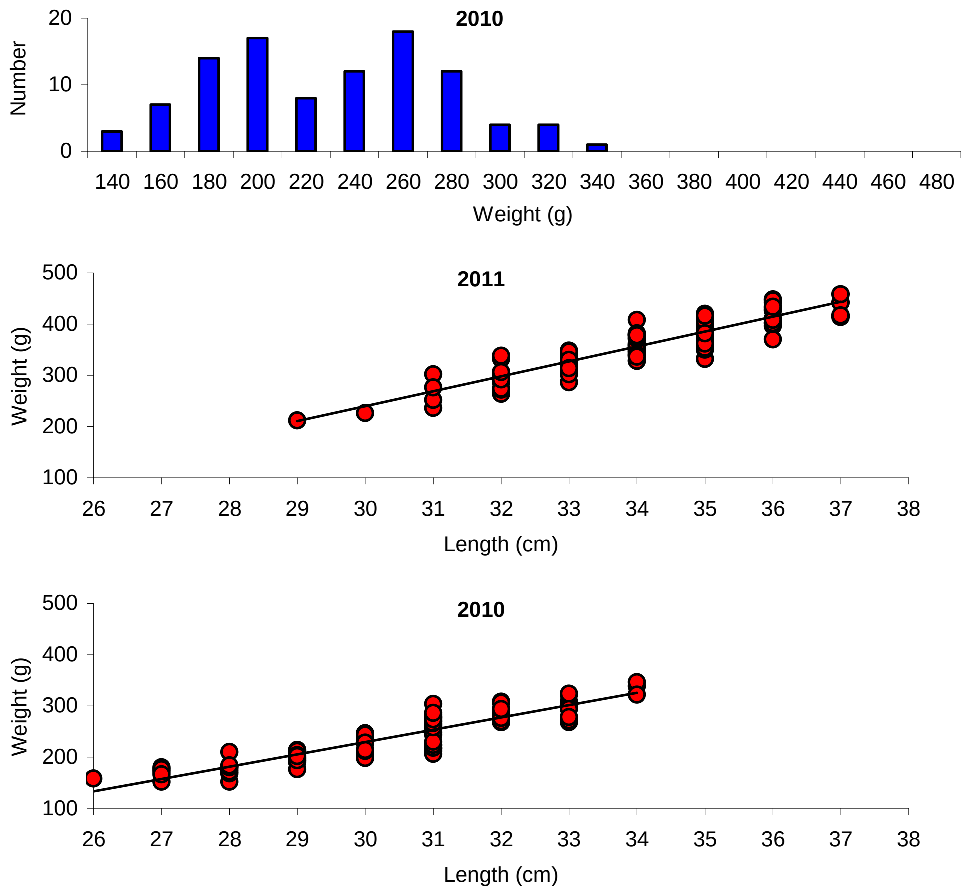


figure 2.2 *Length frequency distribution, weight distribution and length-weight relationship of the tagged smolts.*

2.3 Method

2.3.1 Insertion of transponders

The 200 salmon smolts were equipped with transponders by experienced staff from VisAdvies BV and the Royal Dutch Angling Association, on 22, 23, 24 March 2010 (N=100) and on 2 and 3 March 2011 (N=100). The smolts (Loire-Allier stem) were obtained from fish farm Chanteuges (France), and were temporarily held in storage by Mohnen Aquaculture (Germany). The smolts were selected for their external fitness and had a minimum weight of 150 grams and a minimum length of 25 cm. The minimum weight was chosen based on the weight of the transponder (11.5 g). For fish is the "rule of thumb" that the weight of the transponder does not to exceed 2% of its body weight. Studies in rainbow trout showed that tags with a ratio of 6-12% of the weight of the fish caused no significant changes in behaviour (Brown *et al*. 1999). The ratio of a smolt of 150 g is 7.7%. The worst ratio in these tagged smolts was 7.6%. For 91.5% of the tagged smolts this was less than 6%.

The fish were stored for several days in a basin at fish farm Valkenswaard (Netherlands), after that they were provided with an internal transponder. Before tagging, the length (cm) and weight (g) was recorded. In the period between the moment of tagging and the release in the river Roer, the smolts were stored in a tank at the site of fish farm Valkenswaard. The time they were held at the fish farm was - depending on the tag date - in 2010 2-4 days, and 11-12 days in 2011. During this period smolts were regularly checked for abnormal behaviour and healing of the wounds, but no problems occurred and all fish appeared to be healthy and fit.

The transponders weigh 11.5 grams in air and are contained within a shell of HDPE (High Density Poly Ethylene), Ø: 13 mm; length: 38 mm. Transponders were inserted surgically. The fish were brought into a state of surgical anaesthesia by applying a solution of benzocaine 100 ppm. The fish was placed in specially designed surgical facilities. The operation made use of sterile drapes, gloves and surgical material. An incision was made approximately 2-2.5 cm along the *linea alba* between breast and anal fins, ensuring that the internal organs were not damaged. After the internal control the sterile transponder was placed in the abdomen, and the incision was closed with sutures (Ethicon Vicryl, cutting needle 3 / 0). After surgery the fish was brought to live in a basin with running water, whereby it was continuously observed. As expected, the fish recovered from the operation after a few minutes. After that they began to swim actively in the tank.

The transport from one location - where the tagging took place) to the other, where the fish were being released (upstream of St. Odiliënberg in the tributary Roer - was done by employees of the fish farm Valkenswaard. During transport the smolts were provided with the correct oxygen concentration. The smolts were released on March 25, 2010 and March 14, 2011 (9:30 pm). The red circle on the map in figure 2.3 shows this location.

2.3.2 Data processing

When processing the telemetry data distinction is made between signals, detections and registrations.

- <u>Signal</u>: When a tagged fish passes a detection station, the transponder sends out a signal with a unique code within 24 seconds and up to 64 times.
- <u>Detection</u>: One observation based on a series of 64 signals, collected within 24 seconds.
- <u>Registration</u>: A registration is equivalent to a detection provided the next detection occurs within 3 minutes. This filter is set to three minutes to exclude additional detections of fish that linger within the range of the detection station.

An important aspect related to detection is the swimming direction. If a fish is recorded for the second time within three minutes at the same station, it is assumed that the swimming direction is reversed. On the basis of records from consecutive detection stations it has been determined that in 91.5% of the cases, the swimming direction was indeed opposite (Bij de Vaate & Breukelaar, 2001).
In the case of registration at successive stations, the uncertainty about the swimming direction after passing a station, is of limited relevance. After all, upon registering at each subsequent station the swimming direction is confirmed. If a fish passes the final station several times, the uncertainty about the swimming direction increases. If the swimming direction is not confirmed by a registration with a different station, the certainty decreases with 8.5% per registration.

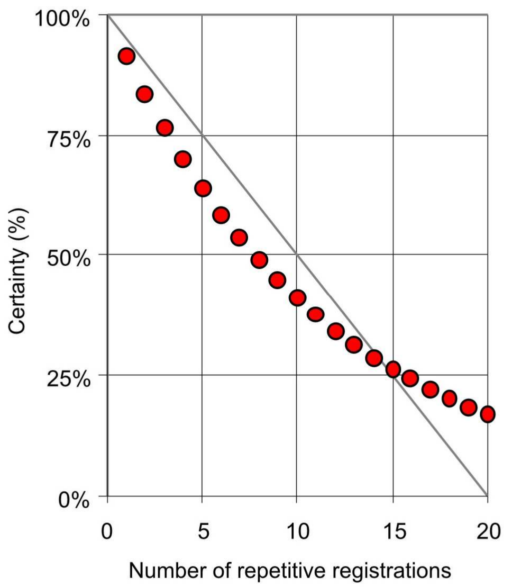


figure 2.3 *Certainty about the swimming direction after successive registrations on one and the same detection station.*

In figure 2.4, the relation between the number of consecutive registrations at one station has been plotted against the reliability that a fish swims in the supposed direction. Following this, it is decided to use up to three registrations for determination of the swimming direction. With three registrations, the certainty that the fish swims in the supposed direction is just over 75%.

Throughout the report, all percentages are expressed relative to the total number of smolts tagged and released, unless otherwise indicated.

3 Results

3.1 Results 2010

Registrations were collected from the time of release on March 25, 2010 to August 29, 2011. A total of 1040 registrations were received from 88 different smolts (88%) derived from 21 different detection stations.

3.1.1 Registrations per station

Of the 100 tagged smolts, 88 passed the detection station in the tributary Roer near the town St. Odiliënberg (table 3.1). After their release in the Roer, 12 smolts were never tracked.

table 3.1 *Smolts that passed the station, and the loss of smolts from one station to the other, during the downstream migration via the Meuse. (Meuse: river Maas; Ben: bottom; Bov: above). *: The overall loss is unknown due to multiple migration routes.*

Name of the station	Number of smolts passed	Loss in numbers compared to the previous station	% that passed, compared to initial release
Roer_st Odiliënberg	88	12	88
Roer_ECI_bov	54	*	*
Vangst ECI-centrale	18	*	*
Meuse_Roermond_bov	56	32	56
Meuse_Buggenum	53	3	53
Meuse_Belfeld_bov	47	6	47
Meuse_Steyl	45	2	45
Meuse_Afferden	39	6	39
Sambeek_stuw_ben	39	0	39
Meuse_Grave_bov	34	5	34
Meuse_Balgoij	34	0	34
Meuse_Megen	33	1	33
Meuse_Lith_stuw+WKC+vispassage	30	3	30
Meuse_Lith_dorp	28	2	28
Bergsche Meuse_ Capelse veer	27	1	27
Spui_Zuidland	2	*	*
Oude Meuse_Spijkenisse	2	*	*
Haringvlietdam_Noord	1	*	*
Haringvlietdam_Zuid	2	*	*
Haringvlietdam_Scheep	0	*	*
Have reached the North Sea	**3**	**24**	**3**

At the station upstream of the ECI hydro power plant 54 smolts were registered. In the smolts bypass at the ECI hydro power plant 18 tagged and 10 untagged smolts have been captured. The low number of captured smolts can be explained by the fact that the smolts bypass was out of order during the period March 31 t / m 7 April 2010, so in that period the smolts could pass the ECI hydro power plant unseen. On the first station in the Meuse (Roermond_stuw_boven) 56 smolts were registered. 32 smolts (57%) reached this station via the ECI hydro power plant, and 24 smolts (43%) via the Hambeek (figure 3.1). Of the 100 tagged smolts 44 never left the tributary Roer.

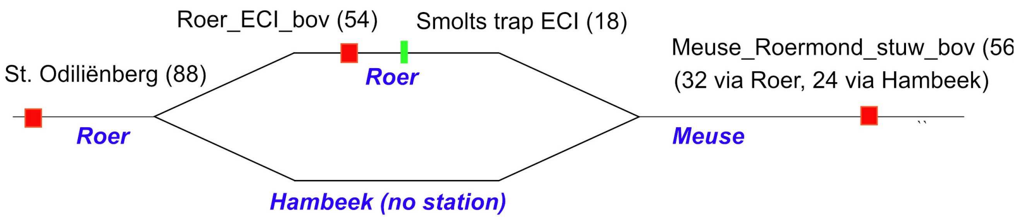


figure 3.1 *Schematic overview of migration via Roer and Hambeek in 2010, in brackets the number of registered smolts.*

A total of 30 smolts passed the sluice-weir complex at the town Lith, including 25 via the hydro power plant, two through the weir and one through the fish passage. From two smolts the route is unknown. The station Lith_dorp was passed by 28 smolts. At the last station in the Meuse at the Capelse Veer 27 smolts were registered.

Finally three specimens reached the North Sea, all via the sea lock Haringvlietdam.

Only one smolt passed the fish passage at Lith in the downstream direction. No smolts were registered at five out of six fish passages in the Dutch part of the Meuse.

3.1.2 Registrations in time

In figure 3.2 the registrations throughout the day are displayed. 68% of all registrations were received in the period between sunrise and sunset. On the registration days, the average length of the day was 13:07 hours and that of the night 10:53 hours. Adjusted for the length of the day, smolts show a slight preference for migration during the day.

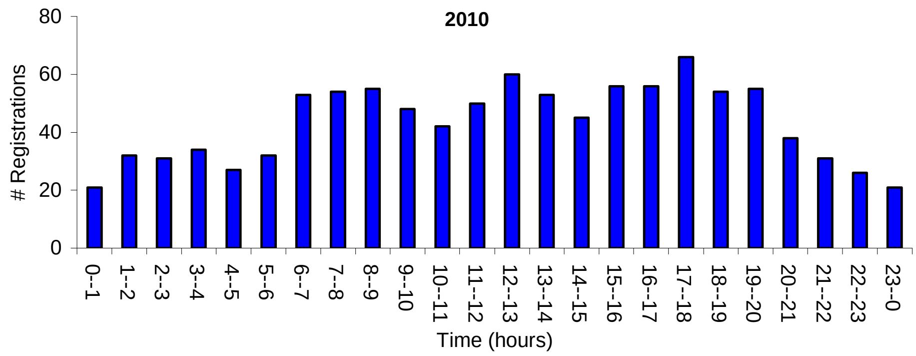


figure 3.2 *Overview of all registrations per hour.*

3.1.3 Registrations in relation to river discharge and water temperature

In figure 3.3. the registrations on the detection stations *Steyl* (above) and *Megen* (below) are shown, plotted against the discharge of the river Meuse at the towns Venlo and Megen. The increase in the number of registrations coincides in both cases with the increase in the discharge of the Meuse.

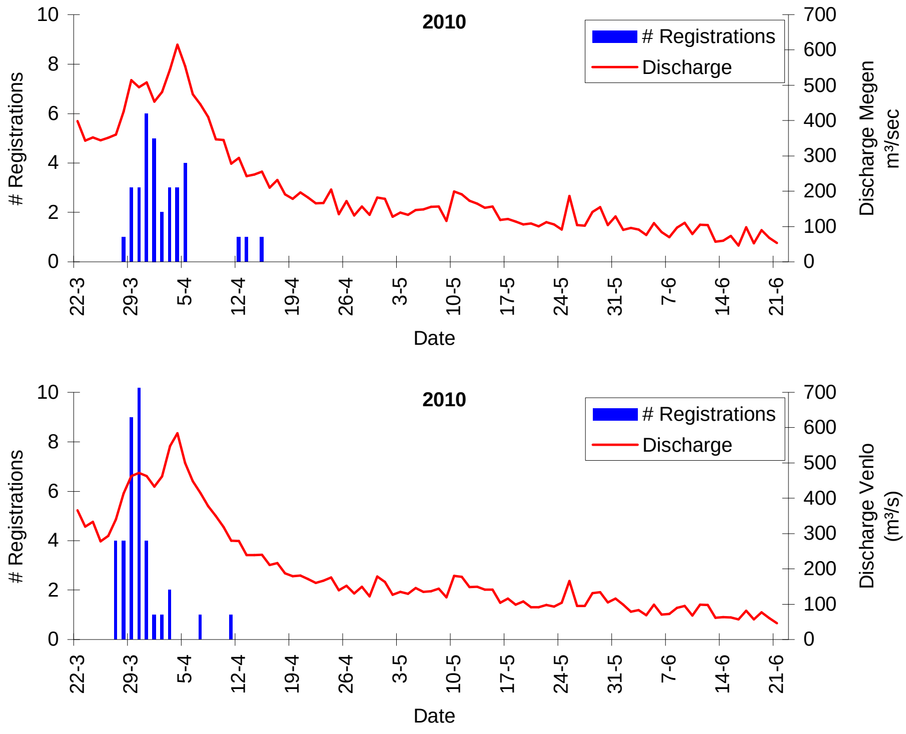


figure 3.3 *Relationship between the number of registrations at detection station Steyl and discharge at measuring point Venlo (above), and the relationship between the number of registrations at detection station Megen and the discharge at measurement point Megen (below).*

In figure 3.4 all registrations of all stations are plotted against temperature. The increase in the number of registrations took place in a period with a water temperature of around 12 degrees.

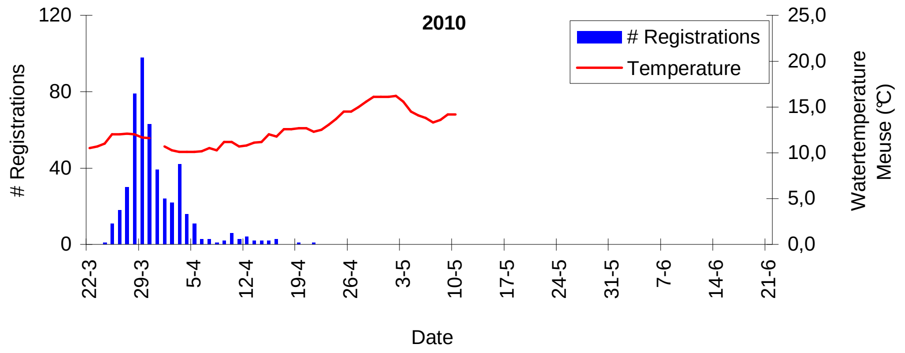


figure 3.4 *Relationship between the number of registrations of all stations in the Meuse and the water temperature of the Meuse at the town Heel.*

3.1.4 Passage Haringvlietdam

table 3.2 *Registrations on the stations north (Noord) and south (Zuid) in the sea lock Haringvlietdam.*

Station	ID smolt	Time
noord	6943	4-04-10 02:52
noord	6943	4-04-10 03:03
noord	6930	4-04-10 11:19
noord	6930	4-04-10 11:28
zuid	6930	4-04-10 12:59
zuid	6930	4-04-10 15:16
zuid	6930	4-04-10 15:56
zuid	6930	4-04-10 16:21
zuid	6930	4-04-10 18:03
zuid	6930	4-04-10 19:14
zuid	6930	4-04-10 20:39
zuid	6917	6-04-10 14:58

The sea lock Haringvlietdam consists of 17 sluices, each with a door at the river- and the sea side. The North Station covers the sluices 1 / 8 and the South Station sluices 9 / 17. The detection cables of the stations are mounted between the river door and the sea door. In general, the river door is always fully opened. The sea door is used for sluicing water. It is possible that fish are recorded when there is no water sluiced. The last received registration is interpreted as the moment when the smolt passes through the dam. Table 3.2 shows the registrations of the stations in the sea lock Haringvlietdam. Three smolts were registered on both the northern and southern station.

Table 3.3 shows the sluicing regime implemented during the period within smolts are reigsterd at the sea lock Haringvlietdam. The first smolt (No. 6943) passed the Haringvlietdam via the north-side on April 4 at 3:03 pm. At that time the opening in the dam was 450 m², divided amongst 9 sluices. A second smolt (No. 6930) was a total of nine times registered at the Haringvliet dam. Remarkably, this smolt has been frequently recorded during the sluicing period, but didn't pass the dam and thus exhibited a clearly unnatural search behaviour. The smolt was registered for the last time, nearly three hours after closing of the sluices. Possibly the fish reached the North Sea through the fish sewers (fish migration facility), but this could not be observed at the detection stations.

The fish sewers were also operative at high tide In order to improve the entry of arriving glass eels. This was during the period when the smolts were registered. Another possibility is that the fish was lying in a sluicing tube, in front of the sea door (where it could not be detected), and that the smolt swam into the sea when the sluice door was again opened.

A third smolt (No. 6917) passed the dam on April 6 at 14:58 hours. At that time the opening in the dam was 294 m², divided over 9 sluicing doors.

table 3.3 *Sluicing regime during the period when smolts were registered at sea lock Haringvlietdam (RWS[1], April 2010).*

Date	Sluicing period	No.'s open sluices	Total opening (m²)
3/4 april	20:54-05:22 hour	8 -10, 12-17	450
4 april	09:33-17:45 hour	8 -10, 12-17	404
4/5 april	21:35-06:05 hour	8 -10, 12-17	404
5 april	09:59-18:50 hour	8 -10, 12-17	360
5-april	21:34-06:38 hour	8 -10, 12-17	294
6-april	10:59-19:33 hour	8 -10, 12-17	294

3.1.5 Movement speeds

To get an idea of the speed at which the smolts move, the duration is calculated between the time off release and registration at station Bergsche *Meuse_Capelse_Veer* (168 km). The movement speeds (its swimming speed + river speed) of the smolts were ranked ascending in figure 3.5. The average speed of travel of the smolts in this section was 0,24 m/s (21,1 km/day). The fastest fish moved with 0,46 m/s (39,9 km/day).

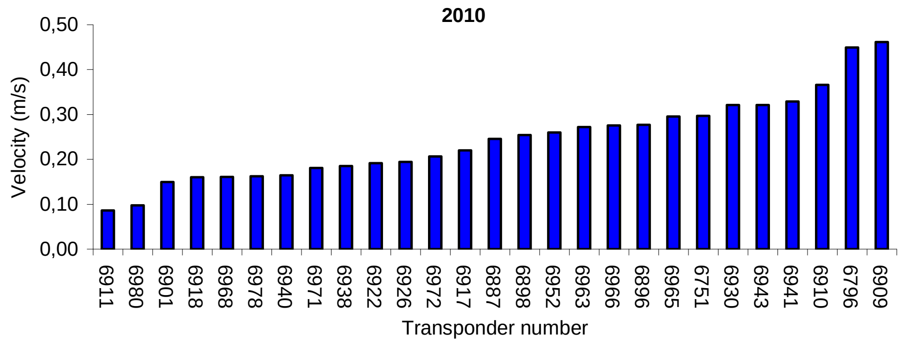


figure 3.5 *Movement speeds of smolts on the route from the release site in the Roer to the detection station in the Meuse at Capelse Veer.*

3.2 Results 2011

Registrations are collected starting from the release time on March 14, 2011 until August 29, 2011. A total of 2308 registrations were received from 65 different smolts (65%) derived from 27 different detection stations.

3.2.1 Registrations per station

Of the 100 tagged smolts, 65 passed the detection station in the Roer at *St. Odiliënberg* (table 3.4). 35 smolts were never detected after their release in the Roer.

[1] Rijkswaterstaat (RWS) = the implementing body of the Ministry of Transport, Public Works and Water Management.

At the detection station upstream of the ECI hydro power plant 46 smolts were registered. At the ECI hydro power plant 51 tagged smolts were caught in the smolts by-pass. Probably five smolts passed the detection station upstream of the ECI hydro power plant unseen.

At the station *Roermond_stuw_boven* 55 smolts were registered. Of these, 35 smolts (64%) passed via the ECI hydro power plant, and 20 smolts (36%) passed via the Hambeek before they reached the Meuse (figure 3.6). This means that 16 smolts, which were caught at the ECI hydro power plant did not reach station Roermond_stuw_boven. Of the total 100 tagged smolts 45 never left the Roer.

table 3.4 *Smolts that passed the consecutive detection stations, and losses of smolts during their downstream migration via the Meuse. (Meuse: river Maas; Ben: below; Bov: above) .*: total loss is unknown due to multiple migration routes.*

Name of the Station	Number of smolts that passed	Loss in numbers compared to the previous station	% that passed, compared to initial release
Roer_st Odiliënberg	65	35	65
Roer_Roermond ECI_bov	46	*	*
Vangst ECI-centrale	51	*	*
Meuse_Roermond_bov	55	10	55
Meuse_Buggenum	50	5	50
Meuse_Belfeld_bov	41	9	41
Meuse_Steyl	36	5	36
Meuse_Afferden	32	4	32
Meuse_Sambeek_ben_stuw	30	2	30
Meuse_Grave_bov	29	1	29
Meuse_Balgoij	29	0	29
Meuse_Megen	29	0	29
Meuse_Lith_stuw+WKC+vispassage	28	1	28
Meuse_Lith_dorp	22	6	22
Bergsche Meuse_ Capelse veer	21	1	21
Spui_Zuidland	1	*	*
Oude Meuse_Spijkenisse	2	*	*
Haringvlietdam_Noord	0	*	*
Haringvlietdam_Zuid	0	*	*
Haringvlietdam_Scheep	2	*	*
Reached the North Sea	**2**	**19**	**2**

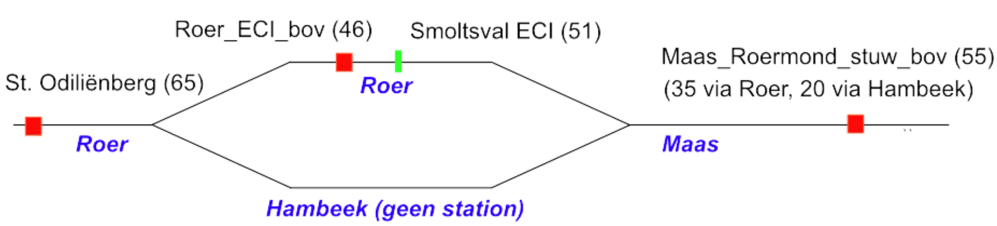


figure 3.6 *Schematic overview of migration via Roer and Hambeek in 2011, in brackets the number of registered smolts.*

Only one smolt used a fish passage at Lith downstream. The other five fish passages in the Dutch part of the Meuse were not used by the tagged smolts.

A total of 28 smolts passed the sluice-weir complex at the town Lith, including 24 via the hydro power plant. Of four passing smolts the route is unknown. 22 smolts passed at station Lith_dorp. At the last station in the Meuse (Capelse Veer) 21 smolts were registered. Finally two specimens reached the North Sea, both via the sea lock Haringvlietdam.

3.2.2 Registrations in time

In figure 3.7 the registrations are displayed throughout the day. 71% of all registrations were received in the period between sunrise and sunset. On the registration days, the average duration of the day was 12:55 hours, and the average duration of the night was 11:05 hours. Adjusted for the length of the days salmon smolts showed a slight preference for migration during the day.

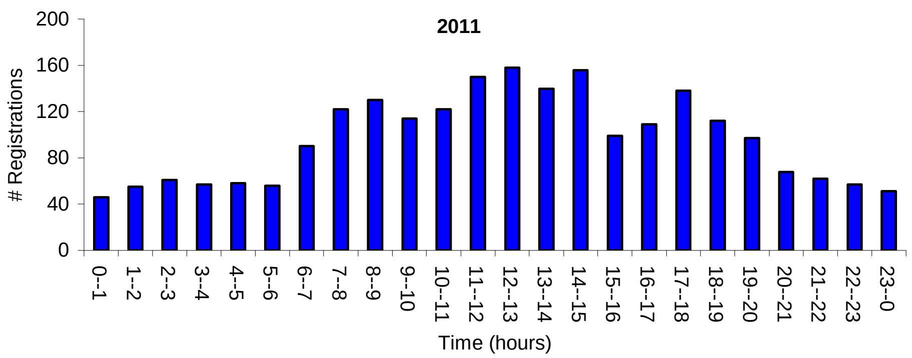
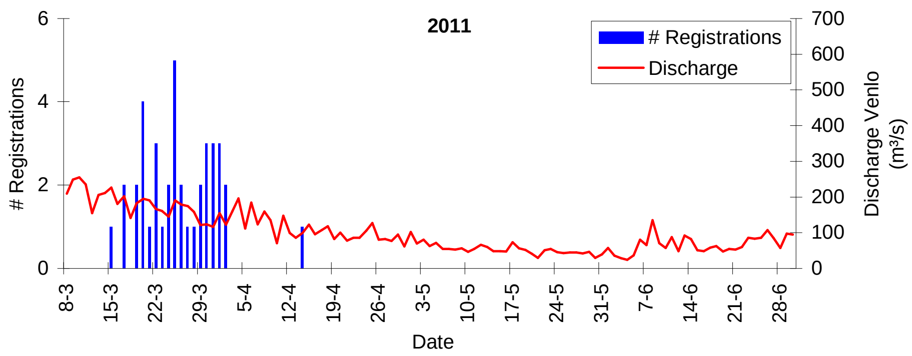


figure 3.7 *Overview of all registrations per hour.*

3.2.3 Registrations in relation to river discharge and water temperature

figure 3.8 shows the registrations at the detection stations *Steyl* (above) en *Megen* (below), compared with the discharge of the Meuse at Venlo and Megen. At both reference points, no relationship is observed between the number of registrations and the discharge of the Meuse.



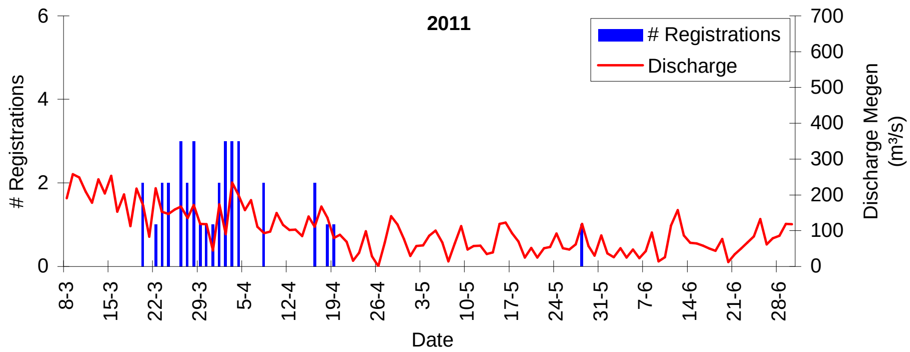


figure 3.8 *Relationship between the number of registrations at station Steyl and the discharge at measuring point Venlo (above), and the relationship between the number of registrations at station Megen and the discharge at measuring point Megen (below).*

In figure 3.9 all observed registrations of all stations are plotted against temperature. The increase in the number of registrations occurred in the period when the water temperature rose from 9 to 12 degrees.

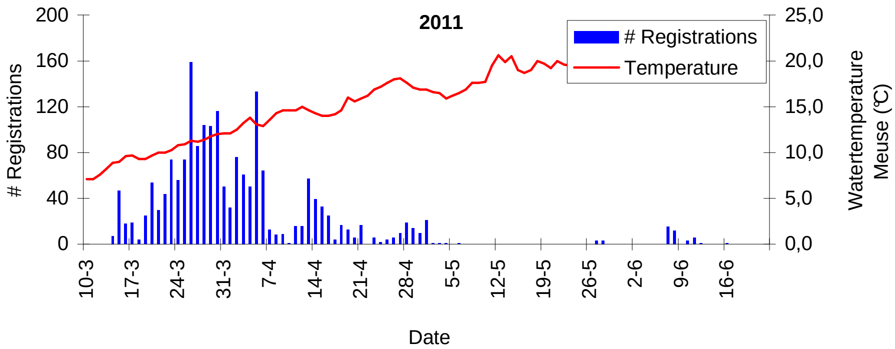


figure 3.9 *Relationship between the number of registrations at all stations in the Meuse and the watertemperature of the Meuse at the measuring point near the town Heel.*

3.2.4 Passage Haringvlietdam

In 2011, two of the 100 tagged smolts (2%) reached the North Sea. Remarkably, both smolt passed via the shipping sluice in town Stellendam and not through the sluices in the sea lock Haringvlietdam. Smolts can reach the shipping sluice via the inland harbour of Stellendam, and eventually reach the North Sea via the outer harbour of Stellendam (figure 3.10). The first smolt (No. 8620) passed the shipping sluice on April 15 at 10:26 pm. The second smolt (No. 8642) passed this location also on April 15, but several hours later at 17:28 hours. While sluicing boats during high tide it is possible that a limited amount of salt water flows into the inner harbour. Nevertheless the outflow of fresh water via this sluice is almost nil compared to masses of water that are being sluiced through the sea lock Haringvlietdam.

figure 3.10 *The Haringvlietdam with the outer harbour at the top left (North) and at the bottom left the inner harbour (sea lock Haringvliet). The shipping lock is inside the red circle.*

On April 15 the sluices of sea lock Haringvlietdam were opened from 03:44 hours to 11:16 hours and from 16:35 hours to 00:06 hours the next day (table 3.5). Thus that day the smolts had ample possibility of using the sea lock Haringvlietdam and escape to the North Sea. Because of the low river discharges on April 15, and the week before, only one sluice was open. This opening in the dam was 25m². The sea lock Haringvlietdam seems to be a physical barrier for smolt in the hours around high tide.

table 3.5 *Drainage regime during the period when smolts were registered at the sea lock Haringvlietdam (RWS, April 2011).*

Date	Drainage period	Number of opened sluices	Total opening (m²)
14 April	03:44 -11:16 hour	14	25
14 April	16:35 -00:06 hour	17	25
15 April	03:44-11:16 hour	17	25
15/16 April	16:35-00:06 hour	17	25

3.2.5 Movement speeds

The movement speeds of smolts were ranked ascending in figure 3.11. The average travel speed (its swimming speed + river speed) of smolt in this river stretch was

0,13 m/s 11,3 km/day): the fastest fish moved with an average of 0,28 m/s (23,9 km/day).

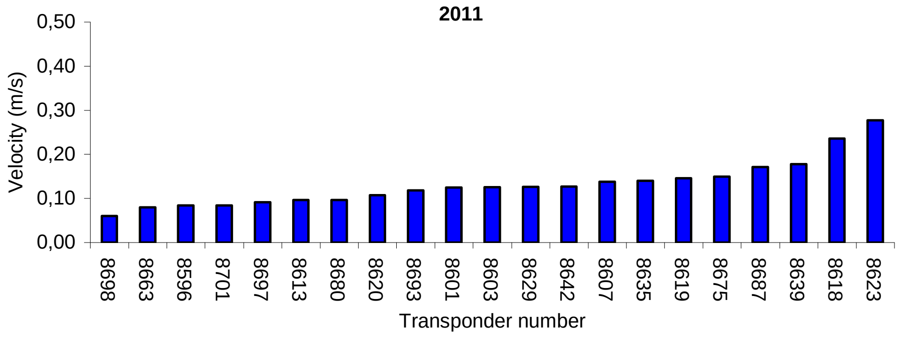


figure 3.11 *Movement speeds of smolts on the route from the release site in the Roer to the station in the Meuse at Capelse Veer.*

3.3 Comparison study years 2010-2011

3.3.1 Mortality of salmon smolts

Figure 3.12 displays the mortality of smolts in the river stretch between the release site and the North Sea (at the sea lock Haringvlietdam). The total mortality of the tagged smolts in the Roer in 2010 and 2011, was 44% and 45%. Mortality between the release site and the first station in *St. Odiliënberg* was much higher in 2011. In 2010 the mortality between the station *St. Odiliënberg* and station *Roermond* in the Meuse was actually higher. 29% and 24% of the tagged smolts disappeared in 2010 and 2011 between *Roermond* and *Capelse Veer*. In the last big river stretch between station *Capelse Veer* and the North Sea, 24% en 19% disappeared in 2010 and 2011. Finally 3% and 2% escaped to the North Sea in 2010 and 2011. All smolts chose the route to the North Sea via the sea lock Haringvlietdam.

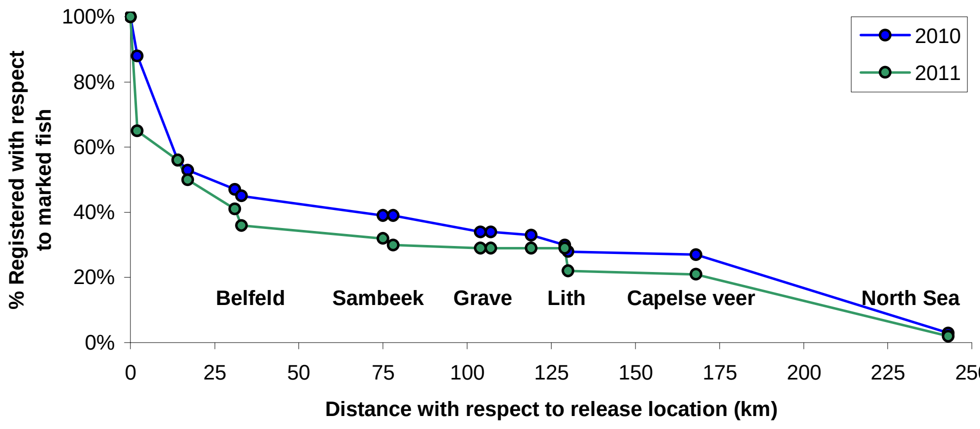


figure 3.12 *Mortality rate of the marked animals.*

3.3.2 Discharge Meuse

figure 3.13 shows the discharge of the Meuse near the town Venlo for both years in the first month after the release of tagged smolts. In 2010 the discharge increased during the first two weeks, then took off again. The discharge in 2011 was relatively low and fairly constant.

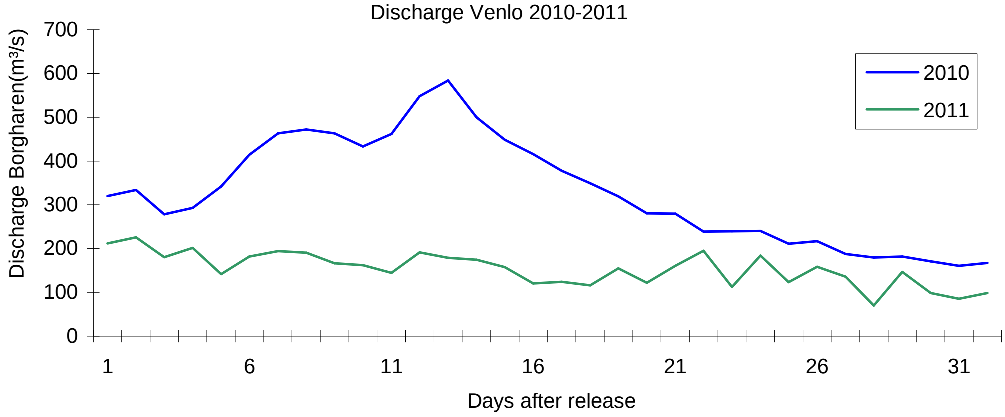


figure 3.13 Discharge in the Meuse near the town Venlo.

3.3.3 Other findings

Registrations

In 2011, over twice as many registrations were recorded than in 2010. This is mainly due to the considerable difference in the number of detections at stations at the weir in Lith. In 2010, a total of 58 detections were recorded at stations in the fish ladder, the weir and below and above stream of the hydro power plant. In 2011, 1122 detections were recorded. At the station on the upstream side of the hydro power plant, the smolts were recorded an average of 29 times in 2011 (N = 24). In 2010, the smolt recorded at this station averaged 1.5 times (N = 15). For comparison, this analysis is also performed on the registrations station of *Megen*, where no physical barrier exists. The smolts on that locations were recorded 1.0 times on average in 2010 and 1.5 times on average in 2011. It seems that the smolts in 2011 were in doubt to approach the turbine. Possibly the discharge of the Meuse plays an important role. At the recording times in 2011 at *Megen*, the average discharge in 2010 was 482 m³ / s and 137 m³ / s. Possibly the smolts were unable to stay at the inlet of the turbines due to higher discharges, and were carried away with the water currents. This phenomenon has also been established during a study of the behaviour of silver eel at the inlet area of the hydro power plant Lith (Spierts *et al*., 2008). To prevent the fish from being carried away with the strong currents, a maximum velocity of 0.3 m / sec is advised in the design of the fish guidance system (Handbuch Querbauwerke, 2005).

Mortality in relation to fish weight

The average weight of the tagged smolt was 238 ± 46 g in 2010 and 354 ± 53 g in 2011. At the last station in the Meuse at *Capelse Veer* the average weight of the smolts recorded in both years, was 240 ± 51 g and 375 ± 47g. In both years, no significant weight-related mortality was observed.

Movement speeds

The average speed of travel of the smolt on the route between the release site and station *Capelse Veer* was in 2010 and 2011, 0.24 m / s (21.1 km / day) and 0.13 m / s (11.3 km / days). During migration the smolts moved to sea at a speed of 5 to 20 kilometers per day. Compared to 2010, the discharge was low in 2011. It thus seems that the smolts are mainly carried along with the currents, which corresponds to the results of previous studies (Vis & Spierts, 2010; 2011). In another study only one exceptional case with a movement speed of 70 km/day is mentioned (De Laak, 2007).

Migration activity

Adjusted for the duration of the day, in both study years salmon smolts have a slight preference for migration during the day. This is opposite to the outcomes of research on smolt migration in the Meuse, carried out in 2009 (Vis & Vriese, 2009) and 2011 (Vis & Spierts, 2011), but in accordance with a study carried out in 2010 (Vis & Spierts, 2010). In a Danish telemetry study it was shown that the migration of salmon smolts took place for 85% during the night (Aarestrup *et al*., 2002).

Migration behaviour

It is known that smolts lower themselves down the river in groups. Based on the registrations of the smolts it becomes clear that the smolts pass shortly after each other at the station in the Roer near *St. Odiliënberg*. Figure 3.14 shows the time between the registration moments of the several smolts at station *Roer_St. Odiliënberg*. Here only the first detection of every smolt was used at that station. From the figure it can be deduced that the time difference between the recordings is usually several minutes, indicating that the smolts descended the Roer in groups. 62% of the registered smolts passed within 10 minutes of each other. The smolts were released 1 km upstream of the detection station. This analysis was also applied to the registrations at a number of stations on the Meuse. On the first station in the Meuse near Roermond, 17% of the registered smolts passed within 10 minutes of each other.

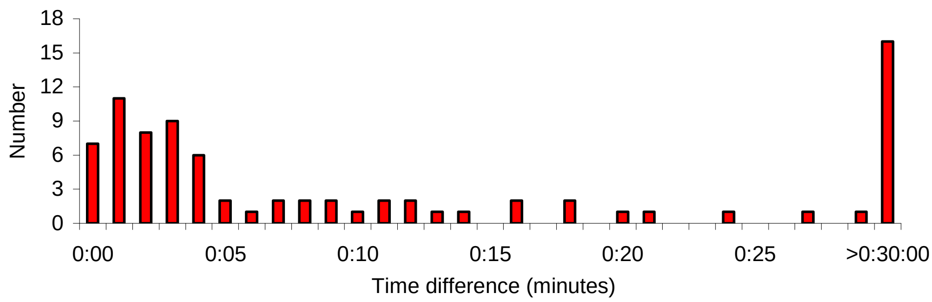


figure 3.14 *Time between the registrations of the various smolts at station St Odiliënberg in 2010 and 2011.*

Registrations at the stations *Megen* en *Capelse Veer* were also examined. Both stations are not in the immediate vicinity of dams, allowing possible temporary gathering of smolts. At these stations in both cases 2% of the smolts passed within 10 minutes of each other. In 95% and 92% of the cases the time difference was over 1 hour.

From the above it can be concluded that the smolts in the river Meuse are just individually on the move. On the other hand the observed non-group behaviour could also be explained by the use of a too low number of smolts.

Reported transponders

figure 3.15 *The area near the Claus Power Plant in Maasbracht, where the transponders 6841, 6895, 6937 (island above) and 6942 (island below) were found.*

The transponders include an inscription (phone number) so that findings can be reported. In both survey years no transponders were reported back.

Following the high mortality of test fish in the Roer, a search was held to look for lost transponders in the Roer. Using a mobile antenna, transponders were being searched for, from the dam at weir Wasserberg (across the border in Vlodrop) to the ECI hydro power plant in Roermond. In both years no transponders were found.

There was also searched for transponders with mobile antennae on the islands around the Claus Power Plant in Maasbracht, a well-known resting place for cormorants (see figure 3.15). It is possible that cormorants leave eaten transponders on these nesting places. On September 2, 2010 four transponders were found on that location, all originating from the tagged smolts. Two of these transponders (No. 6841 and 6942) had never been recorded on any NedAp tracking station. No 6895 was only registered at the station in the Roer in St. Odiliënberg. And No. 6937 was registered at station Odiliënberg and at station Roer_ Eci_bov. It is therefore likely that the predation of smolts by cormorants took place on the Roer. During another search, a year later, on October 24, 2011 no transponders were found near the Claus Power Plant.

3.4 Function of the fish guidance system at the ECI Hydro power plant for salmon smolts

At the ECI Hydro power plant in Roermond a fish guidance system was build. This system consists of a 'duckweed' fence with such a little distance between the bars that it is not possible for the smolts to pass that fence or get sucked into the turbines. Besides this fence, a specially designed bypass gives smolts the possibility to pass the hydro power plant safely in three ways. This includes a capture device with which the vulnerable smolts can be captured undamaged (smolts bypass). Alternatives routes passing the hydro power plant redirect the smolts via the fish passage or via another alternative passage that leads fish under the building (eel bypass).

In 2010 there was a high discharge in the Roer. Because of the high dirt load in the river Roer it was not possible to monitor the smolts bypass for several days. Because of this, only part of the smolts that passed the hydro power plant upstream, were captured. It appeared that during the peak discharges of the river, seven smolts ended up in the garbage can, in which they were swept with the automated fence cleaning system. Nevertheless, the operation of this system is such that healthy fish can certainly escape during this cleaning process. Probably this system worked to a lesser extent during the peak discharge in the spring of 2010, because of the many branches and leaves. Besides that it was observed that the test fish in 2010 showed a little lesser fitness compared to the test fish used in 2011. This was due to a (well treated) fungal infection, and this could also have played a role in having the 2010 smolts getting caught in the cleaning system. In 2011 there was a low discharge in the Roer. Of the 55 smolts that were registered upstream of the ECI, 51 were registered in the smolts bypass. The other four smolts probably passed unnoticed via the eel bypass, or through the fish passage. This shows that both the smolts bypass and the fish guidance system both worked well.

Previous research showed that there is an estimated mortality of 24% amongst migrating smolts, due to the passage through the hydro power plant Linne (Kemper *et al*., 2010). This mortality consists of immediate and postponed mortality. At the ECI hydro power plant it is not physically possible for smolts to come into contact with the turbines, because of the limited distance between the bars of the dirt fence. Such a system and fence can significantly reduce the mortality at turbines that are not yet quipped with a fish guidance system.

3.5 Comparison with other studies on smolts in the tributary Berwijn (B).

Besides the research described in this report, the implementing body of the Ministry of Transport, Public Works and Water Management, Rijkswaterstaat (RWS) carried out studies since 2009 concerned with the migration of smolts from the Berwijn into the Meuse and the North Sea.

table 3.6 *Mortality of smolts in the tributaries Roer en Berwijn (tagged smolts).*

Project	N tagged	% mortality in tributary
RWS 2010 (Berwijn)	200	30%
RWS 2011 (Berwijn)	200	52%
SNL 2010 (Roer)	100	44%
SNL 2011 (Roer)	100	45%

The Berwijn is a tributary river of the Meuse situated near the Dutch-Belgian border. The design of both studies is similar. In both studies in the Roer and in the Berwijn, there was a high mortality observed within both tributaries (table 3.6). In 2010, 76 out of 200 (38%). Smolts that were released in the Berwijn, reached the station in the Meuse at Roermond. From this point on it is possible to compare results with smolts of the project in the Roer, from which 56 smolts reached the same station in the Meuse near Roermond. In 2011, 200 smolts were also released into the Berwijn. None of those reached Roermond, so for that year it is not possible to make a comparison with the project in the Roer. Figure 3.16 shows for both projects the mortality of smolts in 2010. The number of registered fish for station Roermond in the Meuse is the starting point (100%). In the RWS project the mortality in the stretch between Roermond and Capelse Veer is 88%, and 95% in the Royal Dutch Angling Organisation project. In the RWS project, a relatively high mortality occurs near Lith. In the SNL project a relatively high mortality occurs in the first part of the route.

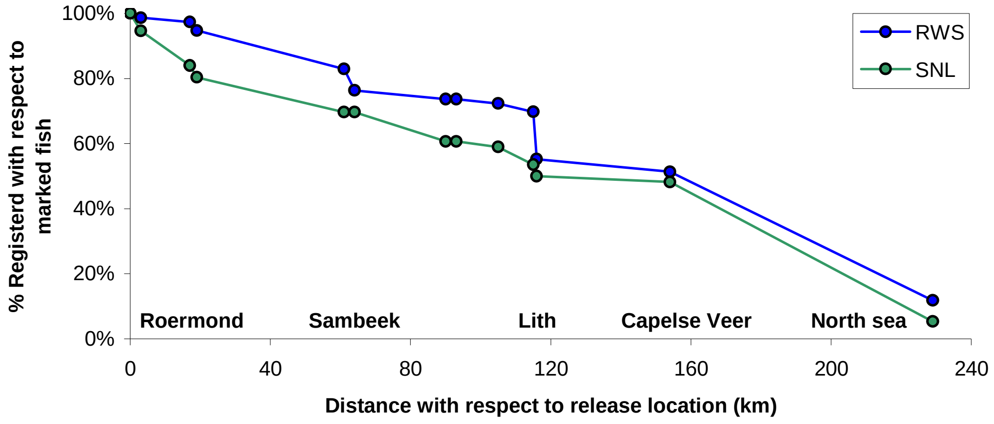


figure 3.16 *Mortality of smolts between Roermond and the North Sea in 2010, compared to the number of registered smolts near Roermond in the river Meuse.*

4 Discussion

Mortality amongst salmon smolts

In 2010 there was a strikingly high mortality of test fish in the stretch between the station St Odiliënberg and the weir in the River Meuse near Roermond. In the first days after the release there was a high discharge in the Roer. At the ECI hydro power plant in Roermond seven tagged smolts were found dead in the smolts bypass and in the duckweed fence. Probably the high peak discharge had a negative impact on the survival of smolts in the Roer – weak fish ending up in the duckweed fence. Also in 2010, a fungal infection was found in some smolts prior to surgery, which possibly weakened them, although during observation at the fish farm Valkenswaard the fish were found fit. In 2011 there was also a high mortality observed in the Roer, but this time upstream of the station *St. Odiliënberg*. Due to the relatively low discharge in 2011 visibility in the river was very high. This may have played a significant role in relation to predation by birds and predatory fish. The high mortality of smolts in the migration study on the Berwijn can be explained in a similar manner. The smolts let themselves drift with the currents during downstream migration, making them more susceptible to predation by large predatory fish (De Laak, 2007). From Danish research it is known that vision-dependent predatory fish and birds cause a substantial mortality on migrating smolts (Koed *et al*., 2002; Koed, 2000). In the estuary of the Danish river Skjern mortality of 39% occurred among salmon smolts, primarily because of predation by cormorants (Koed *et al*., 2006). Based on found transponders at the Claus Power Plant, it could be established that predation by cormorants occurs in the Roer. With decreasing river discharge, the predation of birds and predatory fish on smolts will increase, due to an increase in visibility and a longer residence time in fresh water (Aarestrup *et al*., 2002). It seems unlikely that any smolts in the Roer were left behind.
Starting one month after the release of smolts in 2010, only four smolts were tracked in the Roer, of which finally only one fish left the Roer. In 2011, no smolt was registered in the Roer, one month after the release. During a search for transponders with a mobile antenna, in the Roer between the weir at Wasserberg and the ECI hydro power plant, both in 2010 and 2011, no transponder was found.

On the route between the station in the Meuse at Roermond and the station at the North Sea, in the survey years 2010 and 2011, respectively 29% and 24% of the tagged smolts disappeared. The cause of this mortality may be due to predation by large predatory fish and birds. In the journey from Lith to the North Sea, mortality is also possible due to passage through the hydro power plant at Lith (direct and postponed mortality). Because little smolts passed via the weir, a comparison of between the effect of passage via the weir or passage via the hydro power plant is not possible.

Quality of the test fish

In 2010, prior to the operation of some smolts a fungal infection was found. It was therefore decided to treat all smolts against this infection. After surgery, the smolts were held into storage up to three days. During this storage period and at the release no health problems were found.

In 2011, after tagging, the smolts were kept in storage for observation for 10-11 days. In the period from surgery to release no health problems were found, the wounds from the operation were fully closed. Given the above it is therefore likely that the high mortality of smolts is not related to the condition of the fish.

Sea lock Haringvlietdam as a barrier to downstream migration

After the hydro power plant Lith, sea lock Haringvlietdam is the only barrier that stands between the estuary and the North Sea. The Haringvlietdam prevents a natural transition between fresh and salt water. As a result, the estuary (Hollands Diep and Haringvliet) contains relative fresh water and has a slow current – at some times the water stands still. This is probably of major influence on the orientation of the smolts in the area. Delay in migration may yield an increased risk of predation.

The smolts reach the estuary (Hollands Diep and then finally the Haringvliet) via a route over the Meuse and the Amer. From this area, the smolts have another option to migrate freely to the North Sea via a more complicated route that leads through the so called Nieuwe Waterweg and the harbour of Rotterdam. But the data shows that the smolts didn’t use that route.

The registrations of smolts show that the sea lock Haringvlietdam forms a physical barrier to the smolts in the hours around high water. In the hours around low tide, smolts could reach the North Sea via the sluices.

In 2011 only two smolts reached the North Sea. Both smolts passed the dam via the shipping lock. Possibly the low discharge in the dry spring of 2011 played an important role, and limited the opportunities for smolts to reach the North Sea from the Haringvliet. Meanwhile it was decided in Dutch parliament to implement an appropriate management of the dam (Dutch: Kierbesluit), and consequently open the sluice doors more frequently. It is expected that this will have a positive effect on the chances for smolts to escape to the North Sea. Future research should show the actual effect of this new management of the sea lock on the downstream migration of smolts.

5 Conclusions and recommendations

5.1 Conclusions

On objective 1: **evaluating the performance of the fish guidance system for downstream migrating salmon smolts in the tributary Roer at the ECI hydro power plant in Roermond.**

- Both the fish guidance system and the smolt trap at the ECI-hydro power plant appear to work well. Based on the catches in the smolts bypass and registrations on the upstream station, it appears that the smolts manage to pass through the hydro power plant.
- At the ECI hydro power plant, because of the fine wired duckweed fence, it is for smolts not physically possible to get into contact with the turbines. Such a system significantly reduces mortality at turbines without fish guidance system.

On objective 2: **gaining insight into the migratory behaviour of smolts (route, timing, migration rate, delay, etc.) in the Roer and the Meuse.**

- In 2010, 56 smolts were registered at the first station in the Meuse (Roermond_stuw_boven). 32 smolts (57%) swam via the ECI hydro power plant and 24 smolts (43%) via the Hambeek;
- In 2011, 55 smolts were registered at station Roermond_stuw_boven. 35 smolts (64%) swam via the ECI hydro power plant and 20 smolts (36%) via the Hambeek;
- The smolts that reached the North Sea all opted for the route to the North Sea via the sea lock Haringvlietdam;
- Corrected for the duration of the day, salmon smolts in the Meuse in both study years, showed a slight preference for migration during the day. This picture is opposite to that of smolt migration in the study of the Meuse (Berwijn) in 2009 and 2011, but according to the research carried out in 2010;
- The average traveling speed of the smolts on the route between the location of release and the station Capelse Veer was in 2010 and 2011: 0.24 m / s (21.1 km / day) and 0.13 m / s (11.3 km / day).

On objective 3: **determining factors that influence migration.**

- In 2010 the rise in the number of registrations at the stations *Megen* and *Steyl* coincides with an increase in discharge at the measurement points Megen and Venlo. In 2011, there is no discernible relationship between the number of registrations at the stations *Steyl* and *Megen* and the discharge at measuring points Venlo and Megen.
- The increase in the number of registrations in 2010 took place in a period when the water temperature in the Meuse fluctuated around 12 degrees. In 2011, the number of registrations increased in the period when the water temperature rose from 9 to 12 degrees.

On objective 4: **quantifying the mortality of smolts during their downstream migration, and the final escapement to the sea.**

- The total mortality in the Roer of tagged smolts in 2010 and 2011, was 44% and 45%. In the Meuse between *Roermond* and the *Capelse Veer* in 2010 and 2011, respectively 29% and 24% of tagged smolts disappeared. On the route between the station Capelse Veer and the North Sea, in 2010 and 2011, respectively 24% and 19% of tagged smolts disappeared. Finally in 2010 three smolts (3%) reached the North Sea, in 2011 this were 2 smolts (2%).
- Part of the mortality of smolts seems to be caused by predatory fish and birds. Based on findings from four transponders near the power plant Claus it could be established that predation by cormorants occurred in the Roer.
- The sea lock Haringvlietdam prevents a natural fresh-salt transition in the estuary (Haringvliet en Hollands Diep). This is probably of great influence on the orientation of the smolts in the area. Delay in migration may yield an increased risk of predation.

On objective 5: **comparing migration data from different years, to investigate the discharge in the Meuse and its impact on the successful migration of smolts to the sea.**

- In 2010 there was a strikingly high mortality of test fish in the stretch between the station *St. Odiliënberg* and the weir in the Meuse at Roermond. In the first days after the release there was high discharge in the Roer. At the ECI hydro power plant in Roermond, a total of seven smolts were found dead. Probably they were pushed against the dirt grid by the strong current. The poor quality (fungal infection) of the test fish in 2010, may well have played an important role;
- In 2011, also a high mortality was observed in the Roer, but this time upstream of the station *St. Odiliënberg*. Due to the relatively low discharge in 2011 the visibility in the river was very high. This may have played an important role in the vulnerability of smolts to predation by birds and predatory fish, with which the poor survival could be explained;
- In the stretch from the town Lith to the North Sea, mortality is also possible caused by the passage through the hydro power plant at Lith (immediate and postponed mortality). Because little smolts passed via the weir, a comparison between the effect of passage via the weir and the hydro power plant is not possible;
- The discharge of the Meuse appears to affect the behaviour of smolts near the inlet of the hydro power plant at Lith. In 2010 and 2011 smolts were on average registered 1.5 and 29 times at the inlet of the station at the hydro power plant. It seems that in 2011 the smolts doubted to approach the turbines. Possibly the smolts were unable to stay at the inlet of the turbines due to higher discharges. It is plausible that they were being carried through the turbines with the strong water currents.

On objective 6: **comparing the differences between the migration from both the river Berwijn (in Belgium) and the river Roer (Netherlands), both tributaries of the Meuse.**

- In the RWS project the mortality in the stretch between *Roermond* and *Capelse Veer* is 88%, and 95% in the Royal Dutch Angling Organisation project. In the RWS project, a relatively high mortality occurred near Lith. In the SNL project a relatively high mortality occurred in the first part of the route. In 2011, tagged smolts were also released into the Berwijn. None of them reached Roermond, so for that year, no comparison is possible with the project in the Roer;
- In both studies in the Roer and in the Berwijn there was a high mortality of the tagged smolts observed in the tributaries (30-52%). On both rivers, the loss is probably largely due to predation.

5.2 Recommendations

- In a follow-up study on the migratory behaviour of smolts in the Meuse, more insight could be obtained, focusing on the annual variation of smolt migration and mortality, this in relation to the discharge and distribution of water at the dam at Lith. Also, further studies could provide more insight into the causes of the low escapement rates of smolts. Preferably, further study is carried out after setting up the opening of the sea lock Haringvliet (Dutch: kierbesluit). This will provide more insight in the chances for smolts which migrate downstream the river Meuse and try to escape to the North Sea.
- For any possible further study, it is recommended to keep the smolts in storage during 10 days for observational purposes. In this way, insight is obtained into the possible complications from the surgery. Although in captivity the chances of infection will probably be higher as it is in the wild.
- The amount of discharge appears to affect the mortality of smolts. It is recommended to carry out an extensive literature study on all factors (drainage, water temperature, predation, etc.) which may affect the smolt migration under natural conditions. This study will expand the knowledge of smolts in the Netherlands and also could give more insight in the chances for smolts to reach the North Sea. An analysis of catch data from smolts at the ECI hydro power plant in the Roer could also prove to be a valuable contribution. A start for this is worked out in the annual reports of the fish monitoring program at the ECI hydro power plant.
- It is recommended that in future migration studies, the smolts are being released at dusk. This reduces the chance of predation by birds and predatory fish during the first hours after their release, and then the smolts can adapt to their new environment;
- In both study years, 100 additional unmarked smolts have been released. This with the idea that smolts travel in larger groups, which decreases the individual risk of predation. The results showed that the smolts in the Roer only slightly migrated in groups. The release of large groups of unmarked smolts in order to reduce the risk of predation does not seem sensible according to these findings.

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Appendices

Appendix I Transponder implantation data

Study year 2010

Nr	ID	TL (cm)	Gewicht (g)	Merkdatum	Nr	ID	TL (cm)	Gewich	Merkdatum
1	6736	31	274	24 maart 2010	51	6927	31	262	24 maart 2010
2	6744	29	198	24 maart 2010	52	6928	31	278	24 maart 2010
3	6751	31	230	24 maart 2010	53	6929	30	242	24 maart 2010
4	6760	34	322	24 maart 2010	54	6930	31	224	24 maart 2010
5	6782	30	236	24 maart 2010	55	6931	31	218	24 maart 2010
6	6784	30	212	24 maart 2010	56	6932	32	276	24 maart 2010
7	6796	30	198	24 maart 2010	57	6933	28	184	24 maart 2010
8	6798	28	172	24 maart 2010	58	6934	31	266	24 maart 2010
9	6841	30	214	24 maart 2010	59	6935	29	212	24 maart 2010
10	6859	31	258	24 maart 2010	60	6936	29	208	24 maart 2010
11	6873	29	202	24 maart 2010	61	6937	28	210	24 maart 2010
12	6887	30	246	24 maart 2010	62	6938	27	180	24 maart 2010
13	6888	34	346	23 maart 2010	63	6939	30	242	22 maart 2010
14	6889	29	176	24 maart 2010	64	6940	32	306	22 maart 2010
15	6890	30	246	24 maart 2010	65	6941	29	196	23 maart 2010
16	6891	31	304	24 maart 2010	66	6942	31	276	22 maart 2010
17	6892	31	218	23 maart 2010	67	6943	33	294	24 maart 2010
18	6893	31	264	22 maart 2010	68	6944	29	194	23 maart 2010
19	6894	32	270	23 maart 2010	69	6945	29	214	22 maart 2010
20	6895	33	268	23 maart 2010	70	6946	30	244	23 maart 2010
21	6896	31	216	23 maart 2010	71	6947	31	258	22 maart 2010
22	6897	29	214	23 maart 2010	72	6948	29	204	24 maart 2010
23	6898	31	278	24 maart 2010	73	6949	32	268	23 maart 2010
24	6899	26	158	24 maart 2010	74	6950	30	230	22 maart 2010
25	6900	31	248	23 maart 2010	75	6951	32	280	23 maart 2010
26	6901	30	202	23 maart 2010	76	6952	32	284	22 maart 2010
27	6902	29	194	24 maart 2010	77	6953	32	290	24 maart 2010
28	6903	33	278	24 maart 2010	78	6954	29	198	23 maart 2010
29	6904	29	190	23 maart 2010	79	6955	32	274	23 maart 2010
30	6905	32	268	23 maart 2010	80	6956	33	308	22 maart 2010
31	6906	32	284	24 maart 2010	81	6957	32	280	22 maart 2010
32	6907	30	244	24 maart 2010	82	6958	31	212	23 maart 2010
33	6908	30	226	23 maart 2010	83	6959	32	286	23 maart 2010
34	6909	33	272	23 maart 2010	84	6960	29	191	23 maart 2010
35	6910	31	206	23 maart 2010	85	6961	28	181	23 maart 2010
36	6911	30	238	24 maart 2010	86	6963	33	322	22 maart 2010
37	6912	33	324	23 maart 2010	87	6964	31	244	22 maart 2010
38	6913	30	228	24 maart 2010	88	6965	28	152	22 maart 2010
39	6914	29	200	24 maart 2010	89	6966	28	168	22 maart 2010
40	6916	28	182	24 maart 2010	90	6967	32	308	22 maart 2010
41	6917	31	282	24 maart 2010	91	6968	34	338	22 maart 2010
42	6918	28	176	24 maart 2010	92	6970	32	286	22 maart 2010
43	6919	31	286	24 maart 2010	93	6971	31	224	22 maart 2010
44	6920	31	270	24 maart 2010	94	6972	33	298	22 maart 2010
45	6921	28	180	24 maart 2010	95	6973	32	270	22 maart 2010
46	6922	30	206	24 maart 2010	96	6974	31	270	22 maart 2010
47	6923	27	176	24 maart 2010	97	6975	27	172	22 maart 2010
48	6924	30	246	24 maart 2010	98	6977	27	152	22 maart 2010
49	6925	27	166	24 maart 2010	99	6978	31	258	22 maart 2010
50	6926	32	294	24 maart 2010	100	6980	29	194	22 maart 2010

Study year 2011

Nr	ID	TL (cm)	Gewicht (g)	Merkdatum		Nr	ID	TL (cm)	Gewich	Merkdatum
101	8512	32	338	3 maart 2011		151	8644	34	346	2 maart 2011
102	8539	32	332	3 maart 2011		152	8645	32	292	3 maart 2011
103	8546	32	294	2 maart 2011		153	8646	34	380	2 maart 2011
104	8569	36	402	3 maart 2011		154	8647	34	358	3 maart 2011
105	8591	34	378	3 maart 2011		155	8648	33	334	3 maart 2011
106	8593	34	354	3 maart 2011		156	8650	33	314	3 maart 2011
107	8595	34	362	2 maart 2011		157	8651	33	302	2 maart 2011
108	8596	34	328	2 maart 2011		158	8652	36	446	3 maart 2011
109	8598	34	344	2 maart 2011		159	8653	35	392	2 maart 2011
110	8599	35	406	3 maart 2011		160	8654	31	276	3 maart 2011
111	8600	36	408	2 maart 2011		161	8655	32	274	2 maart 2011
112	8601	34	374	2 maart 2011		162	8656	34	370	2 maart 2011
113	8603	31	302	2 maart 2011		163	8657	37	414	3 maart 2011
114	8606	32	336	3 maart 2011		164	8658	32	286	3 maart 2011
115	8607	34	378	3 maart 2011		165	8659	35	350	2 maart 2011
116	8608	32	290	2 maart 2011		166	8660	35	368	3 maart 2011
117	8609	37	442	3 maart 2011		167	8661	29	212	2 maart 2011
118	8610	35	416	3 maart 2011		168	8663	33	314	3 maart 2011
119	8611	31	236	3 maart 2011		169	8665	35	394	2 maart 2011
120	8612	36	428	2 maart 2011		170	8667	33	330	3 maart 2011
121	8613	33	338	3 maart 2011		171	8668	31	252	2 maart 2011
122	8615	33	304	2 maart 2011		172	8669	34	328	2 maart 2011
123	8616	30	226	2 maart 2011		173	8670	34	340	3 maart 2011
124	8617	35	414	2 maart 2011		174	8671	35	362	3 maart 2011
125	8618	36	402	2 maart 2011		175	8673	35	354	3 maart 2011
126	8619	34	380	2 maart 2011		176	8674	34	356	2 maart 2011
127	8620	37	458	3 maart 2011		177	8675	36	432	2 maart 2011
128	8621	34	378	3 maart 2011		178	8676	34	360	3 maart 2011
129	8622	35	358	2 maart 2011		179	8677	36	434	3 maart 2011
130	8623	36	370	2 maart 2011		180	8679	33	318	2 maart 2011
131	8624	32	272	2 maart 2011		181	8680	34	346	3 maart 2011
132	8625	33	328	3 maart 2011		182	8681	36	448	2 maart 2011
133	8626	35	354	2 maart 2011		183	8684	34	358	2 maart 2011
134	8627	33	326	2 maart 2011		184	8685	34	372	2 maart 2011
135	8628	33	286	2 maart 2011		185	8686	35	380	3 maart 2011
136	8629	36	410	3 maart 2011		186	8687	37	417	3 maart 2011
137	8630	34	376	2 maart 2011		187	8688	32	264	2 maart 2011
138	8631	35	332	2 maart 2011		188	8689	32	306	3 maart 2011
139	8632	34	336	3 maart 2011		189	8690	33	328	2 maart 2011
140	8633	35	420	3 maart 2011		190	8691	35	378	2 maart 2011
141	8634	36	442	3 maart 2011		191	8692	33	348	3 maart 2011
142	8635	35	382	3 maart 2011		192	8693	36	426	2 maart 2011
143	8636	34	350	2 maart 2011		193	8694	32	306	3 maart 2011
144	8637	34	340	2 maart 2011		194	8695	34	408	2 maart 2011
145	8638	33	336	2 maart 2011		195	8696	35	396	2 maart 2011
146	8639	35	414	3 maart 2011		196	8697	32	304	2 maart 2011
147	8640	36	396	3 maart 2011		197	8698	34	382	3 maart 2011
148	8641	33	346	3 maart 2011		198	8700	35	402	2 maart 2011
149	8642	32	300	2 maart 2011		199	8701	36	410	2 maart 2011
150	8643	34	338	2 maart 2011		200	8702	35	380	2 maart 2011

Appendix II Animal experimentation committee approval (DEC)

VISADVIES B.V.
Twentehaven 5
3433 PT Nieuwegein

DATUM
1 maart 2010

ONDERWERP
beoordeling proefplan VA2009_59

BEHANDELD DOOR
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BEZOEKADRES

TELEFOON

FAX

INTERNET

Betreft proefplan VA2009_59
Titel Onderzoek naar migratie van zalm smolts in de Roer, voorjaar 2010-2012: evaluatie werking visgeleiding bij ECI centrale
Aantal dieren 200
Risico van ongerief matig (3)
Status Nieuw proefplan
Artikel 9 functionaris: Dr. Ir. I.L.Y. Spierts
Periode 15 maart 2010 tot 1 juli 2012

Het betreft onderzoek waar al veel ervaring mee is opgedaan en de noodzakelijkheid van het onderzoek wordt in het proefplan duidelijk aangegeven.

- Het proefvoorstel is getoetst aan de hand van de eisen die gesteld worden ten aanzien van de 3 V's. en Art 2a van het Dierproevenbesluit
- Het doel van de proef. wordt onderschreven. Het belang van de proef weegt op tegen het ongerief van de betrokken dieren en er zijn geen alternatieven beschikbaar.
- De uitvoering is verder niet in strijd met andere ethische overwegingen m.b.t. het gebruik van proefdieren.

Voorwaarden/ opmerkingen:

- De indiener dient iedere wijziging van het proefplan ten opzichte van dit advies alsmede onverwachte gebeurtenissen, onverwijld te melden aan de proefdierdeskundige
- Indien het ongerief tijdens de proef afwijkt van het opgegeven (verwachte) ongerief dient dit een welzijnsevaluatie na afloop van de proef te worden gemeld

Advies
Positief advies

Met vriendelijke groet,
Namens de DEC
Drs P.S Kroon, Art 14

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