

Rhine silver eel 2013-2015. Population study of female downstream migrating silver eel, *Anguilla anguilla*, in the Rhine system in 2013-2015.

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SUMMARY

2013-2014

In the autumn of 2013 132 eel were tagged and 55 of these eel were registered (41,7%) on 14 different detection stations in the Rhine river system. All fish were caught with fykes in the Mosel. From the day of releasing the eel (November 13th 2013) until March 1st 2014 in total 139 registrations were recorded. In total 77 eel were never registered on any detection station during this research. This relatively high number of eel that were never registered can possibly be explained by the fact that these eel were transported to the Netherlands in order to be operated, after which they were brought back to Germany to the release sites. Much handling of fish is always a stress factor. Eight eel were not registered on the first station downstream of their release site although they did pass the station. In total 38 eel were registered on the detection station in Xanten (28,8%). In total 30 eel were registered on one of the stations in the Netherlands (22,7%). Only one eel reached the North Sea by passing the detection station Nieuwe Waterweg_Europoort. This particular eel was released in the Lippe. Two eel were registered on the station in the Noord but never reached the next station in the Nieuwe Waterweg or Hartelkanaal. Two other eel were registered on the station in the Oude Maas. Eel that were released in the Rhine were registered the most (65,4% of the total number of eel released in the Rhine), whereas only 14,8% of the eel that were released in the Ruhr were registered. There is no clear explanation why so few eel that were released in the Ruhr were actually registered. The variation in migration velocity is large amongst the registered eel: the slowest eel migrated a distance of 6 km in 46 days (0,1 km/day), whereas the fastest eel travelled a distance of 177 km in one day. It is interesting to notice that both the fastest and the slowest eel were released in the Sieg.

2014-2015

In the autumn of 2014 150 eel were tagged and 62 of these eel were registered (41,3%) on 15 different detection stations in the Rhine river system in the study period between November 23rd 2014 and February 6th 2015. The fish were caught with fykes in the Mosel, near Winnigen, and in the Rhine, Germany. In total 156 registrations were recorded in the study period, and 88 silver eel were never registered. This relatively high number of eel that were never registered can possibly be explained by several factors: 1) the transports to The Netherlands and back; 2) the longer storage periods in the Netherlands, and 3) the handling. These factors can cause substantial stress, ultimately leading to death. However, recent data show another possibility for the few registered eel that were tagged, both in 2013 and 2014. Approximately 1/3 of the eel that were tagged and released in 2013 that were not registered in the time period that was studied, appeared to be registered after the last date that was included in the 2013-2014 (March 1st 2014). This finding suggest that these eel did not die due to the treatment, but appeared to show a delayed migration activity. It might be that these eel temporarily 'lose' their drive to migrate due to the effects of transportation, storage and handling. The exact reason for this behaviour however is until now unknown. The same theory can be applied to the eel that were not registered in the current study, as this was similar as the study of 2013. In total 29 eel were not registered on the first station downstream of their release site, although they did pass the station. This finding is mainly due to malfunctions of the stations in the Ruhr (9 unregistered eel) and in the Wupper (10 unregistered eel). In Xanten 39 eel were registered (26% of all tagged eel). In total 38 (25,33%) eel were registered on one of the stations in the Netherlands. Four eel reached the North Sea through the Nieuwe Waterweg: two eel (released in the Ruhr) through the Oude Maas, one eel (released in the Lippe) through the Lek, and one eel (released in the Rhein) through the Noord. Also, one eel reached the Harinvliet sluices, but after spending two days at this location the fish returned upstream and was last detected in the Oude Maas. Another 14 eel likely reached the North Sea, but were not detected on the most downstream stations. Eel that were released in the Rhine were registered the most (56,74% of total number of released eel in the Rhein). From the eel that were released in the Lippe 53,3% were registered. Only 30 % of the eel that were released in the Ruhr were registered. This phenomenon was also seen in the study of 2013. The slowest eel migrated a distance of 6 km in 104 days (0,06 km/day), whereas the fastest eel travelled a distance of 233 km in three day (77,7 km/day). The actual migration velocity of the fish is actually higher when fish do not swim continuously but have periods of inactivity.

CONTENTS

1 INTRODUCTION	1
1.1 Background.....	1
1.2 Objectives	1
1.3 Reader	1
2 MATERIAL AND METHODS	2
2.1 Telemetry: NEDAP Trail system®	2
2.2 Silver eel	3
2.3 Surgical procedure.....	4
2.4 Releasement of eel	5
2.5 Data analysis	6
3 RESULTS	7
3.1 2013	7
3.1.1 Eel tagging data	7
3.1.2 Registrations 2013-2014	10
3.1.3 Migration routes in the Rhine system.....	12
3.1.4 Downstream migration velocity	15
3.2 2014	16
3.2.1 Eel tagging data	16
3.2.2 Registrations 2014-2015	19
3.2.3 Migration routes in the Rhine system.....	22
3.2.4 Downstream migration velocity	24
4 CONCLUSIONS AND RECOMMENDATIONS	26
4.1 2013	26
4.1.1 Conclusions.....	26
4.1.2 Recommendations	26
4.2 2014	27
4.2.1 Conclusions.....	27
4.2.2 Recommendations	27
4.3 Short comparison of both studies	28
5 REFERENCES	29
 APPENDICES	
APPENDIX I: EEL DATA 2013	
APPENDIX II: EEL DATA 2014	
APPENDIX III: REGISTRATIONS NEDAP TRAIL SYSTEM® 2013-2014	
APPENDIX IV REGISTRATIONS NEDAP TRAIL SYSTEM® 2014-2015	
APPENDIX V REGISTRATIONS IN RELATION TO MOON CYCLE AND WATER DISCHARGE	
2004 - 2010 AND 2012	

1 INTRODUCTION

1.1 Background

Since 2004 the 'Landesamt für Natur, Umwelt und Verbraucherschutz NRW (LANUV)' has released silver eel (*Anguilla Anguilla*) in the tributaries of the German part of the river Rhine for the purpose of: studying: 1) the migratory behavior of silver eel from the Rhine system to the North sea, and 2) the success in actually reaching the sea. From 2006 to 2008 approximately 50% of all tagged eel were registered directly downstream from the release site. In 2009, 2010 and 2012 this was 89%, 68% and 46%, respectively. The percentage of registered eel that actually reached the North sea in these years was relatively low: the escapement was 32%, 26%, 34%, 32%, 16%, 22%, and 21% from 2004 until 2010 and 9% in 2012.

ATKB was asked to tag and release 150 silver eel in the autumn of 2013 and another 150 eel in the autumn of 2014. The study is performed in cooperation RWS WVL (the Netherlands) and LANUV NRW (Germany). The results of these studies are presented in this report.

1.2 Objectives

The objectives of this study are to:

1. determine the relative importance of different migration pathways for silver eel in the lower Rhine system in 2013-2014 and in 2014-2015;
2. quantify the losses of silver eel in the different river stretches of the lower Rhine system in these years;
3. understand effects of possible migration barriers for eel on their journey to sea, and
4. quantify the escapement of released eel to sea.

Strategic objective

The strategic objective is to determine the: 1) migration pathways of downstream migrating silver eel released in various branches of the Rhine system in Germany; 2) actual escapement of these eel to the North sea, and 3) mortality rates during this migration.

In table 1.1 the parties that participated in these study are summarized.

No.	Participant	Acronym
1	Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen, FB 26 - Fischereiökologie , Heinsbergerstr. 53, 57399 Kirchundem, Germany. Coordinator: Karin Camara.	LANUV
2	RWS WVL, Postbus 17, 8200 AA Lelystad, the Netherlands. Coordinator: André Breukelaar	RWS WVL
3	ATKB, Poppenbouwing 34, 4191 NZ Geldermalsen, the Netherlands. Coordinator: Dr. Ir. Igor L.Y. Spierts	ATKB

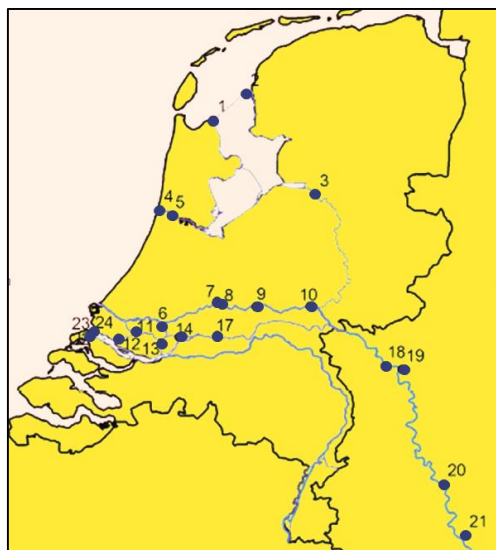
Table 1.1. List of participants

1.3 Reader

After this introduction the material and methods that were used are discussed in chapter two. In chapter three the results of both studies are presented. In chapter four the conclusions follow, in which also the results and conclusions of both studies will be compared. Finally, in chapter five the references are presented.

2 MATERIAL AND METHODS

2.1 Telemetry: NEDAP Trail system®



In these studies the NEDAP Trail system® was used. This system is based on the inductive coupling between an antenna loop and a ferrite rod antenna within transponders. The system consists of (1) a network of detection stations placed on strategically chosen locations along the river Rhine (figure 2.1 and table 2.1) and Meuse and its tributaries, and (2) implantable transponders. The identification system can be used in rivers, canals and estuaries.

For the transmission mode a narrow Low Frequency (LF) band approach (33.25 kHz), low bit rate, was chosen. This approach results in a high sensitive receiver with a low chance of interference from radio signals and other man made disturbances. The choice of the frequency is based on the consideration that coupling between the tag (in this study a transponder) and the antenna on the river bottom is a loosely coupled transformer.

Figure 2.1. Network of detection stations of the NEDAP Trail system® in the Rhine system and lower river delta that are important for the current study.

Nr.	Name	Nr.	Name
1	IJsselmeer_Den Oever	13	Dordtsche Kil_s'Gravendeel
2	IJsselmeer_Kornwerderzand	14	BenMerwede_Slledrech
3	IJssel_Kampen	15	Beneden Merwede_Boven Hardinxveld
4	NZK_IJmuiden_gemaal	16	Waal_Vuren
5	NZK_Velsen	17	Waal_Brakel
6	De Noord_Kinderdijk	18	Rijn_Xanten
7	Lek_Nieuwegein	19	Lippe_Wesel
8	Nederrijn_Hagestein	20	Wupper_Burrig
9	Nederrijn_Maurik	21	Sieg_Menden
10	Nederrijn_Arnhem	22	Haringvliet_Stellendam_noord
11	Oude Maas_Spijkenisse	23	Haringvliet_Stellendam_zuid
12	Spui_Zuidland	24	HV_Stellendam_scheep

Table 2.1. List of stations of the NEDAP Trail system® in the Rhine system and lower river delta that are important for the current study (Ben: downstream).

This means that no radio signals are emitted and therefore no interference is caused to radio users. The system consists of many detection stations and implantable transponders. The network of detection stations is shown in figure 2.1 (situation on May 1st 2010), and the locations are given in table 2.1 (in Dutch). On November 19th 2009 and March 11th 2010 two new stations were added to the NEDAP TRAIL System® network (in the Hartelkanaal and the Nieuwe Waterweg, respectively). A detection station that was installed in the river Wupper (Germany) in 2008, near Bürrig, makes it possible to also register the start of the downstream migration immediately when fish leave the river Wupper and subsequently enter the river Rhine.



Figure 2.2. NEDAP transponder.

Every 4 seconds the transmitter generates an interrogating signal which triggers a transponder that might pass the antenna loop. The transponder responds by transmitting its unique signal, which is subsequently demodulated by the receiver, decoded, and recorded by a microprocessor unit. This unit is connected to a telephone modem/internet. Transmission of a transponder signal takes two periods of 8 seconds, separated by 8 seconds of silence. In each transmission period of 8 seconds the unique code number of that particular transponder is transmitted 32 times.

After the complete transmission period of 24 seconds the transponder is mute for two minutes to prevent the batteries from running down in case a tagged fish should stop above an antenna. The implantable transponder consists of a biocompatible glass tube with a diameter of 15 mm and a length of approximately 66 mm (figure 2.2). Inside the transponder is a ferrite rod with a length of 25 mm, a custom made integrated electronic circuit, and a battery with a diameter of 12 mm and a length of 10 mm.

The battery ensures a lifetime of at least one and a half to two years, depending on the number of registrations. In water, each transponder weights approx. 17 g. Field tests showed that the detection system still functioned properly at a maximum antenna length of 550 m, a water depth of 15 m and a passing velocity of 5-6 m s⁻¹. Effects of ship engine noises are negligible. When the transponder is close to the hull of a vessel (less than 10 cm) the signal detection is interrupted. Maximum tolerable conductivity of the water of the river was not tested. Calculations showed however that a conductivity of less than 6,000 µS cm⁻¹ did not affect transmission when the distance between the antenna and the transponder did not exceed 15 m. When a tagged fish passes a detection station its unique ID-number (amongst other information) is logged onto a data storage system.

2.2 Silver eel

2013

In total 150 silver eel were caught in the Mosel, near Winnigen, Germany. Due to issues concerning the Law on Animal Experiments all fish were transported from the Mosel in Winnigen in Germany to the fish culture centre Valkenswaard, the Netherlands, in order to be tagged on Dutch soil. The transportation was performed on November 8th 2013 by skilled employees of the fish culture centre Valkenswaard. Fish were stored for a maximum period of 48 h in two large well aerated, fish tanks (1000 l each) before being operated on. The water temperature in the tanks was 9° C. During the surgical procedure it appeared that only 133 of these 150 fish had the desired minimum weight of approximately 700 g cm and or the desired condition. Current technical limitations (e.g. size of the antenna coil in the transponder) of the NEDAP system restrict a further reduction of transponder size, thus making it impossible to tag eel that are too small. Lacroix *et al.* (2004) stated that transponder length should not exceed 16% of the body length and transponder weight should be less than 8% of the body weight, which was respected in this study. The 17 eel that were of incorrect size or weight or were not in good condition were not used in this study, but were released in the wild together with the tagged eel. One silver eel died the day after surgery. The fish had sea lamprey wounds which probably led to its death after surgery (figure 2.3). Therefore the total number of tagged and released fish in 2013 is 132.



Figure 2.3. Eel with sea lamprey wounds.

2014

In total approximately 175 silver eel (200 kg) were caught in the Mosel (N=49), near Winnigen and in the Rhine (N=42), Germany. Another 59 silver eel were from a mixed origin. Due to issues concerning the Law on Animal Experiments all fish were transported from the Schleuse Lehmen (mr. Toni Kröger) in Germany to the fish culture centre Valkenswaard, the Netherlands, in order to be tagged on Dutch soil.

The transportation was performed on Oktober 19th 2014 by skilled employees of the fish culture centre Valkenswaard. Fish were stored for a maximum period of 48 h in two large well aerated, fish tanks (1000 l each) before being operated on. The water temperature in the tanks was 9° C. During the surgical procedure the best 150 fish (concerning health, condition, weight and total length) were selected. These fish all had the desired minimum weight of approximately 700 g cm and or the desired condition. The approximate 25 eel that were of incorrect size or weight or were not in good condition were not used in this study, but were released in the wild together with the tagged eel.

2.3 Surgical procedure

Transponders were implanted in the abdominal cavity of the silver eel (Lucas, 1989; Moore *et al.*, 1990; McKinley *et al.*, 1994), according to Vriese (1995) by a skilled crew of four employees from ATKb. In the study of Vriese (1995) 25 rainbow trout (*Oncorhynchus mykiss*, Walbaum) were implanted with dummy transponders and kept in captivity. The implanted fish did not show any significant difference in either growth or behaviour during a 6 months period, compared to non-implanted fish. Histological analyses showed some encapsulation of transponders in only two of these fish, most likely due to the effect of insufficient cleaning. None of the implanted fish died as a result of the implantation. In several other studies transponders were successfully implanted in eel (Baras & Jeandrain, 1998; Bruijs *et al.*, 2003; Vriese *et al.*, 2006; 2008, Vis & Spierts, 2010). In the current study fish were anaesthetised with Benzocaine. Detailed photos of the surgical procedure are shown in figure 2.4. Feeding of eel was ceased 24 hours before their operation. After surgery, fish were held shortly for observation in a well aerated recovery tank. When the eel was reacting normally, in terms of breathing, equilibrium and swimming motion, it was placed in one of the five larger holding tanks.



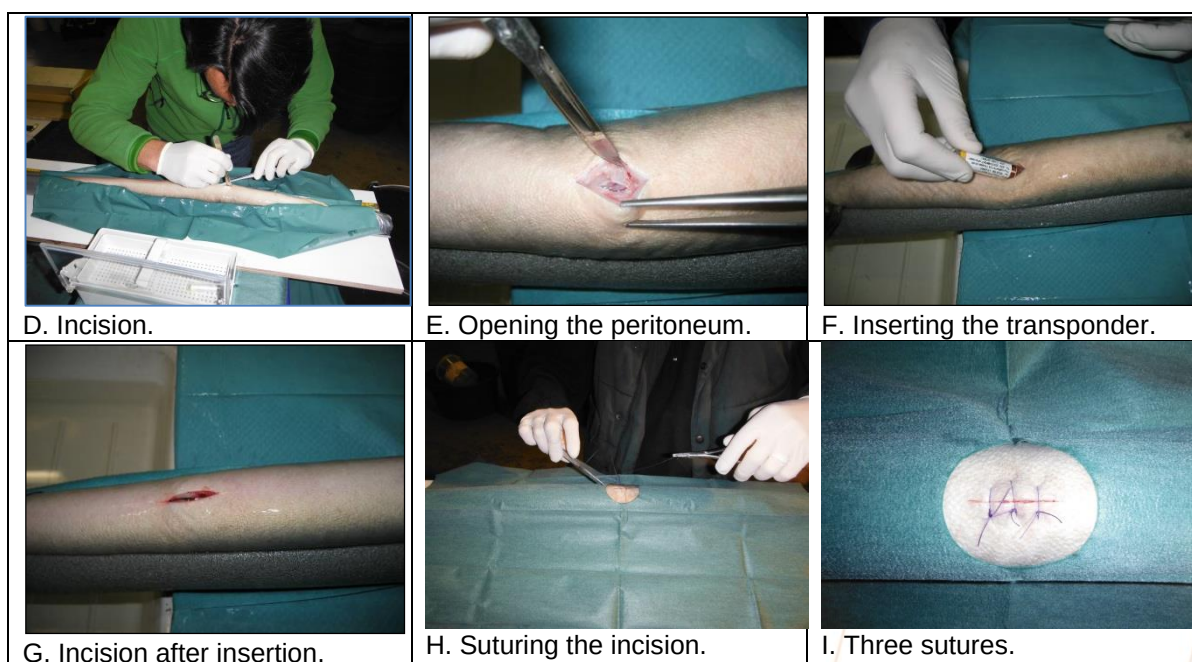


Figure 2.4. Details of surgical procedure.

The status of maturity of each implanted eel (silver, intermediate or yellow stage) was determined by measuring the: (A) vertical and horizontal eye-diameter, (B) total length, (C) bodyweight, and (D) pectoral fin length. Subsequently the Eye Index (EI) was calculated, using Pankhurst's algorithm (1982). Eel were also checked for their silvering status based on external appearance, and only fish classified as 'silver' or 'intermediate' were used.

2013

All 132 fish were tagged on November 11th and 12th 2013 in Valkenswaard. After finishing the surgical procedures and measurements all tagged eel were stored in Valkenswaard (24-48 h) before they were released in the various branches of the Rhine in Germany on November 13th 2013.

2014

All 150 fish were tagged on October 20th, 21st and 22nd in Valkenswaard. After finishing the surgical procedures and measurements all tagged eel were stored in Valkenswaard (24-72 h) before they were released in the various branches of the Rhine in Germany on October 23rd 2014.

2.4 Releasement of eel

2013

River	# eel	Date	Time
Lippe	26	November 13 th 2013	10:00 h
Ruhr	27	November 13 th 2013	11:00 h
Wupper	27	November 13 th 2013	12:15 h
Sieg	26	November 13 th 2013	13:45 h
Rhine	26	November 13 th 2013	15:30 h

On November 13th 2013 all eel were transported from the fish culture centre Valkenswaard to the five release sites. The transportation was performed by skilled employees of fish culture centre Valkenswaard. Eel were released in five batches into the rivers Lippe, Ruhr, Wupper, Sieg and Rhine (table 2.2 and figure 2.5).

Table 2.2. Eel release data 2013.

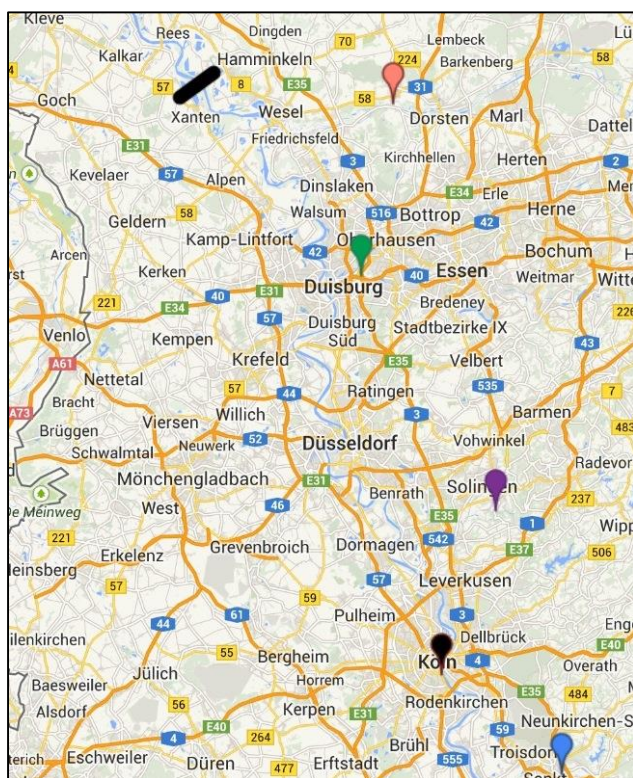


Figure 2.5. Release sites of the five batches of tagged eel in 2013 and 2014. Marks: Lippe: red; Ruhr: green; Wupper: purple; Sieg: blue and Rhein: black. Black line: first downstream NEDAP detection station in Xanten.

2014

River	# eel	Date	Time
Ruhr	30	October 23 rd 2014	09:30 h
Lippe	30	October 23 rd 2014	10:30 h
Wupper	30	October 23 rd 2014	11:30 h
Sieg	30	October 23 rd 2014	13:00 h
Rhine	30	October 23 rd 2014	14:30 h

On October 23rd 2014 all 150 silver eel were transported from the fish culture centre Valkenswaard to the five release sites in Germany. The transportation was performed by skilled employees of fish culture centre Valkenswaard. Eel were released in five batches into the rivers Ruhr, Lippe, Wupper, Sieg and Rhine (table 2.3 and figure 2.5).

Table 2.3. Eel release data 2014.

2.5 Data analysis

After releasing the eel RWS WVL (the Netherlands) regularly provided Excel files with eel registrations which were subsequently analysed. False registrations, i.e. other fish species and system and routine checks, of transponder signals were disregarded. Occasionally eel were not registered, due to: (1) stations being out of order, or (2) high water events. When a fish was registered more than once within three minutes at a specific detection station, the separate registrations were joined together and considered to be one single registration. To determine the swimming direction of migrating eel it was assumed that when a station was crossed once, the fish was moving downstream, and when a station was crossed twice, the eel was moving upstream, and so forth. This assumption was necessary as the NEDAP TRAIL System® cannot detect swimming direction. In an earlier study 91,5% of the fish reached the next detection station exactly as determined from the sequence of registrations on a particular detection station (Bij de Vaate & Breukelaar, 2001).

3 RESULTS

3.1 2013

3.1.1 Eel tagging data

River	# eel	Mean length (cm)	Mean weight (g)	Mean Eye Index	Mean cond. factor
Lippe	26	85,4	1291	9,4	1
Ruhr	27	86,7	1324	10,6	1
Wupper	27	84	1137	11,1	1
Sieg	26	84,4	1203	11,2	1
Rhine	26	84,5	1242	8,7	1

In table 3.1 the eel tagging data are summarized for each separate group. All groups have comparable total lengths and weights. Only the Ruhr group was on average heavier and longer. This is due to the fact that one eel in this group had a total length of 111 cm and a weight of 3345 g! In appendix I all eel 2013 tagging and transponder data are shown.

Table 3.1. Eel tagging data 2013

The total length of all tagged eel was $85 \pm 7,6$ cm (mean $\pm$ STD) and was normally distributed (figure 3.1). The minimum length of the tagged fish was 70 cm and the maximum length was 111 cm. The weight was $1239,1 \pm 409,7$ g (mean $\pm$ STD) and normally distributed (figure 3,2). Only the large eel of 111 cm and 3345 g was 'off scale'. The minimum weight was 691 g. Figure 3.3 shows the length-weight relation of all tagged eel.

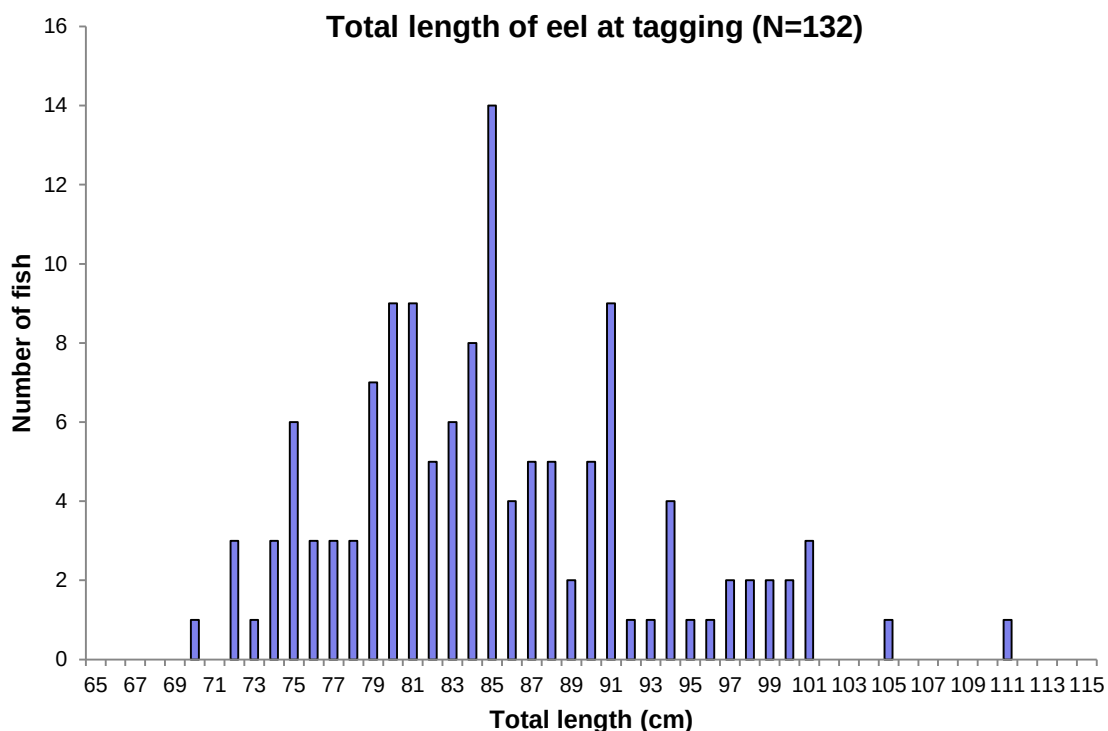


Figure 3.1. Length frequency distribution of the tagged eel.

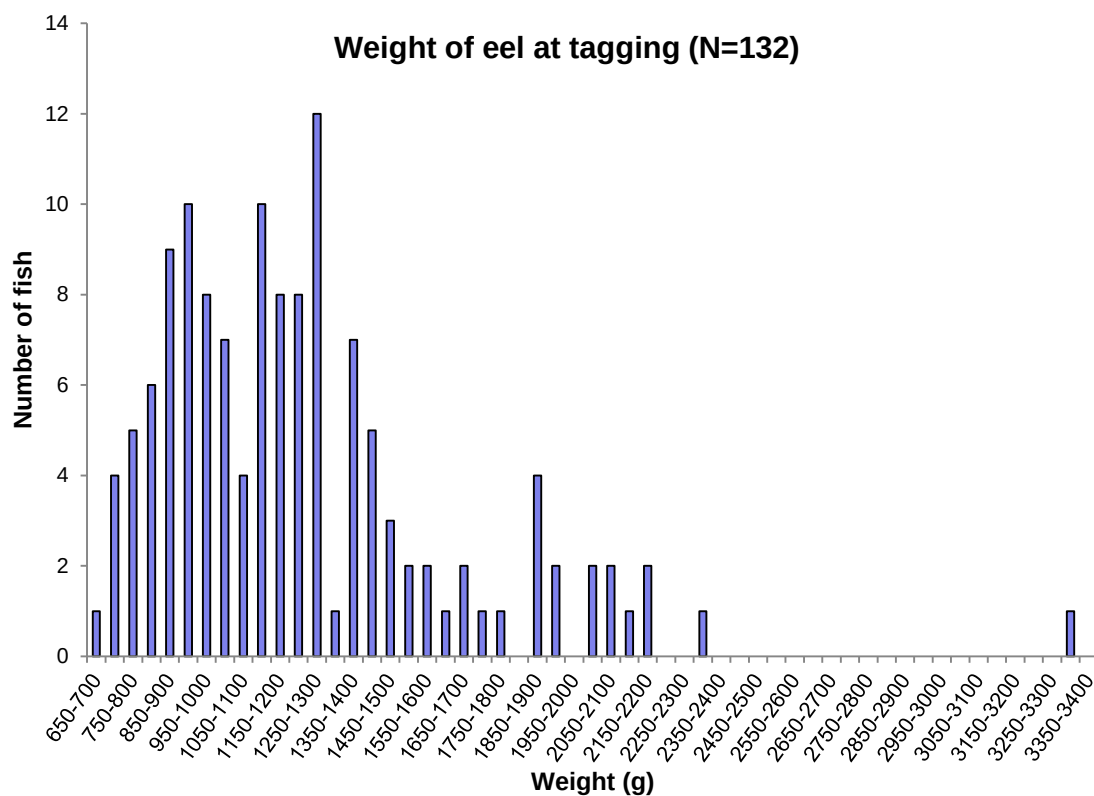


Figure 3.2. Weight distribution of the tagged eel.

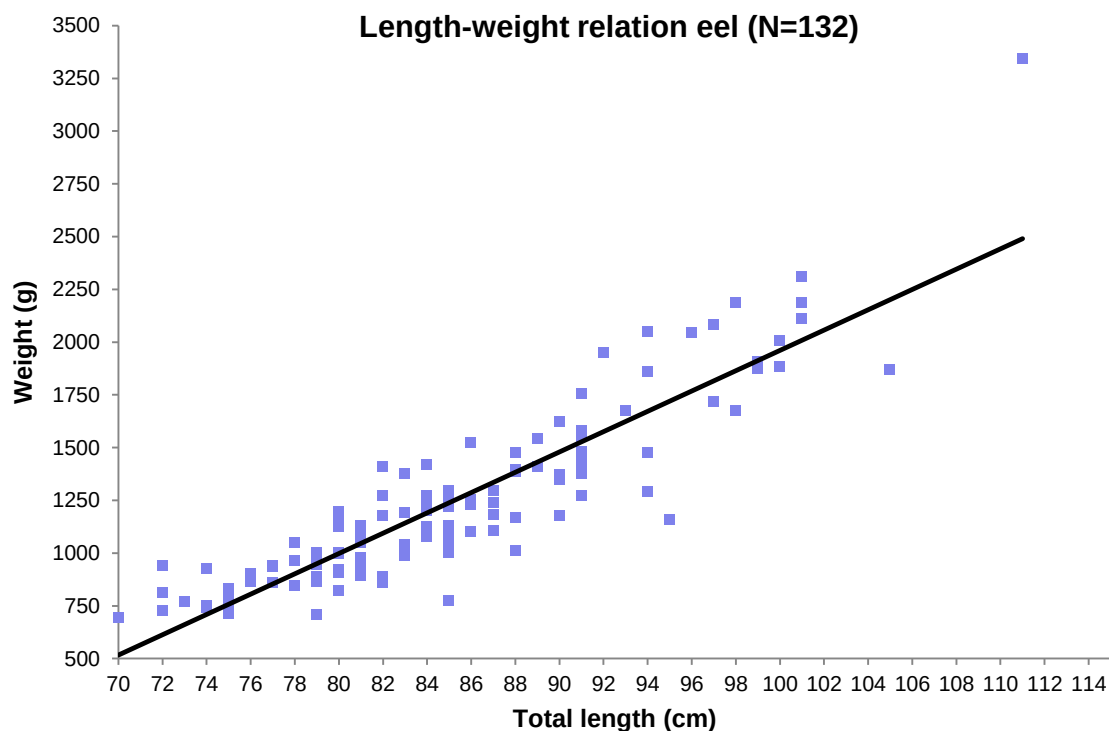


Figure 3.3. Length weight relation of the tagged eel (black: trend line).

The condition of the eel is shown in figure 3.4.

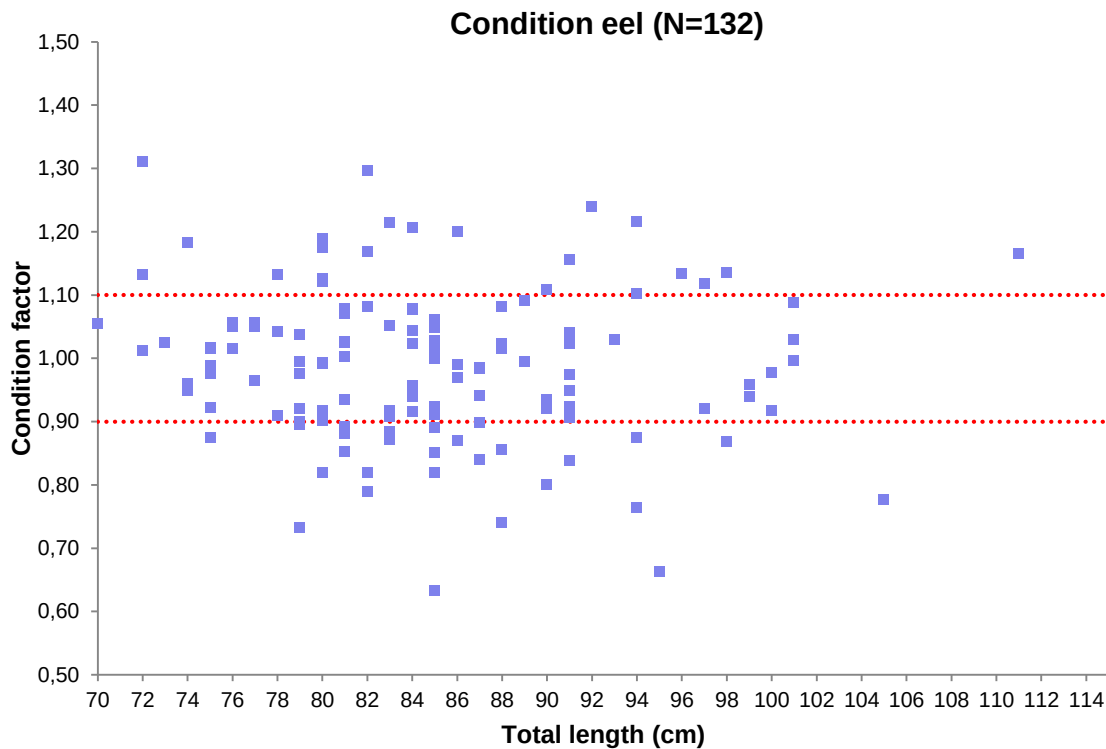


Figure 3.4. Condition of all tagged eel (red dotted lines: conditions between 0,9 and 1,1 are considered to be normal.).

The tagged eel had a mean condition of $0,99 \pm 0,12$ (mean $\pm$ STD). The maximum condition factor was 1,31 and the minimum was 0,63. Of all tagged eel 65,2 % (86 eel) had a normal condition. 15,9% Of all eel (21 fish) had a condition above 1,1, and another 18,9 % (25 eel) had a condition below 0,9. Already during the operation procedure it was clear that the eel were not in a super physical condition, as many fish were rather inactive.

In figure 3.5 the Eye Index (EI) of all tagged eel is shown. The EI was $10,2 \pm 1,91$ (mean $\pm$ STD) and varied from 5,7 to 15,1. Pankhurst (1982) stated that eel with an EI of $\geq 6,5$ can be marked as silver eel. Only 2,3% of all eel (3 fish) had an EI < 6.5 .

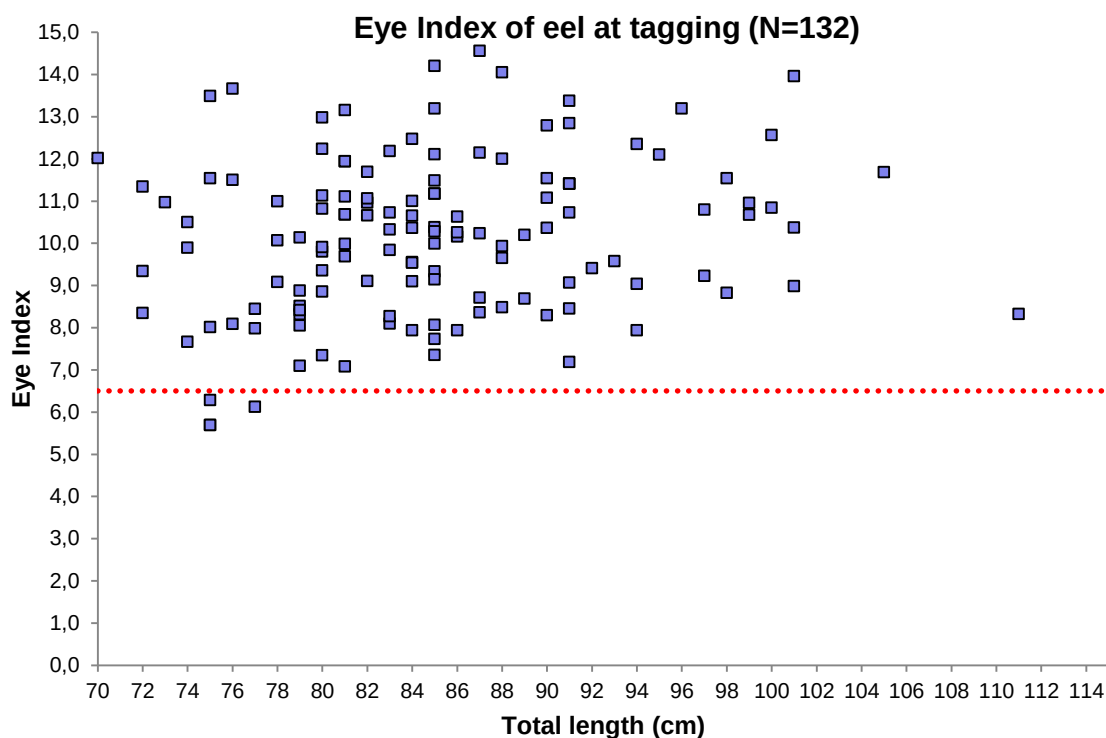


Figure 3.5. Eye Index of all tagged eel (red dotted line: eel with an EI $\geq 6,5$ are marked as silver eel).

3.1.2 Registrations 2013-2014

Registrations in the Rhine system

In this study all registrations from the day of releasing the eel (November 13th 2013) until March 1st 2014 are used (see appendix III). In total 55 eel were registered (41,7% of all tagged eel) with in total 139 registrations on 14 different stations. In table 3.2 the number of registrations and the number of eel that were registered on the various stations are shown.

Station name	# Registrations	# Fish
BenMerwerde_Sliedrecht	9	6
DeNoord_Kinderdijk	24	2
IJssel_Kampen	1	1
Lek_Nieuwegein	1	1
Lippe_Wesel	11	11
Nederrijn_Arnhem	1	1
Nederrijn_Maurik_WKC_ben	1	1
NieuweWaterweg_Europoort	3	1
OudeMaas_Spijkenisse	2	2
Rijn_Xanten	38	38
Ruhr_Duisburg	2	2
Sieg_Menden	8	7
Waal_Brakel	28	27
Wupper_Burrig	10	10

Table 3.2. Number of detections and eel that passed the various stations in the Rhine system (ben: downstream station).

In total eight eel were not registered on the first station downstream of their release site although they did pass the station (see table 3.3).

Transponder nr.	Release site	The percentage of eel that were registered in total (41,7%) is relatively low compared to the amount of eel that were registered in previous years (55%, 53%, 47%, 52%, 89%, 68%, 76% for 2004-2010 respectively, and 46% for 2012). The relatively low number of eel that were registered can possibly be explained by the fact that these eel were transported to the Netherlands in order to be operated, after which they were brought back to Germany to the release sites. Much handling of fish is always a stress factor.
12724	Lippe	
12887	Ruhr	
12896	Ruhr	
12735	Sieg	
12763	Sieg	
12800	Sieg	
12744	Wupper	
12843	Wupper	

Table 3.3. Overview of eel that were not registered on the first station downstream of their release site.

In total 38 eel were registered on the detection station in Xanten (28,8%). 30 Eel were registered on one of the stations in the Netherlands (22,7%). 7 Fish did pass Xanten but were not registered on that station (see also paragraph 3.1.3). Only one fish (transponder number 12199) reached the North Sea by passing the detection station Nieuwe Waterweg_Europoort. This eel was released in the Lippe.

In table 3.4 the number of eel are shown for each release site. The percentages are expressed as eel that were registered for each release site separately. It is immediately clear that the amount of eel that were released in the Rhine were registered the most (65,4%), whereas only 14,8% of the eel that were released in the Ruhr were registered. Three of these eel were last registered in Xanten, and one was last registered at the detection station BenMerwede_Sliedrecht. There is no clear explanation why so few eel that were released in the Ruhr were actually registered.

Release site	# tagged eel (N)	Registered eel (N)	
		#	% Of released at each site
Lippe	26	12	46,2
Ruhr	27	4	14,8
Wupper	27	12	44,4
Sieg	26	10	38,5
Rhine	26	17	65,4

Table 3.4. Number and percentages of registered eel for release site.

Time of registrations

The time of detecting eel during the day is an indication for their migration activity, as it is assumed eel mostly migrate during the first dark hours of the night, between sunset and midnight (Breukelaar *et al.*, 2009).

The results of the studies in 2004-2010 and 2012 however do not support this assumption (see table 3.5 and figure 3.6). In the current study the eel had a slight preference for migrating during night time: 74 detections (53%, see table 3.5 and figure 3.6).

Year	# And % of registrations at daytime (06:00-1800 h)		# And % of registrations at night time (06:00-1800 h)	
2004	100	47%	112	53%
2005	89	49%	93	51%
2006	103	39%	170	61%
2007	56	46%	67	54%
2008	91	35%	171	65%
2009 (Unkelmühle)	148	42%	204	58%
2009 (Rhine/Lippe)	43	35%	79	65%
2010	91	52%	85	48%
2012	96	50%	97	50%
2013	65	47%	74	53%

Table 3.5. Number and percentages of registrations during daytime and night time.

Registrations during the day

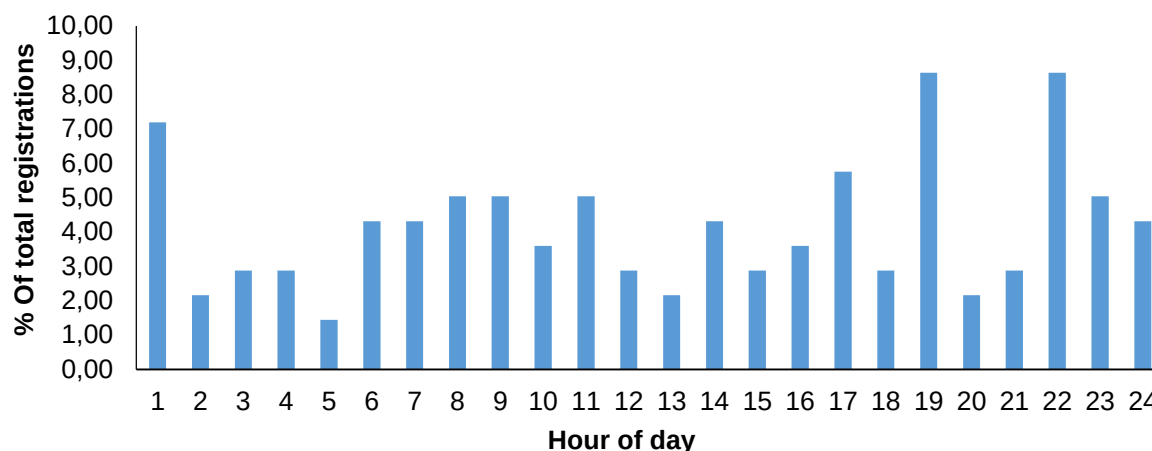


Figure 3.6. Percentage of total registrations during a 24 h period.

Registrations in relation to water discharge and moon cycle

In figure 3.7 the discharge of the Rhine in Lobith (m^3/s), the number of detections and the moon cycle is shown for the research period. There seems to be a tendency of increased migration activity around new moon and during periods with high water discharge of the Rhine (at Lobith), although this relationship is not very pronounced. Appendix IV gives an overview of the registrations of tagged eel on one hand, and water discharge and moon cycle on the other hand during the studies in in 2004-2010 and 2012). Most registrations occurred in the first month after releasing the eel.

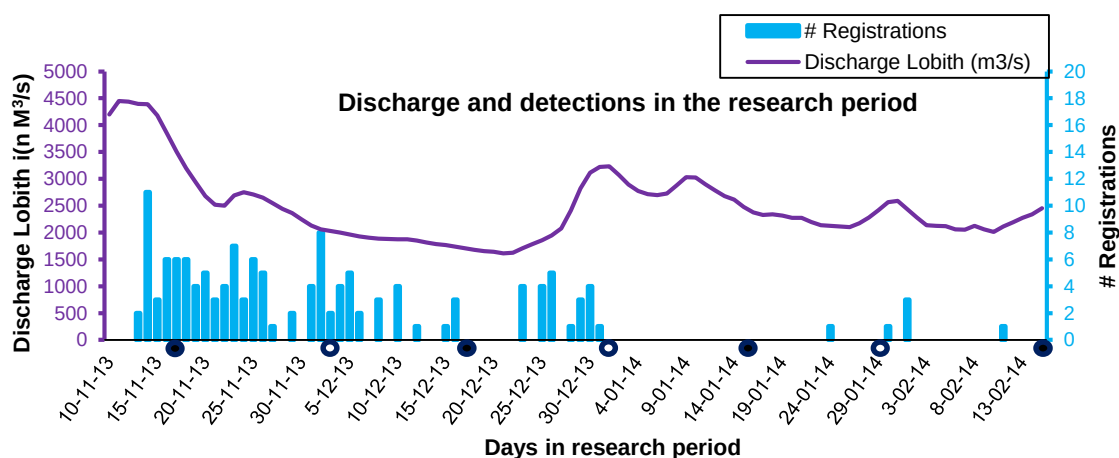


Figure 3.7. Discharge, detections and moon cycle during the research period. Black circles: full moon; open circles: new moon.

3.1.3 Migration routes in the Rhine system

In tables 3.6-3.10 the individual registrations of eel on detection stations are shown for each released group separately, sorted by transponder number. The eel that was released in the Lippe and that did reach the North Sea successfully is highlighted in red in table 3.6. In each table the days between releasing the eel and their last registration is shown in the last column.

Transp. Nr.	Migration route	# Days release-last registration
12193	Lippe_Wesel	12
12198	Lippe_Wesel; Rijn_Xanten	16
12199	Lippe_Wesel; Rijn_Xanten; Waal_Brakel; OudeMaas_Spijkenisse; NieuweWaterweg_Europoort	47
12203	Lippe_Wesel	78
12206	Lippe_Wesel+ Rijn_Xanten; Waal_Brakel	13
12209	Lippe_Wesel; Rijn_Xanten; Waal_Brakel	22
12213	Lippe_Wesel; Waal_Brakel; BenMerwerde_Sliedrecht; DeNoord_Kinderdijk	33
12214	Lippe_Wesel; Rijn_Xanten; Waal_Brakel; OudeMaas_Spijkenisse	90
12222	Lippe_Wesel; Waal_Brakel	9
12232	Lippe_Wesel; Rijn_Xanten; Waal_Brakel	20
12713	Lippe_Wesel; Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrecht	43
12724	Rijn_Xanten; Waal_Brakel	8

Table 3.6. Individual migration routes of silver eel released in the Lippe. Tagged: 26 eel; registered: 12 eel.

Transp. Nr.	Migration route	# Days release-last registration
12171	Ruhr_Duisburg; BenMerwerde_Sliedrecht	9
12887	Rijn_Xanten	6
12888	Ruhr_Duisburg; Rijn_Xanten	13
12896	Rijn_Xanten	1

Table 3.7. Individual migration routes of silver eel released in the Ruhr. Tagged: 27 eel; registered: 4 eel.

Transp. Nr.	Migration route	# Days release-last registration
12717	Wupper_Burrig; Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrecht	7
12739	Wupper_Burrig	5
12744	Waal_Brakel; BenMerwerde_Sliedrecht; DeNoord_Kinderdijk	27
12746	Wupper_Burrig	10
12756	Wupper_Burrig; Rijn_Xanten	7
12757	Wupper_Burrig; Rijn_Xanten	40
12770	Wupper_Burrig; Waal_Brakel; BenMerwerde_Sliedrecht	80
12793	Wupper_Burrig	11
12796	Wupper_Burrig	40
12819	Wupper_Burrig; Rijn_Xanten; Waal_Brakel	3
12838	Wupper_Burrig; Waal_Brakel	48
12843	Rijn_Xanten; Waal_Brakel	13

Table 3.8. Individual migration routes of silver eel released in the Wupper. Tagged: 27 eel; registered: 12 eel.

Transp. Nr.	Migration route	# Days release-last registration
12735	Rijn_Xanten; Waal_Brakel	19
12748	Sieg_Menden; Rijn_Xanten	4
12751	Sieg_Menden	0
12763	Rijn_Xanten; Waal_Brakel	25
12765	Sieg_Menden	4
12789	Sieg_Menden	46
12797	Sieg_Menden; Rijn_Xanten; Waal_Brakel	29
12800	Rijn_Xanten; Waal_Brakel	4
12828	Sieg_Menden; Rijn_Xanten; IJssel_Kampen	5
12868	Sieg_Menden	3

Table 3.9. Individual migration routes of silver eel released in the Sieg. Tagged: 26 eel; registered: 10 eel.

Transp. Nr.	Migration route	# Days release-last registration
12716	Rijn_Xanten	47
12732	Rijn_Xanten; Waal_Brakel	2
12734	Rijn_Xanten	1
12767	Rijn_Xanten	1
12774	Rijn_Xanten	13
12784	Rijn_Xanten; Waal_Brakel	12
12791	Rijn_Xanten	5
12794	Rijn_Xanten; Nederrijn_Arnhem; Nederrijn_Maurik_WKC_ben; Lek_Nieuwegein	6
12803	Rijn_Xanten	45
12813	Rijn_Xanten	5
12842	Rijn_Xanten; Waal_Brakel	13
12850	Rijn_Xanten; Waal_Brakel	2
12851	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrecht	10
12860	Waal_Brakel	14
12864	Rijn_Xanten	9
12865	Rijn_Xanten; Waal_Brakel	27
12877	Rijn_Xanten; Waal_Brakel	25

Table 3.10. Individual migration routes of silver eel released in the Rhein. Tagged: 26 eel; registered: 17 eel.

When downstream migrating eel pass the station at the Oude Maas, they can reach the North Sea either by passing the Hartelkanaal and Nieuwe Waterweg or swim directly to the Nieuwe Waterweg. Only one eel out of 55 registered eel (1,8%) reached the North Sea by passing the stations OudeMaas_Spijkenisse and NieuweWaterweg_Europoort. In previous years it was assumed that an eel successfully reached the North sea when passing one of the detection stations in the Noord, the Oude Maas or the Lek. In the current situation with two new stations (Nieuwe Waterweg and hartelkanaal) it is assumed that eel that were registered one of these two stations successfully reached the North Sea.

In this study two eel were registered on the station in the Noord (transponder numbers 12213, released in the Lippe, and transponder number 12744, released in the Wupper), but never reached the next station in the Nieuwe Waterweg or Hartelkanaal. Two other eel the station in the Oude Maas (transponder number 12214 and 12199, both released in the Lippe). One of these latter eel did reach the North Sea by passing the station in the NieuweWaterweg_Europoort (see table 3.6). On eel did pass the station in the Lek_Nieuwegein, but did not reach the sea.

So in theory one eel did reach the sea. When using the 'old' method five eel (9,1% of the registered eel) reached the North Sea. The percentage escapement of registered silver eel to the North sea in

2004-2010 and 2012 was 32%, 26%, 34%, 32%, 16%, 22%, 21% and 9% respectively. It is possible that eel which are present in the higher parts of the river Rhine can still reach the sea in the near future.

3.1.4 Downstream migration velocity

For this section it is important to notice that only those detection stations are used for which is certain that eel can only reach these stations through one route. In this way the migration velocity can reliably be determined. Detection stations that can be reached by several different routes (i.e. Oude Maas_Spijkenisse, Spui_Zuidland, etc.) are left out in this section.

The variation in migration velocity is large amongst the registered eel: the slowest eel migrated a distance of 6 km in 46 days (0,1 km/day), whereas the fastest eel travelled a distance of 177 km in one day (177 km/day, see table 3.11). The actual migration velocity of the fish is actually higher when fish do not swim continuously but have periods of inactivity. With a velocity of 177 km/day (2,05 m/s) and an average river flow velocity of 1 m/s, the eel is swimming downstream with a velocity of 1,05 m/s. It is interesting to notice that both the fastest and the slowest eel was released in the Sieg.

Release location	Stationname	# Registrations	Fastest migration		Slowest migration		Mean migration		Distance in km
			days	km/day	days	km/day	days	km/day	
Lippe	Lippe_Wesel	11	5	4,2	78	0,3	25,7	0,8	21
	Rijn_Xanten	8	7	4,7	43	0,8	23,9	1,4	33
	Waal_Brakel	9	8	19,9	47	3,4	23,9	6,7	159
	BenMerwerde_Sliedrecht	2	12	14,8	43	4,1	27,5	6,4	177
	DeNoord_Kinderdijk	23	18	11,1	33	6,1	22,3	8,9	200
Total Lippe		53	5	19,9	78	0,3	23,7	3,0	
Ruhr	Ruhr_Duisburg	2	7	0,4	12	0,3	9,5	0,3	3
	Rijn_Xanten	3	1	53,0	13	4,1	6,7	8,0	53
	BenMerwerde_Sliedrecht	1	9	21,9	9	21,9	9,0	21,9	197
Total Ruhr		6	1	53,0	13	0,3	8,0	10,1	
Wupper	Wupper_Burrig	10	1	20,0	40	0,5	15,7	1,3	20
	Rijn_Xanten	5	2	53,5	40	2,7	12,8	8,4	107
	Waal_Brakel	6	3	77,7	72	3,2	27,8	8,4	233
	BenMerwerde_Sliedrecht	5	7	35,9	80	3,1	54,8	4,6	251
	DeNoord_Kinderdijk	1	27	10,1	27	10,1	27,0	10,1	274
Total Wupper		27	1	77,7	80	0,5	25,5	6,5	
Sieg	Sieg_Menden	8	0,5	12,0	46	0,1	7,5	0,8	6
	Rijn_Xanten	6	1	177,0	21	8,4	8,3	21,2	177
	Waal_Brakel	5	4	75,8	29	10,4	20,4	14,9	303
	IJssel_Kampen	1	5	68,0	5	68,0	5,0	68,0	340
Total Sieg		20	0,5	177,0	46	0,1	10,9	26,2	
Rhein	Rijn_Xanten	16	1	140,0	47	3,0	10,3	13,7	140
	Waal_Brakel	8	2	133,0	27	9,9	13,0	20,5	266
	BenMerwerde_Sliedrecht	1	10	28,4	10	28,4	10,0	28,4	284
	Nederrijn_Arnhem	1	5	39,8	5	39,8	5,0	39,8	199
	Nederrijn_Maurik_WKC_ben	1	6	39,0	6	39,0	6,0	39,0	234
	Lek_Nieuwegein	1	6	42,5	6	42,5	6,0	42,5	255
Total Rhein		28	1	140,0	47	3,0	10,5	30,6	

Table 3.11. Overview of the migration velocities of registered eel from the five release locations to the different detection stations.

3.2 2014

3.2.1 Eel tagging data

In table 3.12 the eel tagging data are summarized for each separate group. Most groups have

River	# eel	Mean length (cm)	Mean weight (g)	Mean Eye Index	Mean cond. factor
Lippe	30	83,6	1133	8,6	0,97
Ruhr	30	85,7	1290	8,4	0,99
Wupper	30	81,9	1074	9,4	0,97
Sieg	30	83,9	1098	7,3	0,91
Rhine	30	83,4	1169	10,0	0,99

comparable total lengths and weights. Only the Ruhr group was, similar as in 2013 (by coincidence), on average heavier and longer than the other groups. This is due to the fact that a larger group of fish in this batch were, in comparison to fish in the other batches, both longer and heavier. In appendix II all eel 2014 tagging and transponder data are shown.

Table 3.12. Eel tagging data 2014.

The total length of all tagged eel was $83,7 \pm 8$ cm (mean $\pm$ STD) and was normally distributed (figure 3.8). This mean length was slightly lower than that of the eel in 2013 ($85 \pm 7,6$ cm). The minimum length of the tagged fish was 67 cm and the maximum length was 102 cm. The weight was $1152,6 \pm 360,3$ g (mean $\pm$ STD, in 2013 this was $1239,1 \pm 409,7$ g) and normally distributed (figure 3,9). The minimum weight was 655 g and the maximum weight was 2190 g. Finally figure 3.10 shows the length-weight relation of all tagged eel, which is nicely distributed around the trend line for all fish.

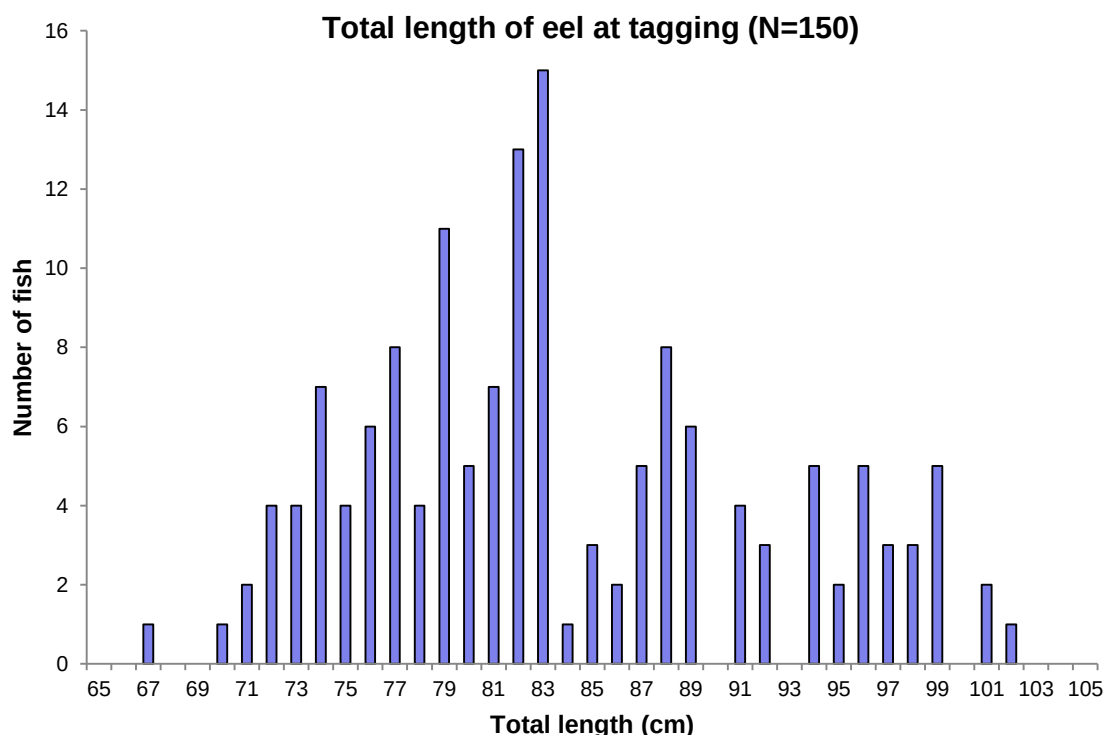


Figure 3.8. Length frequency distribution of the tagged eel.

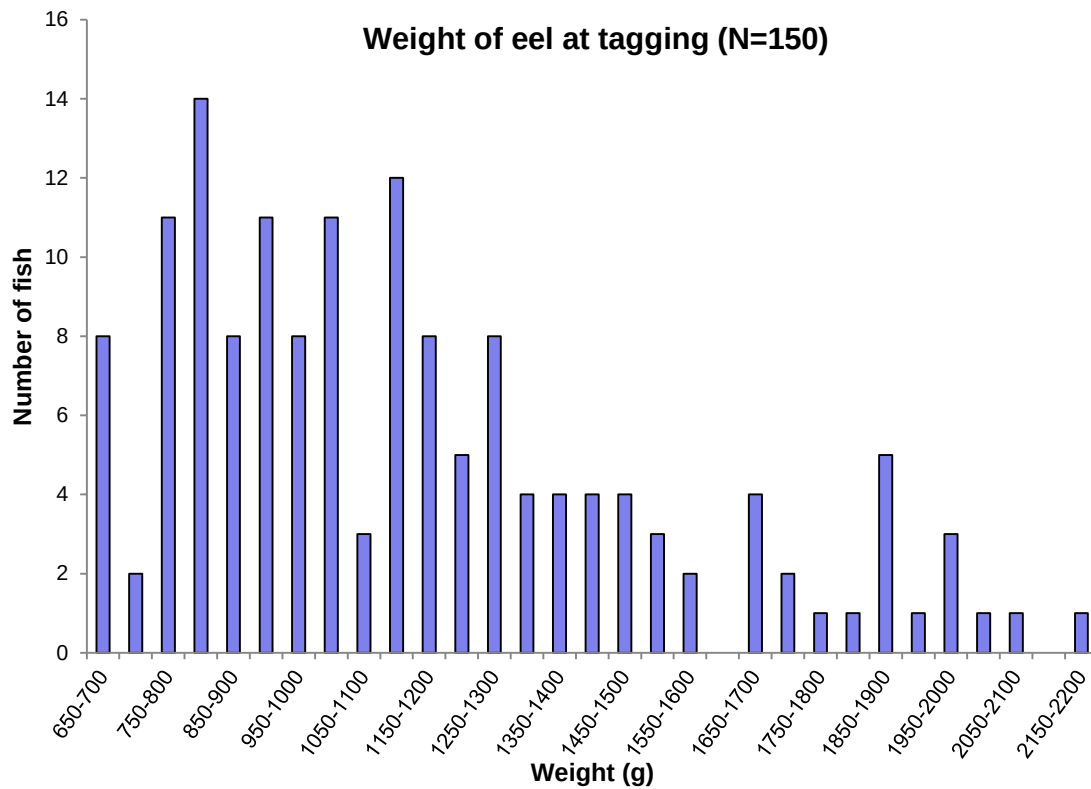


Figure 3.9. Weight distribution of the tagged eel.

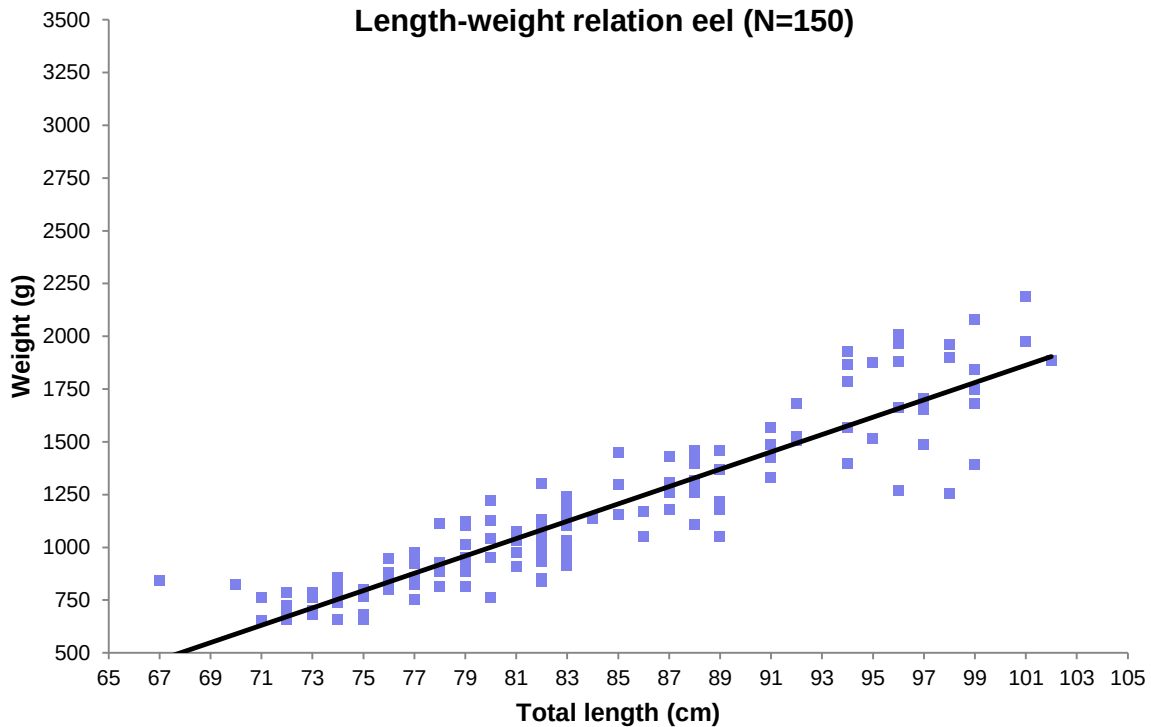


Figure 3.10. Length weight relation of the tagged eel (black: trend line).

The condition of the eel is shown in figure 3.11.

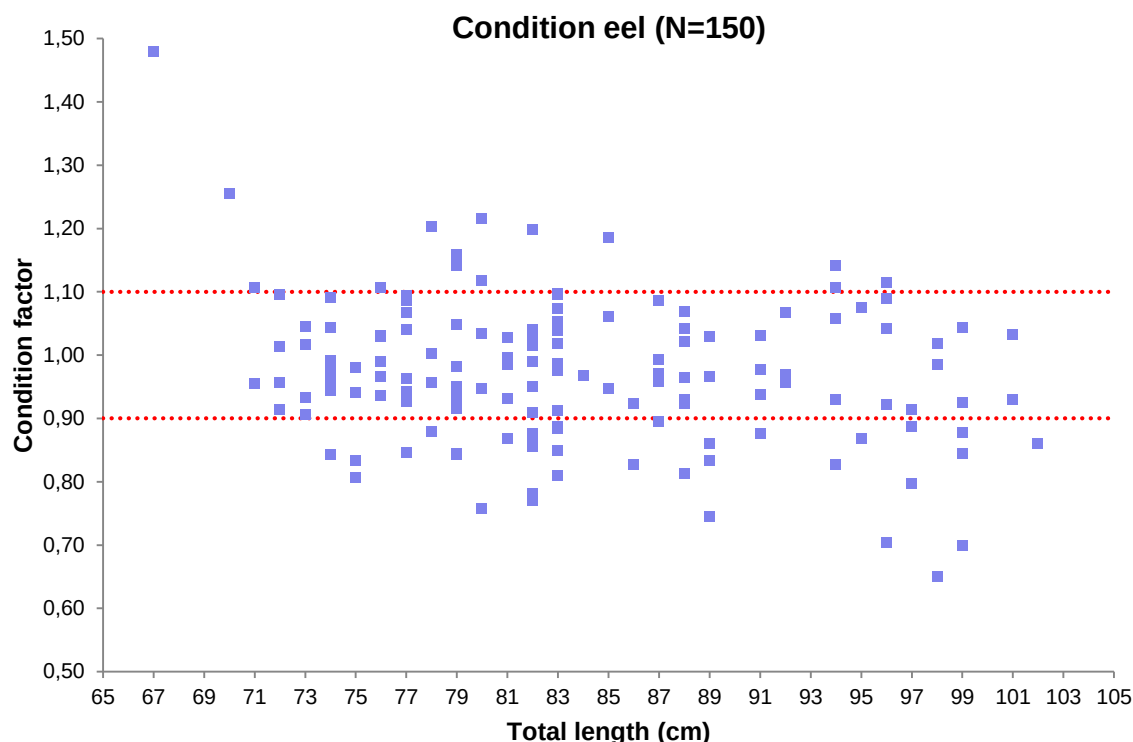


Figure 3.11. Condition of all tagged eel (red dotted lines: conditions between 0,9 and 1,1 are considered to be normal.).

The tagged eel had a mean condition factor of $0,97 \pm 0,12$ (mean $\pm$ STD, this was 0,99 in 2013). The maximum condition factor was 1,48, which was substantial larger than in 2013 (1,31). Interestingly his maximum condition factor was found in the smallest silver eel that was tagged (Rhine group, 67 cm and 843 g, see upper left dot in figure 3,11). The minimum condition factor was 0,65.

Of all tagged eel 66 % (99 eel) had a normal condition, in 2013 this was 65,2%. 9,3% Of all eel (14 fish) had a condition above 1,1. This is substantial more than in the group of 2013 (15,7%), but as mentioned earlier, for the group of silver eel of 2013 it was already clear during the operation procedure that these fish were not in a super physical condition, as many fish were rather inactive. Finally 24,7% of the fish (37 eel) of the 2014 group had a condition below 0,9.

In figure 3.12 the Eye Index (EI) of all tagged eel is shown. The EI was $8,7 \pm 1,9$ (mean $\pm$ STD) and varied from 4 to 15. Pankhurst (1982) stated that eel with an EI of $\geq 6,5$ can be marked as silver eel. 11,33% Of all eel (17 fish) had an EI < 6.5.

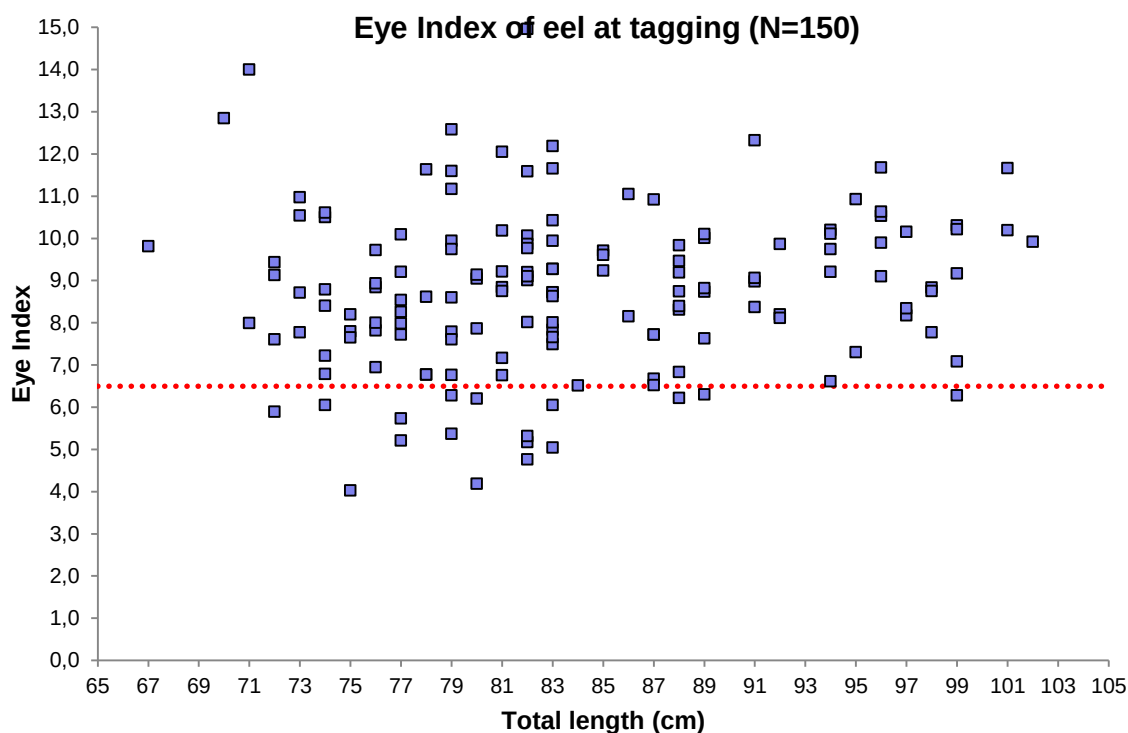


Figure 3.12. Eye Index of all tagged eel (red dotted line: eel with an EI $\geq 6,5$ are marked as silver eel).

3.2.2 Registrations 2014-2015

Registrations in the Rhine system

In this study all registrations from the day of releasing the eel (October 23rd 2014) until Februari 6th 2015 are used (see appendix IV). In total 62 eel were registered (41,3% of all tagged eel, this was almost equal to the percentage registered eel in 2013, 41,7%) with in total 156 registrations on 15 different stations. In table 3.13 the number of registrations and the number of eel that were registered on the various stations are shown.

Stationname	# Registrations	# Fish
BenMerwerde_Sliedrech	9	9
DeNoord_Kinderdijk	4	4
DKil_sGravendeel	1	1
HV_Stellendam_SpuiSluizen	14	1
Lek_Nieuwegein	3	3
Lippe_Wesel	13	13
Nederrijn_Amerongen	4	4
Nederrijn_Arnhem	4	4
Nederrijn_Maurik_WKC_ben	4	4
NieuweWaterweg_Europoort	5	4
OudeMaas_Spijkenisse	14	13
Rijn_Xanten	39	39
Sieg_Menden	8	8
Spui_Zuidland	2	2
Waal_Brakel	32	32

Table 3.13. Number of detections and eel that passed the various stations in the Rhine system (ben: downstream station).

In total 29 eel were not registered on the first station downstream of their release site although they did pass the station (see table 3.14). No fish were registered on the stations Ruhr-Duisberg and Wupper_Burrig. It is a known fact that the station Ruhr_Duisberg has many interferences making a clear registration difficult. In 2013 only two eel out of four that did pass this station were registered. For the station Wupper_Burrig a clear explanation for the fact that no eel were registered there is not known.

Transponder nr.	Release site	The percentage that were registered in total is, similar as in 2013, very low (41,3%) compared to the amount of eel that were registered in previous years (55%, 53%, 47%, 52%, 89%, 68%, 76%, for 2004-2010 respectively, and 46% for 2012). This relatively low number of eel that were registered can possibly (similar as in 2013) be explained by the fact that these eel were transported to the Netherlands in order to be operated, after which they were brought back to Germany to the release sites. Much handling of fish is always a stress factor. More recent data however show that approximately 1/3 of the eel that were tagged and released in 2013 that were not registered in the time period that was studied, appeared to be registered after the last date that was included in the 2013-2014 (March 1 st 2014).
12733	Lippe	
13190	Lippe	
13198	Lippe	
13124	Rhein	
13137	Rhein	
13140	Rhein	
13169	Rhein	
13172	Rhein	
All registered fish N=9)	Ruhr	
13228	Sieg	
13231	Sieg	
All registered fish (N=10)	Wupper	

Table 3.14. Overview of eel that were not registered on the first station downstream of their release site.

This finding suggest that these eel did not die due to the treatment (transport to the Netherlands, handling, storage period, etc.), as discussed previously, but appeared to show a delayed migration activity. It might be the case that these eel temporarily 'lose' their drive to migrate due to the effects of transportation, storage and handling. The exact reason for this behaviour however is until now not known (see also the discussion in paragraph 4.3).

In total 39 eel were registered on the detection station in Xanten (26% of all tagged eel). 38 (25,33%) Eel were registered on one of the stations in the Netherlands. 11 Fish did pass Xanten but were not registered on that station (see also paragraph 3.2.3). Four eel reached the North Sea by passing the detection station Nieuwe Waterweg_Europoort (see also figures 3.16-3.21). One eel did reach the station HV_Stellendam_SpuiSluizen, but after spending two days at this location the fish returned upstream and was last registered at the station OudeMaas_Spijkenisse (eel nr. 13260, release location Lippe).

In table 3.15 the number of eel are shown for each release site. The percentages are expressed as eel that were registered for each release site separately. It is clear that the amount of eel that were released in the Rhine were registered the most (56,74%). From the eel that were released in the Lippe 53,3% were registered. Only 30 % of the eel that were released in the Ruhr were registered. This phenomenon was also seen in the study of 2013. There is no clear explanation why so few eel that were released in the Ruhr were actually registered.

release site	# tagged eel (N)	Registered eel (N)	
		#	% Of released at each site
Lippe	30	16	53,3
Rhein	30	17	56,7
Rhur	30	9	30,0
Sieg	30	10	33,3
Wupper	30	10	33,3

Table 3.15. Number and percentages of registered eel for release site.

Time of registrations

The time of detecting eel during the day is an indication for their migration activity, as it is assumed eel mostly migrate during the first dark hours of the night, between sunset and midnight (Breukelaar *et al.*, 2009). In the current study the eel had a preference for migrating during night time: 94 detections (60%, see table 3.16 and figure 3.13).

Year	# And % of registrations at daytime (06:00-1800 h)		# And % of registrations at night time (06:00-1800 h)	
2004	100	47%	112	53%
2005	89	49%	93	51%
2006	103	39%	170	61%
2007	56	46%	67	54%
2008	91	35%	171	65%
2009 (Unkelmühle)	148	42%	204	58%
2009 (Rhine/Lippe)	43	35%	79	65%
2010	91	52%	85	48%
2012	96	50%	97	50%
2013	65	47%	74	53%
2014	62	40%	94	60%

Table 3.16. Number and percentages of registrations during daytime and night time.

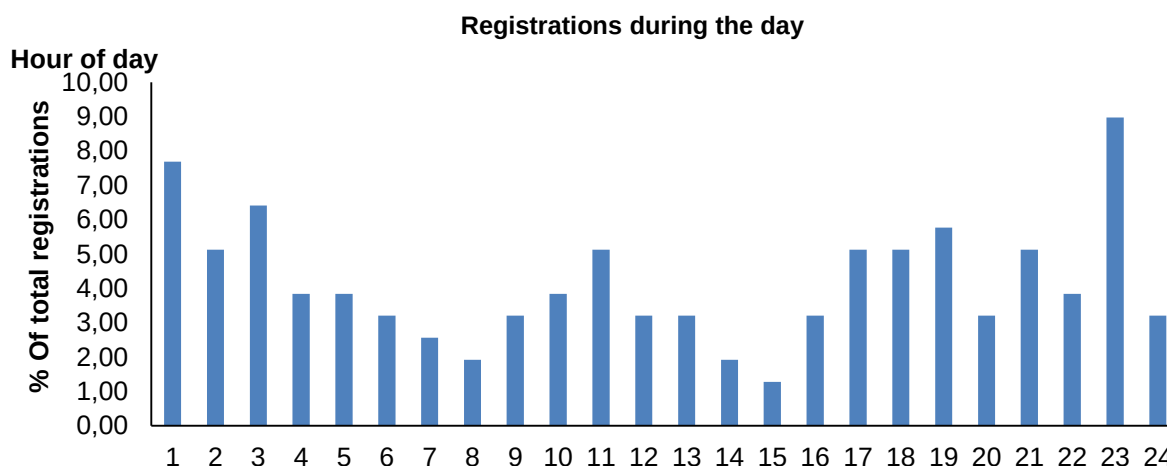


Figure 3.13. Percentage of total registrations during a 24 h period.

Registrations in relation to water discharge and moon cycle

In figure 3.14 the discharge of the Rhine in Lobith (m³/s), the number of detections and the moon cycle is shown for the research period. Similar as in the study of 2013 in this study there also seems to be a tendency of increased migration activity around new moon and during periods with high water discharge of the Rhine (at Lobith). This relationship is mainly visible during the peaks in registrations in the first part of the study period (2014). Appendix IV gives an overview of the registrations of tagged eel on one hand, and water discharge and moon cycle on the other hand during the studies in in 2004-2010 and 2012).

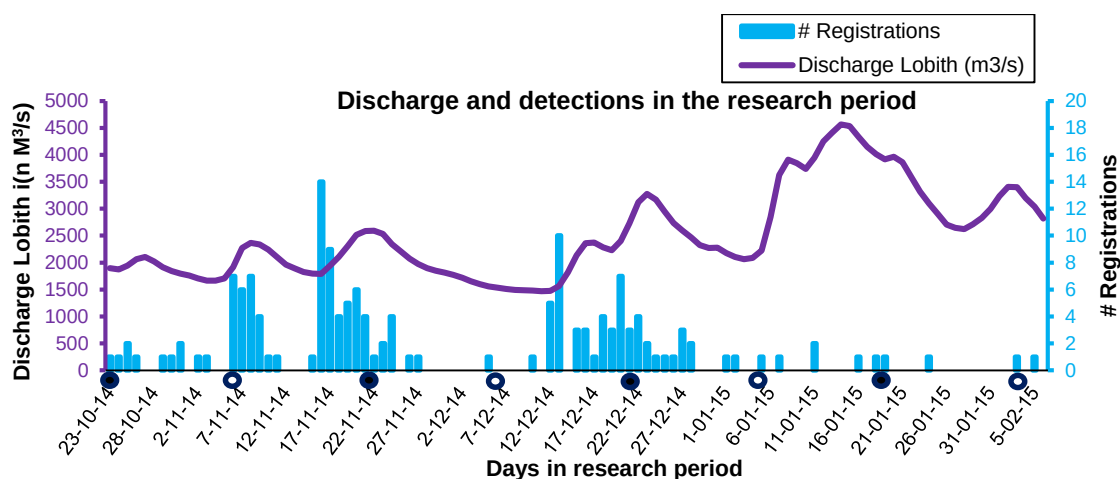


Figure 3.14. Discharge, detections and moon cycle during the research period. Black circles: full moon; open circles: new moon.

3.2.3 Migration routes in the Rhine system

In tables 3.17-3.21 the individual registrations of eel on detection stations are shown for each released group separately, sorted by transponder number. Eel that did reach the North Sea successfully are highlighted in red in tables 3.16, 3.18 and 3.21. In each table the days between releasing the eel and their last registration is shown in the last column.

Transp. Nr.	Migrationroute	#Days release-last registration
12168	Lippe_Wesel; BenMerwerde_Sliedrech; DeNoord_Kinderdijk	32
12728	Lippe_Wesel	7
12733	Rijn_Xanten	25
12812	Lippe_Wesel; Waal_Brakel;OudeMaas_Spijkenisse	26
12816	Lippe_Wesel; Waal_Brakel;OudeMaas_Spijkenisse	29
12870	Lippe_Wesel; Rijn_Xanten; Nederrijn_Arnhem;Nederrijn_Maurik_WKC_ben; Nederrijn_Amerongen; Lek_Nieuwegein; NieuweWaterweg_Europoort	77
12938	Lippe_Wesel; Nederrijn_Arnhem; Nederrijn_Maurik_WKC_ben; Nederrijn_Amerongen; Lek_Nieuwegein	57
13134	Lippe_Wesel; Rijn_Xanten; Waal_Brakel	33
13174	Lippe_Wesel; Rijn_Xanten	15
13180	Lippe_Wesel; Rijn_Xanten	60
13187	Lippe_Wesel; Rijn_Xanten; Waal_Brakel	89
13190	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech	30
13191	Lippe_Wesel	106
13198	Waal_Brakel	44
13219	Lippe_Wesel; Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech;	26
13232	Lippe_Wesel; Rijn_Xanten	25

Table 3.17. Individual migration routes of silver eel released in the Lippe. Tagged: 30 eel; registered: 16 eel.

Transp Nr.	Migrationroute	#Days release-last registration
13101	Rijn_Xante; Waal_Brakel	59
13152	Rijn_Xanten; Waal_Brakel; OudeMaas_Spijkenisse; NieuweWaterweg_Europoort	66
13153	Rijn_Xanten	66
13162	Waal_Brakel	59
13165	Waal_Brakel	86
13168	Rijn_Xanten	67
13183	Rijn_Xanten; Waal_Brakel; OudeMaas_Spijkenisse; NieuweWaterweg_Europoort	62
13240	Rijn_Xanten	59
13266	Rijn_Xanten	51

Table 3.18. Individual migration routes of silver eel released in the Ruhr. Tagged: 30 eel; registered: 9 eel.

Transp. Nr.	Migrationroute	#Days release-last registration
12740	Rijn_Xanten	59
12830	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech	4
12841	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech	9
12891	Rijn_Xanten	71
12910	Rijn_Xanten	26
12953	Rijn_Xanten; Nederrijn_Arnhem; Nederrijn_Maurik_WKC_ben Nederrijn_Amerongen; Lek_Nieuwegein	81
12959	Rijn_Xanten	58
12993	Waal_Brakel	30
13246	Rijn_Xanten	72
13249	Waal_Brakel; BenMerwerde_Sliedrech; OudeMaas_Spijkenisse	16

Table 3.19. Individual migration routes of silver eel released in the Wupper. Tagged: 30 eel; registered: 10 eel.

Transp. Nr.	Migrationroute	#Days release-last registration
12912	Sieg_Menden	104
12939	Sieg_Menden	59
13090	Sieg_Menden	2
13228	Waal_Brakel	81
13231	Waal_Brakel	27
13237	Sieg_Menden	49
13239	Sieg_Menden; Rijn_Xanten; Waal_Brakel; OudeMaas_Spijkenisse;	61
13242	Sieg_Menden; Rijn_Xanten; Nederrijn_Arnhem; Nederrijn_Maurik_WKC_ben; Nederrijn_Amerongen	30
13257	Sieg_Menden	25
13260	Sieg_Menden; Rijn_Xanten; Waal_Brakel; HV_Stellendam_SpuiSluizen; Spui_Zuidland; OudeMaas_Spijkenisse	56

Table 3.20. Individual migration routes of silver eel released in the Sieg. Tagged: 30 eel; registered: 10 eel.

Transp. Nr.	Migrationroute	#Days release-last registration
13124	Waal_Brakel; OudeMaas_Spijkenisse	20
13125	Rijn_Xanten; Waal_Brakel	67
13133	Rijn_Xanten	94
13135	Waal_Brakel	61
13137	Waal_Brakel; OudeMaas_Spijkenisse	58
13138	Rijn_Xanten; Waal_Brakel	59
13140	Waal_Brakel; DKil_sGravendeel; OudeMaas_Spijkenisse	18
13142	Rijn_Xanten	59
13143	Rijn_Xanten; OudeMaas_Spijkenisse	17
13145	Rijn_Xanten;Waal_Brakel; BenMerwerde_Sliedrech;DeNoord_Kinderdijk	17
13146	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech; DeNoord_Kinderdijk; NieuweWaterweg_Europoort	35
13147	Rijn_Xanten;Waal_Brakel;OudeMaas_Spijkenisse	55
13149	Rijn_Xanten	16
13166	Rijn_Xanten; Waal_Brakel; BenMerwerde_Sliedrech; DeNoord_Kinderdijk	18
13169	Waal_Brakel; OudeMaas_Spijkenisse	26
13172	Waal_Brakel; Spui_Zuidland	64
13196	Rijn_Xanten	28

Table 3.21. Individual migration routes of silver eel released in the Rhein. Tagged: 30 eel; registered: 17 eel.

In the current situation with two new stations (Nieuwe Waterweg and hartelkanaal) it is assumed that eel that were registered one of these two stations successfully reached the North Sea.

When assuming this situation four out of 62 registered eel (1,6%) reached the North Sea by passing the station NieuweWaterweg_Europoort. Two eel (transponder numbers 13152 and 13183, both released in the Ruhr) were registered on the station OudeMaas_Spijkenisse and reached the North Sea after passing the station NieuweWaterweg_Europoort. One eel reached the sea by passing the station in the Nieuwe Waterweg after first having past the station Lek_Nieuwegein (transponder number 12870, released in the Lippe). One eel (transponder number 13146 and released in the Rhein) did reach the sea by passing the station DeNoord_Kinderdijk.

In previous years it was assumed that an eel successfully reached the North sea when passing one of the detection stations in the Noord, the Oude Maas or the Lek. Three eel that were registered on the station DeNoord_Kinderdijk (transponder numbers 12168 (released in the Lippe), 13145 and 13166 (both released in the Rhein) never reached the next station NieuweWaterweg_Europoort. Eleven eel did pass the station in the Oude Maas but were not registered after that. Finally another two eel were registered on the station in the Lek in Nieuwegein but were not registered at any other station after that.

So in theory four eel did reach the sea. When using the 'old' method 20 eel (32,3% of the registered eel) reached the North Sea. The percentage escapement of registered silver eel to the North sea in 2004-2010 and 2012 was 32%, 26%, 34%, 32%, 16%, 22%, 21% and 9% respectively. In 2013 this escapement was 9,1%, so in comparison with these percentages a substantial amount of eel that were registered in the current study reached the North Sea. It is possible that eel which are still present in the higher parts of the river Rhine, or eel that did not migrate at all after releasement (see also paragraphs 3.2.2 and 4.3) can still reach the sea in the near future.

3.2.4 Downstream migration velocity

For this section it is important to notice that only those detection stations are used for which is certain that eel can only reach these stations through one route. In this way the migration velocity can reliably be determined. Detection stations that can be reached by several different routes (i.e. Oude Maas_Spijkenisse, Spui_Zuidland, etc.) are left out in this section.

The variation in migration velocity is large amongst the registered eel: the slowest eel migrated a distance of 6 km in 104 days (0,06 km/day), whereas the fastest eel travelled a distance of 233 km in three day (77,7 km/day, see table 3.22). The actual migration velocity of the fish is actually higher when fish do not swim continuously but have periods of inactivity.

Release location	Stationname	# Registrations	Fastest migration		Slowest migration		Mean migration		Distance in km
			days	km/day	days	km/day	days	km/day	
Lippe	Lippe_Wesel	13	7	3,0	106	0,2	32,5	0,6	21
	Rijn_Xanten	9	15	2,2	88	0,4	34,9	0,9	33
	Waal_Brakel	7	25	6,4	89	1,8	39,1	4,1	159
	Nederrijn_Arnhem	2	28	3,3	33	2,8	30,5	3,0	92
	Nederrijn_Maurik_WKC_ben	2	29	4,4	57	2,2	43,0	3,0	127
	Nederrijn_Amerongen	2	29	4,4	57	2,2	43,0	3,0	127
	Lek_Nieuwegein	2	32	4,6	57	2,6	44,5	3,3	148
	BenMerwerde_Sliedrech	3	26	6,8	30	5,9	27,7	6,4	177
	DeNoord_Kinderdijk	1	32	5,3	32	5,3	32,0	5,3	171
Total Lippe		41	7	6,8	106	0,2	35,3	3,3	
Rhein	Rijn_Xanten	11	11	12,7	94	1,5	34,4	4,1	140
	Waal_Brakel	12	16	16,6	67	4,0	38,6	6,9	266
	BenMerwerde_Sliedrech	3	17	16,7	18	15,8	17,7	16,1	284
	DeNoord_Kinderdijk	3	17	8,1	19	7,3	18,0	7,7	138
Total Rhein		29	11	16,7	94	1,5	32,7	8,7	
Rhur	Rijn_Xanten	7	51	1,0	67	0,8	60,6	0,9	53
	Waal_Brakel	5	59	3,0	86	2,1	66,0	2,7	179
Total Rhur		12	51	3,0	86	0,8	62,8	1,8	
Sieg	Sieg_Menden	8	0	6,0	104	0,1	34,6	0,2	6
	Rijn_Xanten	3	26	6,8	28	6,3	27,0	6,6	177
	Waal_Brakel	4	27	11,2	81	3,7	41,0	7,4	303
	Nederrijn_Arnhem	1	29	8,1	29	8,1	29,0	8,1	236
	Nederrijn_Maurik_WKC_ben	1	30	9,0	30	9,0	30,0	9,0	271
	Nederrijn_Amerongen	1	30	9,0	30	9,0	30,0	9,0	271
Total Sieg		18	0	11,2	104	0,1	33,9	6,7	
Wupper	Rijn_Xanten	9	3	35,7	72	1,5	37,7	2,8	107
	Waal_Brakel	4	3	77,7	30	7,8	14,3	16,4	233
	Nederrijn_Arnhem	1	31	5,4	31	5,4	31,0	5,4	166
	Nederrijn_Maurik_WKC_ben	1	33	6,1	33	6,1	33,0	6,1	201
	Nederrijn_Amerongen	1	33	6,1	33	6,1	33,0	6,1	201
	Lek_Nieuwegein	1	81	2,7	81	2,7	81,0	2,7	222
	BenMerwerde_Sliedrech	3	4	62,8	15	16,7	9,3	26,9	251
Total Wupper		20	3	77,7	81	1,5	30,1	9,5	

Table 3.22. Overview of the migration velocities of registered eel from the five release locations to the different detection stations.

4 CONCLUSIONS AND RECOMMENDATIONS

4.1 2013

4.1.1 Conclusions

- In this study 132 eel were tagged and 55 of these eel were registered (41,7%) on 14 different detection stations in the Rhine river system. From the day of releasing the eel (November 13th 2013) until March 1st 2014 in total 139 registrations were recorded.
- In total 77 eel were never registered on any detection station during this research. This relatively high number of eel that were never registered can possibly be explained by the fact that these eel were transported to the Netherlands in order to be operated, after which they were brought back to Germany to the release sites. Much handling of fish is always a stress factor.
- Eight eel were not registered on the first station downstream of their release site although they did pass the station.
- In total 38 eel were registered on the detection station in Xanten (28,8%), of which 30 eel were registered on one of the stations in the Netherlands (22,7%).
- Only one eel (transponder number 12199) reached the North Sea by passing the detection station Nieuwe Waterweg_Europoort. This particular eel was released in the Lippe.
- Two eel were registered on the station in the Noord but never reached the next station in the Nieuwe Waterweg or Hartelkanaal. Two other eel were registered on the station in the Oude Maas.
- Eel that were released in the Rhine were registered on the most (65,4%), whereas only 14,8% of the eel that were released in the Ruhr were registered. There is no clear explanation why so few eel that were released in the Ruhr were actually registered.
- In this study eel had a slight preference for migrating during night time (74 detections, 53%).
- Most registrations occurred in the first month after releasing the eel. There seems to be no relation between water discharge and moon cycle on one hand, and eel migration activity on the other hand.
- The variation in migration velocity is large amongst the registered eel: the slowest eel migrated a distance of 6 km in 46 days (0,1 km/day), whereas the fastest eel travelled a distance of 177 km in one day. It is interesting to notice that both the fastest and the slowest eel were released in the Sieg.
- The actual migration velocity is actually higher when fish do not swim continuously but have periods of inactivity. With a velocity of 177 km/day (2,05 m/s) and an average river flow velocity of 1 m/s, the fastest eel swam downstream with a velocity of 1,05 m/s.

4.1.2 Recommendations

- The enormous losses of eel that were released in the Ruhr in Germany, approximately 3 km upstream of the detection station Ruhr_Duisburg are striking in this study. Out of 27 fish that were released at that location only four (less than 15%) were actually registered. Three of these fish were last registered in Xanten and one in Sliedrecht. All the other 23 eel were registered nowhere, not even three km downstream of their release site. A big question arises therefore: what happened to these eel in this short stretch of the river Ruhr to its estuary in the Rhine? It is therefore recommended to thoroughly investigate what actually happens to downstream migrating fish in this part of the Ruhr, using the NEDAP Telemetry System® in the near future.

4.2 2014

4.2.1 Conclusions

- In this study 150 eel were tagged and 62 were actually registered (41,7%) on 15 different detection stations in the Rhine river system. From the day of releasing the eel (October 23rd 2014) until Februari 6th 2015 in total 156 registrations were recorded.
- In total 88 eel were never registered on any detection station during this research. This high number can possibly be explained by various factors: the eel were transported to the Netherlands in order to be operated and were stored for a relatively long period, handling time, delayed migration or no migration drive at all.
- In total 29 eel were not registered on the first station downstream of their release site although they did pass the station.
- No fish were registered on the stations Ruhr-Duisberg and Wupper_Burrig. The station Ruhr_Duisberg has many interferences making a clear registration difficult. For the station Wupper_Burrig a clear explanation for no registrations at all lacks.
- In total 39 eel were registered on the detection station in Xanten (26% of all tagged eel). 38 (25,33%) Eel were registered on one of the stations in the Netherlands.
- Four eel reached the North Sea through the Nieuwe Waterweg. Two of these eel (released in the Ruhr) were registered in the Oude Maas. One eel was registered in the Lek (released in the Lippe), and one eel (released in the Rhein) did reach the sea by passing the station DeNoord_Kinderdijk.
- One eel did reach the station HV_Stellendam_SpuiSluizen, but after spending two days at this location the fish returned upstream and was last registered at the station OudeMaas_Spijkenisse.
- Eel that were released in the Rhine were registered the most (56,74%). From the eel that were released in the Lippe 53,3% were registered. Only 30 % of the eel that were released in the Ruhr were registered. This phenomenon was also seen in the study of 2013. There is no clear explanation why so few of these latter were actually registered.
- Eel had a preference for migrating during night time: 94 detections (60%).
- The slowest eel migrated a distance of 6 km in 104 days (0,06 km/day), whereas the fastest eel travelled a distance of 233 km in three day (77,7 km/day). The actual migration velocity of the fish is actually higher when fish do not swim continuously but have periods of inactivity.

4.2.2 Recommendations

- Based on the findings that in both studies high percentages of eel were not registered in the research period, and the fact that approximately 1/3 of the eel tagged in 2013 were registered after the last date of the study period (March 1st 2014) it would be advisable to have a closer look at the exact release locations by a field study to find NEDAP registrations using the manual registration station on a boat on each release site and a trajectory downstream. Also a prolonged study period concerning gathering and analysing registrations for each study year is in this respect advisable. Finally it would be a good exercise to do an overall study of all eel tagging researches (2004 until 2014), including all registrations in the entire period. This exercise, combined with a thorough literature study on the matter, might give new insights in the exact behaviour of the eel, also regarding environmental conditions (water temperature, water discharge, strong or soft winter, etc.) ATKB already performed such overall studies for downstream migrating silver eel and salmon smolts in the Meuse and for upstream migrating adult salmonids from the North Sea into the upstream parts of the Meuse.
- Similar As in 2013, in this study again the fewest percentage of eel were registered from the batch of fish released in the Ruhr in Germany (30%). Again the question arises what actually happens to these unregistered eel in that part of the river. A thorough field study with a mobile NEDAP detection station on a boat in that part of the Ruhr might give new insights: are fish still swimming there, did they die, are the fish gone (upstream)?

4.3 Short comparison of both studies

In both studies a similar percentage of eel were registered in the research period (41,7% and 41,3% for 2013 and 2014 respectively). In 2013 only 8 eel were not registered on the first station downstream of their release site although they did pass the station. In 2014 29 eel were not registered on the first station downstream of their release site, although they did pass the station. This finding is mainly due to malfunctions of these stations in the Ruhr (9 unregistered eel) and in the Wupper (10 unregistered eel). In Xanten 28,8% of all tagged eel were registered in 2013, and 26% in 2014, again similar results. In 2013 and 2014 respectively 22,7% and 25,33% of the tagged eel were registered on one of the stations in the Netherlands (22,7%). One eel did manage to reach the North Sea successfully in 2014, whereas this number was four in 2014. In both studies eel that were released in the Rhine were registered the most (65,4% of the total number of eel released in the Rhine, and 56,74% in 2014). In 2013 only 14,8% of the eel that were released in the Ruhr were registered, whereas this percentage was much higher in 2014 (30%), but still lower than that for the eel released at the other four locations in that year. In both study years the variation in migration velocity is large amongst the registered eel. In 2013 the slowest eel migrated a distance of 6 km in 46 days (0,1 km/day), whereas the fastest eel travelled a distance of 177 km in one day. In 2014 the slowest eel migrated a distance of 6 km in 104 days (0,06 km/day), whereas the fastest eel travelled a distance of 233 km in three day (77,7 km/day, see table 3.22). The actual migration velocity of the fish is actually higher when fish do not swim continuously but have periods of inactivity.

Both in the study 2013 and of 2014 a relatively high percentage of all tagged eel were not registered in the study period (58,3% and 58,7% respectively). After analysing the registrations in 2013 it was concluded that maybe the high losses among the eel of that year could be ascribe to the transport from the eel to the Netherlands and back to Germany and the longer storage and handling periods. These particular factors can cause considerable stress among fish, and ultimately can lead to their death. However, when obtaining the registrations of the tagged eel in the current study an interesting other discovery was done. It appeared that approximately 1/3 of the eel that were tagged and released in 2013 were **not registered** in the time period that was studied, but were registered after the last date that was included in the 2013-2014 (March 1st 2014). Apparently these eel did not die due to their treatment, but just did not migrate in the study period. These eel seem to show a delayed migration activity, but it is not known what causes this phenomenon. The same theory can be applied to the eel that were not registered in the current study, as this percentage was similar as in the study of 2013. Based on the average weight of the tagged eel in 2013 and 2014 (1239 g and 1152 g respectively), the average length (85 cm and 83,7 cm respectively) and the average Eye Index (10,21 and 8,75, respectively) one would assume that all these tagged eel definitely are silver eel, ready to migrate. Pankhurst (1982) stated that eel with an EI of $\geq 6,5$ can be marked as silver eel. 97,7 Of all eel in 2013 and 88,7% of all eel in 2014 had an Eye Index above 6,5. Of course there will always be a certain percentage of fish that do not migrate, despite the fact that their Eye Indices suggest otherwise, but such high percentages of eel that do not migrate directly after releasing them is remarkable. It might be the case that these eel temporarily 'lose' their drive to migrate due to the effects of transportation, storage and handling. It might therefore be interesting to have a closer look at this interesting aspect in both studies (see also recommendations in paragraph 4.2.2).

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