Telemetry study on migration of river lamprey and silver eel in the Hunze and Aa catchment basin

H.V. Winter, A.B. Griffioen, O.A. van Keeken,
P.P. Schollema (Waterschap Hunze en Aa's)

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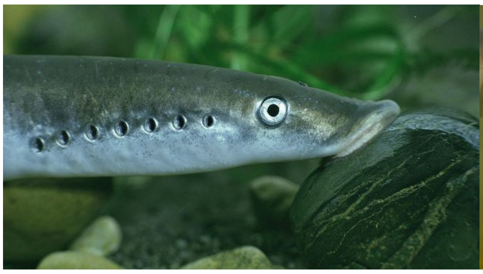


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Client: Waterschap Hunze en Aa's
Aquapark 5
9641 PJ Veendam

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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

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Summary

River lamprey (*Lampetra fluviatilis*) is an important indicator species for both water management (EU Water Frame Directive) and nature management (EU Habitat Directive). Due to its complex life cycle and the need of a succession of specific habitats ranging from rivers to sea, river lamprey is an important indicator species for the integrity of ecosystems and connectivity within and between complete catchment areas. The Drentsche Aa catchment basin hosts one of the few locations in the Netherlands, the Gasterensche Diep a small tributary of the Drentsche Aa, where spawning of river lamprey has been proven. The goal within the catchment basin of the Drentsche Aa is set to further enhance the population of river lamprey. To achieve this, it is necessary to gain insight in the bottlenecks that occur for river lamprey in this area, what the relative importance of these bottlenecks are and what measures might be taken to improve these. The aim of this study was to gain insight in migrational patterns, timing, and success rate, observe the importance of the Gasterensche Diep as a spawning site compared to other tributaries of the Drentsche Aa, observe possible bottlenecks such as ship locks and sluices to enter the fresh water canals, and finally to gain insight in passage of large woody debris which were placed in the Gasterensche Diep to sustain a certain water level. During winter 2009-2010 and 2011-2012 a study has been conducted using VEMCO telemetry techniques to asses the success of upstream migration of 53 river lamprey. In addition 36 eels were used to asses the downstream migration in the catchment area. Fish were surgically implanted with VEMCO V7 transmitters. 18 VR2W VEMCO receivers were installed at 13 different locations to detect up and downstream migration.

For river lamprey a large variation of behavioural patterns was observed for upstream migration making it difficult to analyse. No direct evidence was found that river lamprey entered the freshwater canals through ship locks contrary to the discharge sluices were passage was proven. The Gasterensche Diep is indeed an important tributary for spawning within the Drentsche Aa stream catchment since highly directional movements with relatively high migration speeds varying from 0.1 – 0.3 m/s for a 52 km route was found and no searching behaviour in other tributaries was found. It appears that the conditions within the canal system were not ideal for upstream passage. A low percentage of 15 % (n = 6) of river lampreys successfully passed the canal system to more upstream located streams. Of the six river lampreys entering the Drentsche Aa, five passed the first large woody debris site suggesting that there is no hinder in upstream passage within the spawning grounds. Two of this group returned downstream again. The reasons for a low success rate remains unclear, but an apparent candidate factor related to a low success rate of upstream migration might be the unnatural variation in water flow strength and direction in the Eems Canal. The flow ranged from stagnant to slow flowing and the direction during discharges events is seawards. Other explanations that could influence the upstream migration, could be predation or the surgical treatment.

At least six eels had a successful downstream migration and unexpectedly two additional eels used freshwater ship locks during their decent to the sea in the direction of Lake Lauwersmeer. Of another five to ten eels the escapement could not be confirmed. Five of them possibly used other routes and the other five where last detected near the sea but missed being detected at the stations near the sea (misdetections, death, battery failure or postponed migration). Some searching behaviour was observed in the canal system for eel.

Samenvatting

Rivierprik (*Lampetra fluviatilis*) is een belangrijke indicator soort voor water management (Kader Richtlijn Water) en natuur management (Habitatrichtlijn). Door de complexe levenscyclus en de behoeften van een opeenvolging van specifieke habitats, variërend van rivieren tot zee, is de rivierprik een belangrijke indicatorsoort voor de connectiviteit tussen volledige stroomgebieden. De Drentsche Aa herbergt een van de weinige locaties (Gasterensche Diep) in Nederland waar het paaien van rivierprik is bewezen. Eén van de gestelde doelen voor de Drentsche Aa is om de populatie rivierprikken uit te breiden. Om dit te bereiken is het noodzakelijk inzicht te krijgen in de knelpunten die zich voordoen voor rivierprik. Een van de mogelijke knelpunten zou kunnen zijn dat er dode bomen in het Gasterensche Diep zijn gelegd om de waterstanden in de beek te verhogen. Tijdens de winter van 2009-2010 en 2011-2012 is met behulp van VEMCO telemetrie technieken het succes van de stroomopwaarste migratie van 53 rivierprikken onderzocht. Daarnaast zijn 36 palingen gebruikt om de stroomafwaartse migratie in het gebied te onderzoeken. De dieren werden voorzien van een VEMCO V7 zender en gevolgd middels 18 VR2W VEMCO ontvangers die op 13 verschillende plekken waren opgesteld. Het doel van de studie was om inzicht te krijgen in migratie patronen, migratie timing en migratie succes. Daarnaast de boordeling van het Gasterensche Diep als paaiplaats in vergelijking met andere stromen binnen de Drentsche Aa, het bepalen of knelpunten (schutsluizen, spuisluizen) passeerbaar zijn en de beoordeling of dode bomen in de beek de paai kunnen hinderen.

Bij de stroomopwaartse migratie van rivierprik werd een grote variatie aan gedragspatronen waargenomen waardoor analyse erg moeilijk is. Er is geen direct bewijs gevonden dat rivierprik het Eemskanaal is opgezwommen via de schutsluizen in tegenstelling tot de spuisluizen waar er wel passage heeft plaatsgevonden. Het Gasterensche Diep is inderdaad een belangrijke paaiplaats omdat er gerichte migratie patronen met relatief hoge migratie snelheden (0.1 – 0.3 m/s over 52 km) zijn waargenomen waarbij andere zijtakken zijn genegeerd. Een relatief laag percentage (15%) van de rivierprikken wist met succes via het kanalensysteem meer stroomopwaarts te komen. Uit deze studie blijkt dat het kanalensysteem voorafgaand aan de rivieren niet ideaal is voor stroomopwaarste migratie. Zes rivierprikken zijn de Drentsche Aa opgetrokken en vijf zijn er in geslaagd de bomen in de beek te passeren. Dit suggereert dat er in het stroomgebied van het Gasterensche diep zelf geen directe belemmeringen zijn door de aanwezigheid van de bomen om de paaigronden te bereiken. Echter twee prikken hebben om onbekende redenen het Gasterensche Diep vroegtijdig weer verlaten en zijn weer stroomafwaarts getrokken. De reden dat maar weinig rivierprikken de paaigronden bereiken is niet bekend, maar een belangrijke factor kan zijn dat binnen het kanalen systeem er een onnatuurlijke situatie heerst waar bijvoorbeeld stagnant water de dieren mogelijk in verwarring brengt. Andere verklaringen kunnen predatie of de chirurgische behandeling zelf zijn.

Tenminste zes alen hadden een succesvolle stroomafwaartse migratie via Delfzijl. Onverwacht hebben twee alen via sluizen hun route naar zee vervolgd en zijn uiteindelijk bij het Lauwersmeer gedetecteerd. Van vijf tot tien alen was de migratie naar zee mogelijk ook succesvol, maar niet bevestigd. Deze zijn of voor het laatste gedetecteerd bij Delfzijl of hebben de zee via Nieuw Statenzijl bereikt.

1 Introduction

River lamprey (*Lampetra fluviatilis*) is an important indicator species in relation to both water management (EU Water Frame Directive) and nature management (EU Habitat Directive, EC 1992). River lamprey is a diadromous species that needs relatively fast flowing freshwater streams with coarse substrate to spawn. After spawning, the lamprey larvae (ammocoetes) spent several years buried in fine sediments in freshwater streams living as filter feeders. After transformation they migrate downstream to sea to spent two years at sea feeding on fish as parasites. As adults they migrate back from sea to freshwater streams and rivers to spawn and subsequently die thereafter. Due to its complex life cycle and needs of a succession of specific habitats ranging from rivers to sea, river lamprey is an important indicator for the integrity of ecosystems and connectivity within and between complete catchment areas.

The Drentsche Aa catchment basin hosts one of the few locations in the Netherlands where spawning of river lamprey has been proven. The Gasterensche Diep, a small tributary of the Drentsche Aa, serves as a spawning ground for this species. Until now, and despite intensive exploratory sampling, no river lamprey ammocoetes were found in other parts of the catchment area, except in the Gasterense Diep and an adjacent downstream stretch of a few km in the Oudemolensche Diep (Winter & Griffioen 2007, Schollema unpubl. results).

During winter 2009-2010 a pilot study has been conducted using VEMCO telemetry to test the feasibility and applicability of the telemetry method for the different locations within the catchment areas of the Drentsche Aa and Hunze. One of the goal within the catchment basin of the Drentsche Aa is set to further enhance the population of river lamprey. To achieve this, it is necessary to gain insight in the bottlenecks that occur for river lamprey in this area, what the relative importance of these bottlenecks are and what measures might be taken to improve these. The study was carried out as part of the INTERREG project 'Living North Sea'. Originally, the follow-up telemetry work was scheduled for winter 2010-2011, but due a severe winter with an early start, no river lamprey were caught in that winter. As a consequence the transmitters that were already purchased could not be used in this particular year. Depending on how long transmitters are not used, they will have an increased reduced battery life. For present study those 'old' transmitters were used for an additional shorter lasting study on silver eel (*Anguilla Anguilla)*, whereas new transmitters were used for river lamprey during autumn-winter 2011-2012.

2 Research questions

Research questions related to river lamprey following this study were planned to be addressed in on-going projects where Regional Water Authority Hunze en Aa's takes part in: INTERREG 'Living North Sea', Natura 2000 and Stream Restoration Projects ("Beek op Peil").

1) What part of the river lamprey that arrive at the seaside of Delfzijl succeeds in migrating into the Eemskanaal and to what extend does the recently installed 'fish friendly' sluice management functions in relation to passage success for migratory fish?
2) What routes are taken during upstream migration and to what extend are fish passages passable?
3) Which conditions or factors determine upstream passage success?
4) How important is the Gasterensche Diep within the Drentsche Aa catchment area as a spawning site, i.e. which part of the lamprey entering the Drentsche Aa uses the Gasterensche Diep for spawning?
5) Does directional migration to the spawning site takes place or is there intensive searching behaviour within the catchment basins, and if so to what extend?
6) What is the timing of migration into the Eemskanaal and to the spawning sites?
7) Does the large woody debris that was placed within stream restoration projects hinder the spawning migration of river lamprey?

The general aim of this research was to determine if there are any bottlenecks and habitat selection during upstream migration of river lamprey and to give potential management measures.

3 Materials and Methods

3.1 Study site and receiver location

3.1.1 Study site

The Hunze and Aa catchment area has several smaller streams which are connected to the Wadden Sea via a canal system (Figure 1). The main streams are the Drentsche Aa with many smaller tributaries, and the Hunze. Access water from these catchment areas is discharged through discharge sluices in Delfzijl under free flowing conditions, i.e. when water levels in the Wadden Sea are lower than in the Eems Canal. In recent years, a 'fish-friendly' sluice management for these discharge sluices was adopted. Meaning that the management of the sluice will be consistent with fish migration as good as possible. Parallel to the discharge sluices the inner harbour of Delfzijl is connected to the Wadden Sea by ship locks. Thus, two potential entrances are available for river lamprey to enter the catchment area, discharge sluices and shiplocks (Figure 1 bottom left). Once inside, there are hardly any physical barriers between Delfzijl and the entrance of the Drentsche Aa, the entrance of the Gasterensche Diep and the Hunze. The only possible barrier present is a weir between the entrance of the river Drentsche Aa and the Noord-Willems canal. Due to high winter discharges this weir is usually fully opened allowing fish to migrate upstream freely during the winter. In case of a closure situation, there is a fish pass next to the weir allowing an alternative route for the fish.

The Eems Canal system forms an important connection (or corridor) between different areas that are important for nature conservation. On the one hand the Wadden Sea and on the other hand different stream reaches and landscapes in the Hunze and Drentsche Aa catchment areas (Figure 2). In this study the quality of connectivity between these areas could be assessed both in an upstream direction, using river lamprey, and downstream direction, using silver eel.

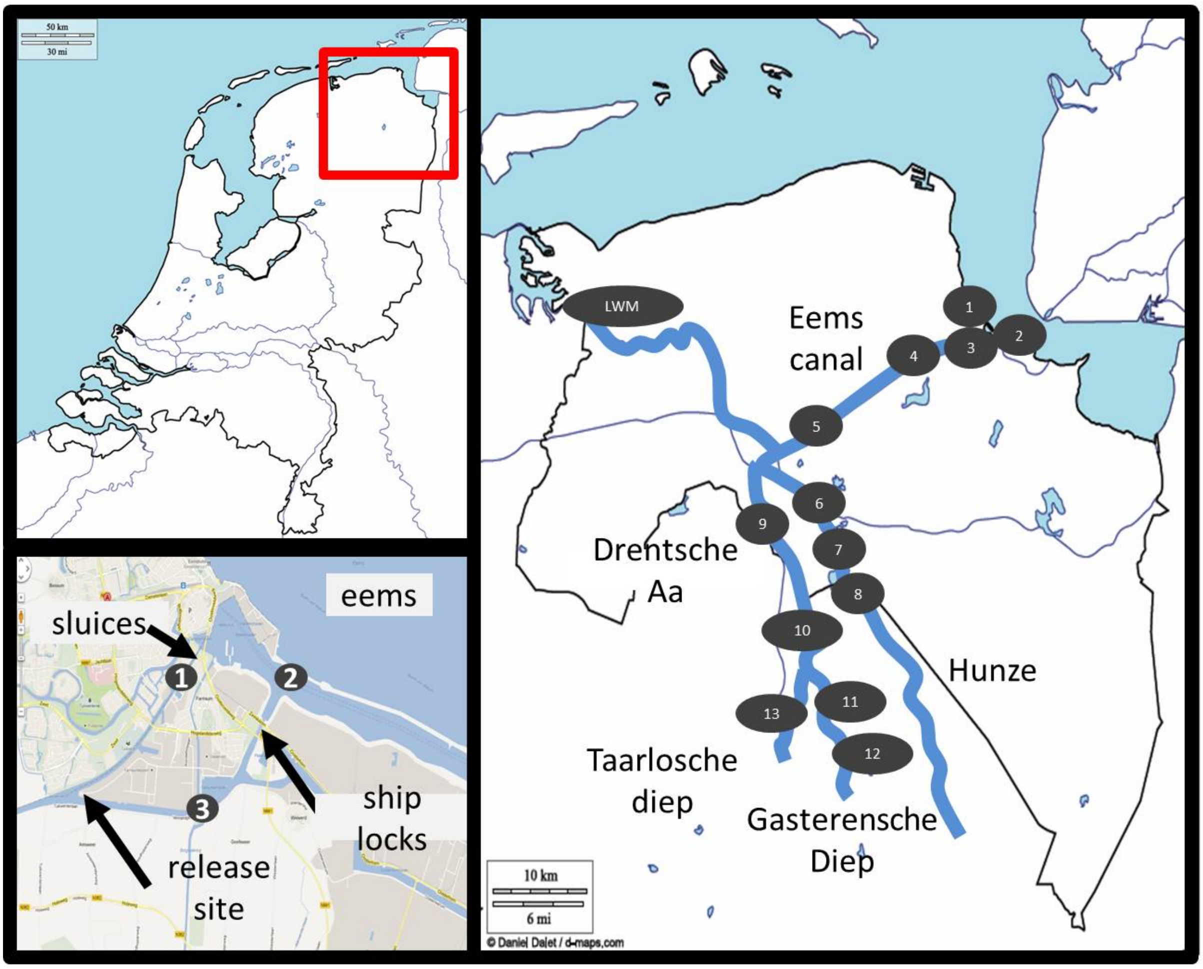

Figure 1. *Overview of the study area; position of catchment area of the Drentsche Aa and Hunze in the Netherlands (top left panel); a schematic overview of the catchment area with the location of the receivers at each station (right panel); and a closer view of Delfzijl with the receivers near the discharge sluices, ship locks and Wadden Sea Harbour (lower left panel). LWM = Lauwersmeer*

3.1.2 Receiver location

To follow the upstream migration of river lamprey, VEMCO VR2W receivers (see chapter 3.2) were installed (see Figure 1 for a broad overview, Figure 2 for exact locations and VEMCO codes of each of the receiver, and see Table 1 for details per receiver and research year). To minimise the risk of fish passing undetected, some strategic points were covered by two receivers (pooled receivers at a station indicated with a number in Table 1). Both entrances of the Eems canal system in Delfzijl were covered with receivers (Figure 1: station 1 discharge sluice, 3 near the ship locks). The marine harbour of Delfzijl was covered by two receivers (station 2). Thus, each river lamprey with a transmitter entering or leaving the Eems Canal system could be detected. To follow river lampreys further upstream through the canal system, two receivers were placed in the Eems canal (Figure 1; station 4, 5), one in the Windschoterdiep Canal (Figure 1: station 6) that leads to the entrance of the Hunze stream and one in the Noord Willems Canal (Figure 1: station 9) that leads to the entrance of the Drentsche Aa stream. Within the streams, two receivers were placed in the Hunze (station 7 North and station 8 South from lake Zuidlaardermeer through which the Hunze flows); two covered the entrance of the Drentsche Aa (station 10); two covered the entrance of the Gasterensche Diep, of which one was located more upstream near a proven spawning site in the Gasterensche Diep (station 11) and one receiver was placed downstream of the first weir that upstream migrants in the Gasterensche Diep encounter (station 12). In the Gasterensche Diep, large woody debris was placed in sections downstream from the receivers at station 11 and in between these and the more upstream receivers (station 12). In addition, the entrance of the Taarlosche Diep was also covered by two receivers (station 13). The Gasterensche Diep and Taarlosche Diep confluence into the Drentsche Aa. The setup allowed to determine which part of the river lamprey that migrates upstream the Drentsche Aa selects the Gasterensche Diep and which part moved into the Taarlosche Diep, which has on average twice the discharge compared to the Gasterensche Diep. The detection range of the acoustic VEMCO receivers will be larger in canals (i.e. 100-150 m) than in smaller streams.

Table 1. Characteristics of the receivers used in the 2009-2012 telemetry study, where VEMCO receiver ID, a short description of the station, the station number that was assigned to it and whether the receiver was active in the 2009/2010 or 2011/2012 telemetry studies.

Receiver ID	**Name location with receiver**	**Station nr.**	**2009**	**2011**
102060	Delfzijl inland side discharge sluice	1	x	x
102058	Delfzijl seaside harbour west	2 (pooled)	x	x
102061	Delfzijl seaside harbour east	2 (pooled)	x	x
102057	Delfzijl inland side ship lock	3	x	x
103669	Eems Canal north east	4		x
102052	Eems Canal Garmerwolde	5	x	x
102054	Canal Winschoterdiep	6	x	x
102063	Hunze north from Lake Zuidlaardermeer	7	x	x
103673	Hunze south from lake Zuidlaardermeer	8		x
103672	Noord Willems Canal	9		x
102053	Drentsche Aa entrance north west	10 (pooled)	x	x
102056	Drentsche Aa entrance south east	10 (pooled)	x	x
103671	Gasterensche Diep entrance north west	11 (pooled)	x	x
103670	Gasterensche Diep entrance south east	11 (pooled)	x	x
103674	Gasterensche Diep voorde 1	12 (pooled)		x
107052	Gasterensche Diep downstream from first weir	12 (pooled)		x
104169	Taarlosche Diep north	13 (pooled)	x	x
107055	Taarlosche Diep south	13 (pooled)	x	x

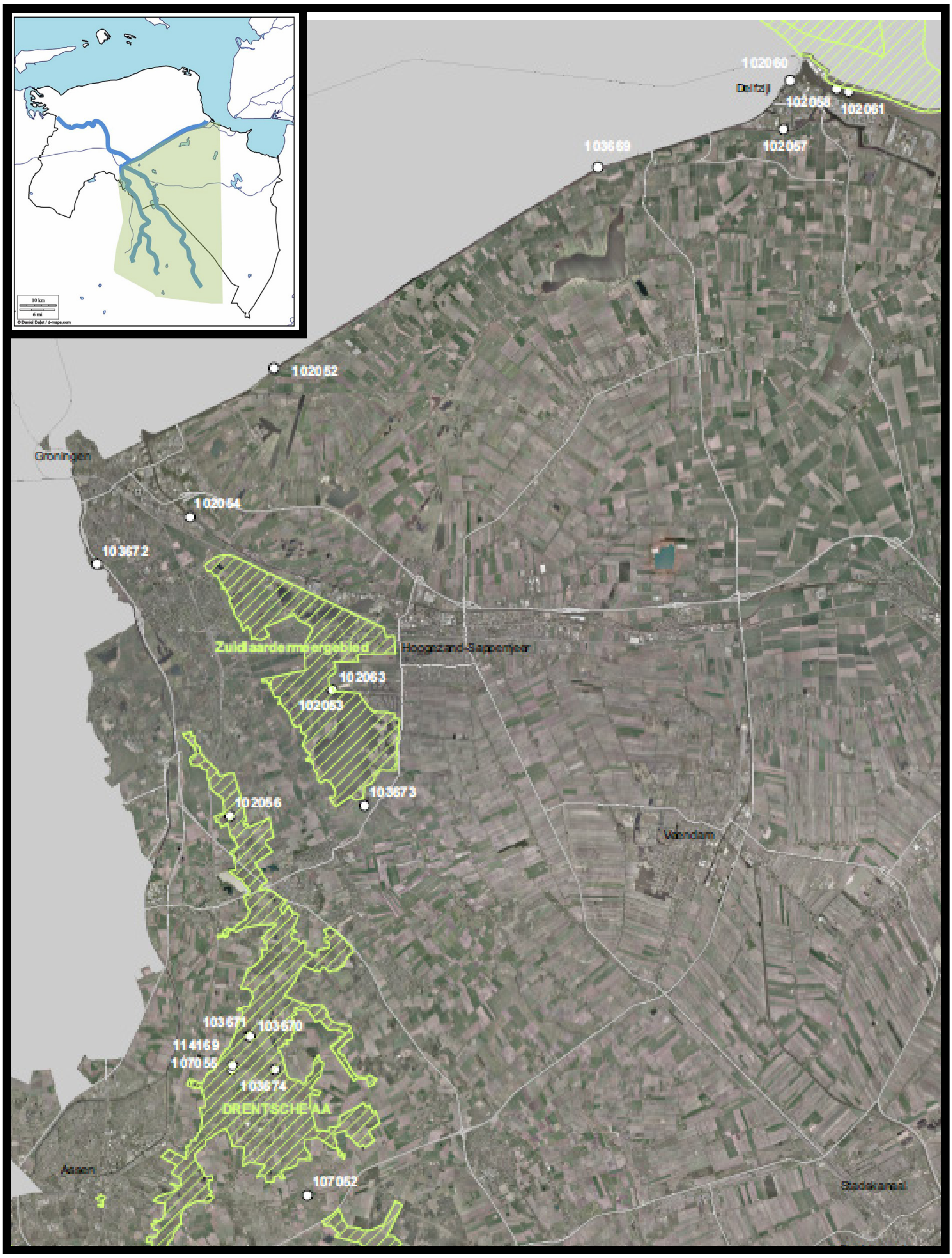

Figure 2. *Overview of the exact locations of each receiver in 2011-2012 and the Natura 2000 areas (marked with green diagonal lines). The study area contains three Natura 2000 area's: Drentsche Aa, Zuidlaardermeer and Waddensea.*

3.2 Test fish and telemetry method

3.2.1 Receivers

VEMCO VR2W receivers were installed to detected fish movement. The receivers records the identification number and time stamp from acoustic transmitters with a frequency of 69 kHz as a tagged animal moves within receiver range. The VR2W consists of a hydrophone, receiver, ID detector, data logging memory, and battery all housed in a submersible case. The VR2W has a battery life of approximately 15 months and can store 1-million detections. The VR2W receivers can detect transmitters that are implanted in the studied test fish. Data from the receivers can be exported to a computer through a Blue Tooth connection using the VEMCO VUE software package. To deploy a VR2W, the receiver was moored along a line, which was connected to a weight at the bottom and a pop-up float.

3.2.2 transmitters

VEMCO V7 Transmitters were surgically implanted in fish and operate at 69 kHz. Each tag sends an acoustic pulse train (8 pulses in approximately 3.2 seconds) at pre-set time intervals. These acoustic pulse trains are random about an average delay time to minimise collisions between different tag pulses. E.g. a transmitter can be set to send a pulse train random between 30 to 45 seconds. Each pulse train includes a specific ID number for each tag to track the individual fish. For this study we used V7, the smallest available transmitters (7x18 mm, 1.4 g in air, 0.7 g in water) suitable for the VR2W receivers.

Photo 1. *Silver eel passing a VEMCO VR2W receiver (photo: Erwin Winter)*

3.2.3 Tagged fish

Originally, 50 river lampreys were planned to be implanted with V7 transmitters for the pilot study in late autumn 2009. Due to the onset of an early severe winter, only 14 river lamprey were caught prior to ice-formation. Those were caught near the ship locks at Delfzijl and used in the telemetry study, Ice formation inhibits fishing with fykenets and ceases the runoff of access freshwater attracting river lamprey from the Eems-Dollard area in the Wadden Sea, hence no more fish could be caught this season.

For late autumn 2010, in addition to the 36 V7 transmitters remaining from 2009, 39 new V7 were purchased, to allow 75 river lamprey to be implanted with transmitters and released in winter 2010/2011. Of these, part were to be released in the marine harbour of Delfzijl, to get an indication of success rate in passing the discharge sluices or ship locks, and part were to be released in the Eems Canal inner harbour (downstream from station 3), to ensure that in case success rate was very low for inward migration from the marine harbour that enough river lamprey were present in the Eems Canal system to follow the distribution and progress in movements within the Hunze and Drentsche Aa catchment areas. Unfortunately, again due to an early and severe winter no river lamprey were caught. Because of this and the fact that the projected battery life for the 36 two year old V7 transmitters was reduced to a level lower than was required to cover the period from release of river lamprey in late autumn to spawning in early spring, it was decided to use these 36 transmitters in autumn 2011 for an additional study on the downstream migration of silver eel for which lower battery life would be suitable. The 39 'old' transmitters were used for river lamprey in late autumn 2011, but because the number was lower than the planned 75, these were not split into two groups and released in both marine harbour and inner harbour. Instead, all 39 river lamprey were released near the site they were caught in the inner harbour of Delfzijl near station 3. Thus, the success rate of river lamprey when migrating from the marine harbour to the Eems Canal could not be determined, but focus was mainly placed on the distribution and progress of river lamprey migrating within the Hunze and Drentsche Aa catchment area.

River lamprey were caught by a local professional fisherman near Delfzijl using fykenets in December 2009 (n=10), February 2010 (n=4), November 2011 (n=30) and December 2011 (n=9).
Eels were caught in the Hunze (n=18) and the Drentsche Aa (n=18) in October 2011. To be sure that only migrating 'silver eels' were used in this study, only eels larger than 60 cm with completely silvery white ventral side were used, rejecting individuals with yellow of partly yellow ventral sides. All individual eels were assumed to be females, since males do not grow that large (Dekker 2000).

For both years combined a total of 53 river lamprey were surgically implanted with a transponder and released on 23rd December 2009 (n=10), 3rd February 2010 (n=4), 11th November 2011 (n=30) and 16th December 2011 (n=9). 36 eels were released at October 5 (n=13) and 18 (n=23) in 2011 (Table 2). The eels and lampreys were anaesthetized with 2-phenoxyethanol (0.9 ml/L), weighed (g), and measured (mm total length). The surgical procedure applied was the best among five different procedures for European eel as tested by Baras & Jeandrain (1998). The VEMCO transmitters were surgically implanted in the body cavity by making a mid ventral 1–2 cm incision in the posterior quarter of the body cavity. The incision was closed using resorbable sutures for eels and river lampreys. Surgery lasted 3–5 min. Eels and lampreys were observed in a recovery tank until swimming behavior was normal. Eels were divided in two batches, one group was released in the Hunze (n = 18) and the other group in the Drentsche Aa (n = 18).

Table 2. Details of the fish in the Drentsche Aa catchment basin used for the telemetry study in 2009 and 2011.

Year	species	transmitter	n	sex	length (cm)	weight (gr)
2009	River lamprey *Lampetra fluviatilis*	V7	9	F	36.6±2.0	
2009	River lamprey *Lampetra fluviatilis*	V7	5	M	34.9±2.4	
2011	River lamprey *Lampetra fluviatilis*	V7	28	F	39.4±1.6	102.3±12.3
2011	River lamprey *Lampetra fluviatilis*	V7	11	M	39.0±2.0	100±13.8
2011	Silver eel *Anguilla anguilla*	V7	36	F	73.3±8.7	795.8±321.2*

*23 were weighted

4 Results

4.1 Telemetry results for river lamprey

Of the 14 river lamprey from the 2009 pilot study, seven were only detected in Delfzijl, five moved downstream through the discharge sluices or ship locks to the Wadden sea of which one returned into the Eems Canal, three moved into the Eems Canal (reached station five) of which one moved further upstream to the Hunze, none reached the Drentsche Aa (Table 3).

Table 3. Results of river lamprey detections for the telemetry study carried out in 2009 (pilot) and 2011. For each individual river lamprey, the order of detections, the time between first and last detection, the furthest station reached and the last station where the fish was detected are given.

			Number of individuals				Station numbers	
			Time between first and last detection					
Year	Patterns in station passage	n	≤ 1 day	2 - 7 days	8 days - 30 days	> 1 month	Most upstream station	Last station
2009	never detected	0						
2009	3	6	2		2	2		3
2009	3-1	1				1		1
2009	3-2-4	1			1		4	4
2009	3-1-2	2		2				2
2009	3-1-3-2	1			1			2
2009	3-4-5	1			1		5	5
2009	3-4-5-4-1-2	1				1	5	2
2009	3-4-5-7	1		1		4	7	7
2011	never detected	8						
2011	2	1	1					2
2011	3	4	4					3
2011	1-2	1	1					2
2011	3-1	1	1					1
2011	3-1-2	1		1				2
2011	3-4-1	1		1			4	1
2011	1-4-3	1	1				4	3
2011	3-4-1-2	4		4			4	2
2011	1-3-4-1-2	1		1			4	2
2011	3-1-4-1-2	1			1		4	2
2011	3-4-3-1-2	2		2			4	2
2011	1-3-4-3-2	1		1			4	2
2011	3-4-3-4-1-2	2		1	1		4	2
2011	3-1-4-3-4-3	1			1		4	3
2011	3-4-3-4-1-4-3-4-3	1		1			4	3
2011	3-4-5	1	1				5	5
2011	3-4-3-4-5-9-10	1		1			10	10
2011	3-4-3-1-2-1-3-4-3-4-5-9	1		1			9	9
2011	3-4-5-9-10-11	1			1		11	11
2011	3-1-4-5-9-10-11	1				1*	11	11
2011	3-4-1-2-1-4-5-9-10-11	1			1		11	11
2011	3-4-5-9-10-11-10-9-5	1				1	11	5
2011	3-4-5-9-10-11-10-9-5-4-3-4-3	1			1		11	3

* last detection at the time of collecting the receivers

Of the 39 river lamprey released in 2011/2012, 13 remained in the Delfzijl area, 16 moved out to the Wadden Sea of which two returned into the Eems Canal and of which one reached the Noord Willems Canal and the other the Gasterensche Diep. Five remained in the Canal systems, and another five moved into the Drentsche Aa of which four progressed into the Gasterensche Diep. Of the latter four river lamprey, two returned to the canal system thereafter. No river lamprey entered the Hunze in 2011/2012. In total 31 river lamprey were either not detected (n = 8) or were not detected further than station four.

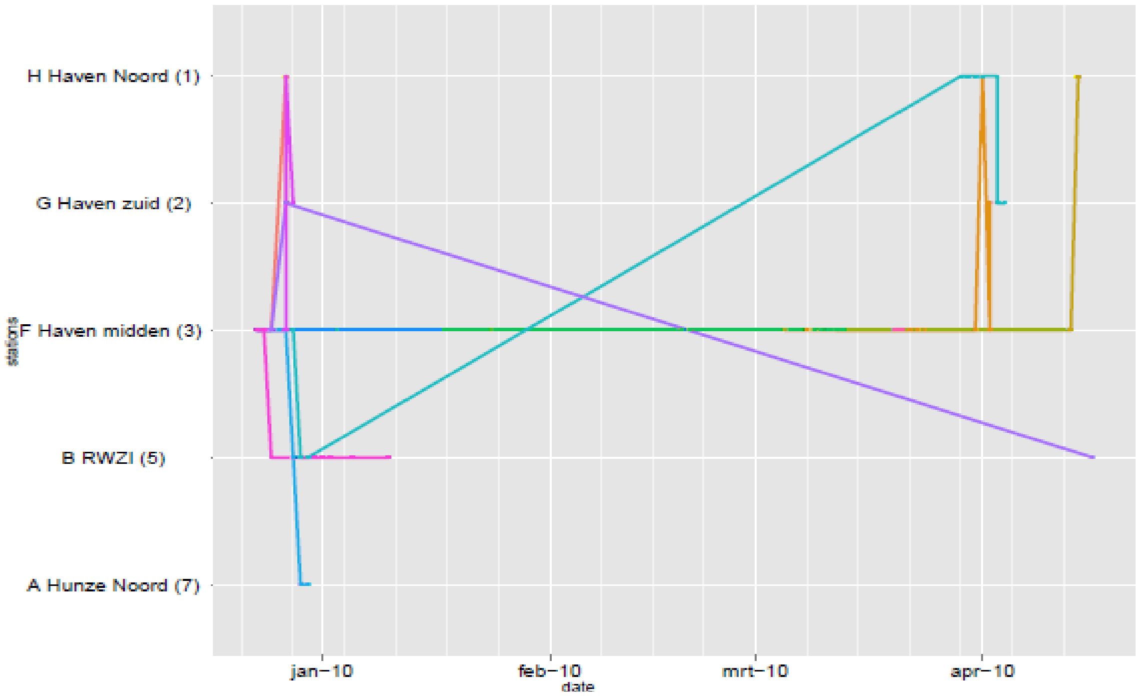

Figure 3. Individual movement patterns (station name and number on y-axis) for river lamprey in 2009/2010.

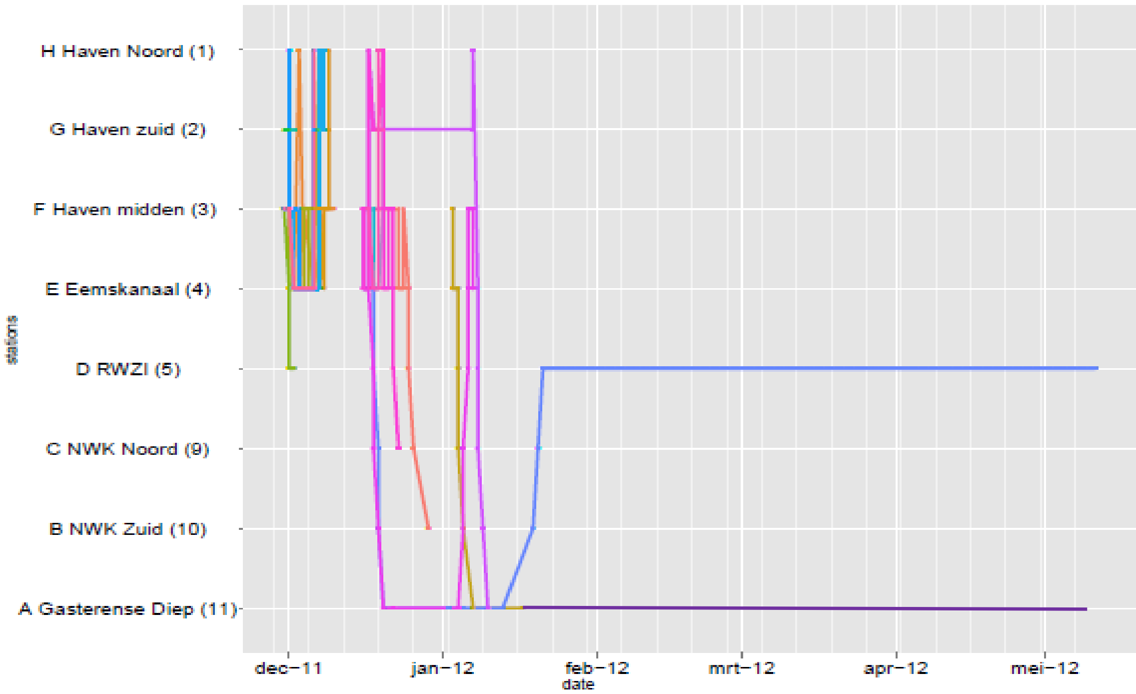

Figure 4. Individual movement patterns (station name and number on y-axis) for river lamprey in 2011/2012

In 2011/2012, in total six out of the 39 river lamprey entered the Drentsche Aa, of which five entered the Gasterensche Diep and none entered the Taarlosche Diep (Table 4). The movement patterns of these six river lamprey were very diverse;

- one moved into the Drentsche Aa but was not detected thereafter, so presumably remained in the Drentsche Aa/Oudemolensche Diep until the spawning period (river lamprey ID 41);
- two moved upstream through the Eems Canal and Noord Willems Canal to enter the Gasterensche Diep and remained there until the spawning period (river lamprey ID 57 and 78);
- one moved out to the Wadden Sea and then returned to the Eems Canal, Noord Willems Canal and entered the Gasterensche Diep to stay there until the spawning period (river lamprey ID 46);
- two moved through the Eems Canal, Noord Willems Canal and stayed in the Gasterensche Diep during late December, early January to return to the canal system and stay there until the spawning period; one in the Delfzijl inner harbor and one being detected for a prolonged period in the Eems Canal at station 5 Garmerwolde (river lamprey ID 43 and 47).

Thus, of these six river lamprey only four at maximum might have spawned in the Drentsche Aa/Oudemolensche Diep (n=1) or Gasterensche Diep (n=3), whereas none of these three progressed as far as the proven spawning site called ‘voorde 1’ (station 12). Of the six river lampreys entering the Drentsche Aa, five passed the first large woody debris site just downstream from station 10 in the Gasterensche Diep.

Most movements of river lamprey took place in December and January (Figure 3 and 4). In 2009/2010 also some movements in the downstream section of the Eems Canal and Delfzijl took place in April, whereas in 2011/2012, two river lamprey remained in the vicinity of two detection stations for prolonged periods until May.

Table 4. *Overview of the passage data for the six river lampreys that entered the Drentsche Aa. For each river lamprey the timing, duration and total number of detections during passage is given per section.*

Fish ID Sex, L cm	Station passage per section	Date: time First detection	Date: time Last detection	Passage duration	Number detections
41	3-4-5-9 (Delfzijl-N Willems Canal)	16-12-2011 19:06	26-12-2011 19:51	10 days	187
F, 39.9	10 (Entrance Drentsche Aa)	29-12-2011 17:54	29-12-2011 18:04	10 min	14
43	3-4-5-9 (Delfzijl-N Willems Canal)	16-12-2011 18:24	19-12-2011 01:06	3 days 7 hr	87
F, 40.3	10 (Entrance Drentsche Aa)	19-12-2011 18:26	19-12-2011 18:34	8 min	10
	11 (Entrance Gasterensche Diep)	20-12-2011 18:28	13-01-2012 19:45	24 days	106
	10 (Entrance Drentsche Aa)	19-01-2012 21:00	19-01-2012 21:06	6 min	5
	9-5 (N Willems Canal- Garmerwolde)	20-01-2012 04:01	11-05-2012 12:35	112 days	82196
46	3-4-1-2 (Delfzijl-Canal-Wadden Sea)	16-12-2011 18:40	19-12-2011 10:32	2 days 14 hr	144
M, 40.6	2-1-4-5-9 (WaddenSea- N Willems Canal)	07-01-2012 13:45	08-01-2012 16:53	1 day 2 hr	210
	10 (Entrance Drentsche Aa)	09-01-2012 02:10	09-01-2012 02:18	8 min	12
	11 (Entrance Gasterensche Diep)	10-01-2012 18:30	10-01-2012 18:39	9 min	10
47	3-4-5-9 (Delfzijl - N Willems Canal)	17-12-2011 20:03	18-12-2011 22:45	1 day 2 hr	52
F, 40.6	10 (Entrance Drentsche Aa)	19-12-2011 05:47	19-12-2011 05:51	4 min	7
	11 (Entrance Gasterensche Diep)	20-12-2011 17:40	04-01-2012 19:25	15 days 2 hr	27
	10 (Entrance Drentsche Aa)	05-01-2012 02:34	05-01-2012 02:36	2 min	2
	9-5-4-3-4-3 (N Willems Canal- Delfzijl)	05-01-2012 21:57	07-01-2012 20:45	1 day 23 hr	84
57	3-4-5-9 (Delfzijl - N Willems Canal)	03-01-2012 19:45	04-01-2012 21:21	1 day 2 hr	54
F, 37.8	10 (Entrance Drentsche Aa)	05-01-2012 07:20	05-01-2012 07:30	10 min	14
	11 (Entrance Gasterensche Diep)	07-01-2012 00:53	17-01-2012 19:12	10 days	11
78	3-1-4-5-9 (Delfzijl – N Willems Canal)	30-11-2011 17:44	07-12-2011 17:04	8 days	77
M, 38.7	10 (Entrance Drentsche Aa)	08-12-2011 01:03	08-12-2012 01:08	5 min	8
	11 (Entrance Gasterensche Diep)	09-12-2011 16:39	10-05-2012 23:22	153 days	97633

Table 5. *Duration of upstream migration and migration speeds for the six river lampreys that reached the Drentsche Aa and the five that reached the Gasterensche Diep.*

ID	Last detection Delfzijl (1 or 3)	First detection Drentsche Aa (10)	First detection Gastensche Diep (11)	Duration of migration Delfzijl - Drentsche Aa ; migration speed	Duration of migration Drentsche Aa – Gasterensche Diep ; migration speed
41	25-12-2011 21:25	29-12-2011 17:54	-	92 h ; 0.10 m/s	-
43	16-12-2011 18:48	19-12-2011 18:26	20-12-2011 18:28	72 h ; 0.14 m/s	12 h ; 0.37 m/s
46*	07-01-2012 21:44	09-01-2012 02:10	10-01-2012 18:31	29 h ; 0.34 m/s	40 h ; 0.11 m/s
47	17-12-2011 20:31	19-12-2011 05:47	20-12-2011 17:40	33 h ; 0.30 m/s	36 h ; 0.12 m/s
57	03-01-2012 20:04	05-01-2012 07:20	07-01-2012 00:53	35 h ; 0.28 m/s	42 h ; 0.10 m/s
78	01-12-2011 20:27	08-12-2011 01:02	09-12-2011 16:39	149 h ; 0.07 m/s .	40 h ; 0.11 m/s

* started the upstream migration from the Wadden Sea between 15:00 and 17:00 on 07-01-2012

Migrations can generally be typified as periods with relatively fast progress alternated with periods without much large scale movements (Figure 3 and 4). Three river lampreys covered the 36 km from Delfzijl to the entrance of the Drentsche Aa in only 29-35 hours, averaging 0.3 m/s (Table 5). One of these river lampreys started from the Wadden Sea just 4-6 hours prior to leaving station 1 in Delfzijl, thus migrating from the Wadden Sea into the Drentsche Aa in under 35 hours. The other three river lampreys, whose duration of migration lasted longer than 35 hours, migrated at average speed of 0.1 m/s (Table 5). The migration speeds in the 16 km section from the entrance of the Drentsche Aa to the entrance of the Gasterensche Diep was 0.1 m/s, except for one river lamprey that showed a migration speed of 0.4 m/s.

When combining the results from 2009/2010 and 2011/2012, different types of behavior might be distinguished (Table 6). Only seven of 53 transpondered river lamprey passed the canal system to move into streams; i.e., six into the Drentsche Aa, of which five entered the Gasterensche Diep and one into the Hunze. The majority, 46 out of 53, did not progress further than the canal system. A substantial part, 21 out of 53, moved out of the canal system to the Wadden Sea, of which three later returned to the canals of which one migrated to the Gasterensche Diep. Swimming back and forward, i.e. returning behavior, along a migratory route was seen in both the canals and streams. However, movement patterns in which river lampreys explored different ‘branches’ of the canal- and stream-systems within the Hunze and Aa catchment area was not observed.

Table 6. Summary of the results of river lamprey and overview of different migration patterns. For each migration pattern the numbers of river lampreys is given as well as their most upstream position (subdivided in sections).

Most upstream position (detection station numbers) ->	Delfzijl (1,3)	Canals (4-6,9)	Hunze (7-8)	Drentsche Aa (10-13)	*Totals*
Last detected within section of most upstream position	20	2	1	3	*26*
Moving downstream after most upstream position, remaining in canals		4		2	*6*
Moving downstream to Wadden Sea after most upstream position	6	12			*18*
Moving downstream to Wadden Sea and then re-entering Eems canal		2		1	*3*
Totals	26	20	1	6	*53*

4.2 Telemetry results for silver eel

Of the 36 silver eel released in the Hunze and Drentsche Aa, eight were never detected (Table 7). The other 28 moved downstream during late autumn and winter of 2011/2012. At least six of the silver eels reached the Wadden Sea via Delfzijl within the period of battery life. Another five were last detected near the Wadden Sea at station three. It is unclear is those eels reached the Wadden Sea. Remarkably, an additional two silver eels were detected to enter Lake Lauwersmeer within another ongoing IMARES project. These two eels must have passed a ship lock between the Eems Canal and the Van Starkenborgh Canal in the city of Groningen and then continued swimming to the canal Reitdiep to finally end up in the Lake Lauwersmeer. Timing of downstream movements varied between individuals ranging from October to January and even March and April (Figure 5, 6). One eel which was released in the Drentsche Aa migrated downstream, was detected at station six in the Winschoterdiep, turned around and continued through the Eems Canal.

Table 7 Results of silver eel detections in the telemetry study carried out in 2011. For each individual eel the order of detections and the time between first and last detection are given.

			Number of individuals				Station numbers
year	Patterns in station passage	N eels	Time between first and last detection ≤ 1 day	2 - 7 days	8 days - 30 days	> 1 month	Last station
2011	never detected	8					
2011	8	2	1			1	8
2011	10	5	4			1	10
2011	8-7+	4	1	3			7
2011	10-9	3		3			9
2011	8-7-6+	1				1	6
2011	8-7-6-LWM*	2		1	1		LWM
2011	10-9-5-4-3	3			1	2	3
2011	10-9-5-4-1-2	1				1	2
2011	8-7-6-5-4-2	1			1		2
2011	8-7-6-5-4-3	1				1	3
2011	8-7-6-5-4-1-2	1				1	2
2011	10-9-5-4-3-2	2			2		2
2011	8-7-6-5-4-3-1-2	1			1		2
2011	10-9-6-5-4-3	1				1	3

+ eels could have been escaped through an alternative route (Winschoterdiep – Eems Dollard) which was not covered by detections stations.

*last detection at Lake Lauwersmeer

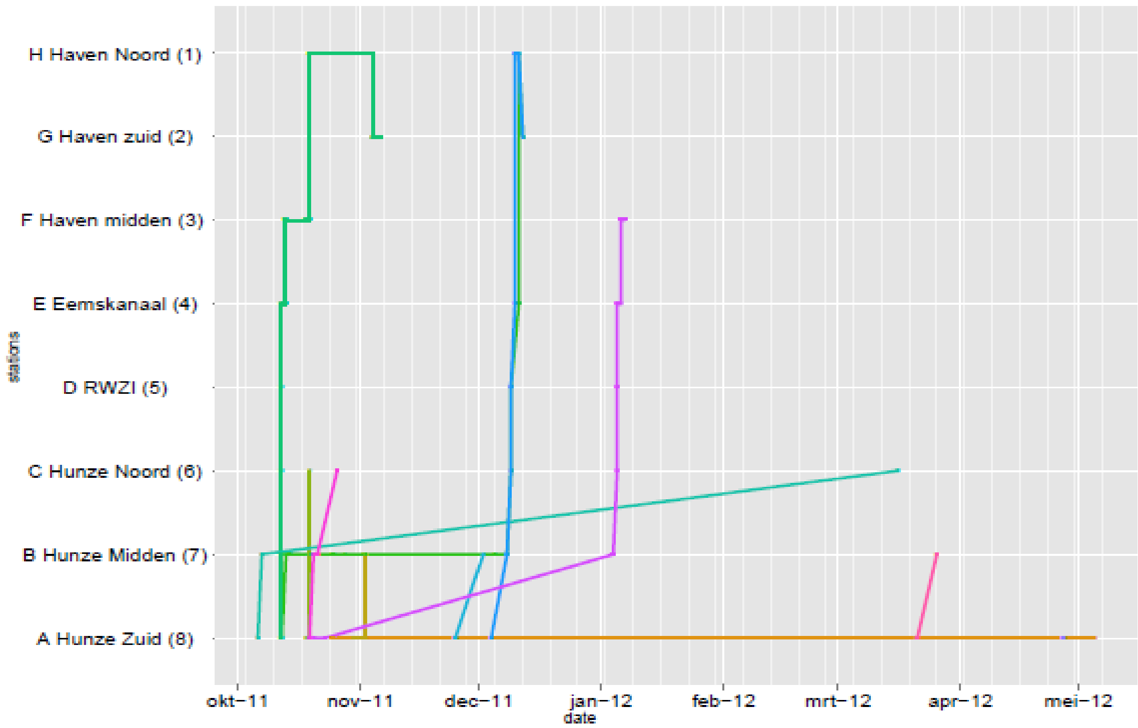

Figure 5. Individual movement patterns (station name and number on y-axis) for silver eel in 2011/2012 released in the River Hunze.

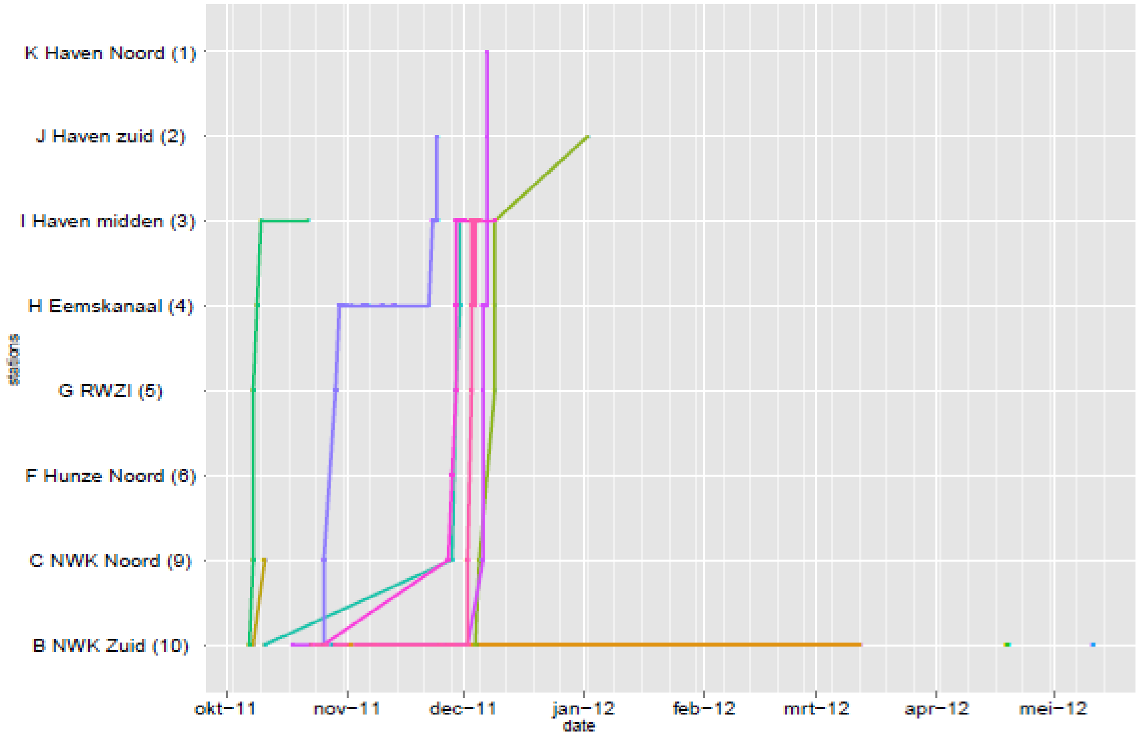

Figure 6. Individual movement patterns (station name and number on y-axis) for silver eel in 2011/2012 released in the River Drentsche Aa.

5 Discussion and conclusions

The different research questions stated at the start of the study will be addressed below:

1) What part of the river lamprey that arrive at the seaside of Delfzijl succeeds in migrating into the Eemskanaal and to what extend does the recently installed 'fish friendly' sluice management functions in relation to passage success for migratory fish?

Due to problems in catching sufficient numbers of river lamprey and the subsequent changed setup, where all 14 river lampreys in 2009/2010 and 39 river lampreys in 2011-2012 were caught and released in the inner harbour of Delfzijl, this could not be determined. Of the 21 river lampreys that moved out of the canal system to the Wadden Sea, three returned, of which at least two entered through the discharge sluice. Not all 21 river lampreys moving out to the Wadden Sea might have been motivated to return to the Eems Canal, suggesting that the actual success rate of river lamprey showing up in the marine harbour will be higher than this 14 % of return rate. How much higher and to what extend this is related to the 'fish-friendly' sluice management could not be determined.

2) What routes are taken during upstream migration and to what extend are fish passes passable?

From Delfzijl, 46 out of 53 river lampreys remained in the canal systems or moved back to the Wadden Sea. Only seven river lampreys moved into upstream streams, i.e. six into the Drentsche Aa of which five moved into the Gasterensche Diep in 2011/2012, and one moved into the Hunze in 2009/2010. The discharge sluice in Delfzijl is passable as proved by at least two returning river lampreys. We found no direct evidence that river lamprey also enter through the ship locks in Delfzijl. However, the fact that the fishermen caught nine of the river lamprey directly inland from these ship locks suggests that they also enter through these ship locks (although it cannot be ruled out that these river lampreys entered through the discharge sluices and then entered the inner harbour from the Eems Canal), perhaps at a lower rate as the few returning river lampreys entered through the discharge sluices.

Within the catchment area of the River Drentsche Aa only one 'fish pass' was passed. Due to the high discharge of the river during the winter the weir next to the 'fish pass' was fully opened allowing the lamprey free access from the Noord Willems Canal into the Drentsche Aa. The routes taken were logical routes, i.e. pathways along which water flows to sea, except that the movements were often not unidirectional and repeatedly returning behaviour was observed in both the canal and stream sections.

3) Which conditions or factors determine upstream passage success?

Given the large variation in observed patterns and relatively low numbers of river lamprey, this is difficult to analyse. Given the low percentage of 15 % (seven out of 43, taking into account that eight individuals were never detected, 43 river lamprey was set to 100 %) of river lampreys that successfully passed the canal system to more upstream located streams, it appears that the conditions within the canal system were not ideal for upstream passage. An apparent candidate factor related to this might be the unnatural variation in water flow strength and direction in the Eems Canal. The flow ranged from stagnant to slow flowing and the direction during discharges events is seawards. Directly after discharge events this changes to inlandwards, and no direction during periods when no water is being discharged through the sluices in Delfzijl. Time series of discharge events in combination to modelling can yield a reconstruction of the flow conditions within the Eems Canal that could be related to the exact timing of river lamprey movements (Foekema et al. 2011, Winter et al 2011). However, also some river lampreys that enter the streams show returning behaviour, leaving the stream in a downstream direction long before the spawning period. This might have been caused by a high discharge event in the Rivers during these weeks. Another candidate factor might be predation, e.g. by cormorants or predatory fish such as pikeperch or pike. Lastly, a potential candidate factor that may also have affected the upstream passage success rate within the catchment areas of Hunze and Drentsche Aa is the experimental treatment itself. The catching process and implantation of the transmitters might have induced unnatural behaviour, or caused additional mortality and therefore leading to an underestimation of success rate. The body cavity of especially male river lamprey is narrow relative to the size of the transmitter. In the pilot none of the river lampreys smaller than 37 cm were detected after passing station 3, which resulted in using only river lamprey larger than 37 cm in the 2011-2012 season.

4) How important is the Gasterensche Diep within the Drentsche Aa catchment area as a spawning site, i.e. which part of the lamprey entering the Drentsche Aa uses the Gasterensche Diep for spawning?

Of the six river lampreys that made it to the Drentsche Aa five entered the Gasterensche Diep and none was observed to enter the Taarlosche Diep. This suggests that the Gasterensche Diep is indeed an important tributary for spawning within the Drentsche Aa stream catchment. This is in line with the results of Winter and Griffioen (2007) for ammocoetes.

5) Is there directional migration to the spawning site taking place or is there intensive searching behaviour within the catchment basins, and if so to what extend?

The six river lamprey that successfully entered the Drentsche Aa stream system all showed highly directional movements with relatively high migration speeds varying from 0.1 – 0.3 m/s for a 52 km route. This is in accordance with the fact that only in the Gasterensche Diep ammocoetes were found so far and the 'pheromone hypothesis' that states that the ammocoetes release pheromones that attract adult river lampreys during upstream migration. The fact that five river lamprey entered the Gasterensche Diep against none that selected the other branch the Taarlosche Diep despite an on average twofold discharge is also in line with this hypothesis. Earlier in the route these lampreys also passed the confluence of the rivers Hunze and Drentsche Aa in the city of Groningen where both rivers deliver about 50% of the discharge. Also on this location all the lampreys proceeded the migration in the direction of the River Drentsche Aa. No searching behaviour in different branches was observed. However, returning behaviour on a directional pathway was common and appeared both in the group that did reach the Gasterensche Diep and the group that did not progress beyond the canal system. The reasons for this remains unclear. Perhaps the unnatural character of the canal system plays a role in combination with a too strong dilution of the pheromones that originated from the Gasterensche Diep.

6) What is the timing of migration into the Eems Canal and to the spawning sites?

Most movements took place in December and January. From February until the spawning period in March-April hardly any movements were observed, except for some small scale movements.

7) Does the large woody debris that was placed within stream restoration projects hinder the spawning migration of river lamprey?

Of the six river lampreys that enter the Drentsche Aa, five passed the first stretch of large woody debris situated in the stretch near the entrance of the Gasterensche Diep. It appears unlikely that an open structure like large woody debris will hinder upstream passage. Indirect effects of sedimentation of coarse substrate with finer substrates and therefore loss of spawning habitats might be a more plausible effect.

Silver eel downstream migration

Although less clear compared to river lamprey, there was variation and to some extend searching behaviour seen in the downstream migration of silver eel (Table 7). At least six and possibly 18 individuals reached the Wadden Sea and is therefore not fully successful. Of this 'successful' group, two eels used an unexpected route through ship locks, four to five eels possibly chose another unexpected route which was not covered by detections stations (Table 7), and several others reached station number three. It may be that eels postponed migration after being blocked at the sluices or ship locks and that they continued migration after the study period or when the batteries of the transmitters were empty.

One eel which was released in the Drentsche Aa was also detected at the Winschoterdiep, but turned around again to the Eems Canal. This suggests that similar as for river lamprey the unnatural variation in water flow strength in the canals could influence downstream migration in which eels may not be able to detect currents guiding them to the sea. The results of the downstream migration of eel is to some extend comparable to the results found by Griffioen et al. (2012) where some eels did migrate through ship locks during the downstream migration. In present study it is however unclear why and under which circumstances eels did migrate through the ship locks while another unblocked route was available at that place. To answer this question further research is needed.

For downstream migrating eels, several migration routes are available depending on discharge and management of several ship locks and sluices. The sluices at Delfzijl, ship locks at Delfzijl, ship locks between the Eems Canal and the Van Starkenborgh Canal in the city of Groningen, and finally the sluices at Nieuw Statenzijl. All possibilities are dependent on different discharge levels for a successful migration to the sea.

6 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2013 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

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Justification

Report number: C012/13
Project Number: 4302101101

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

Approved: Anneke Paijmans
researcher

Signature:

Date: 27 February 2013

Approved: Drs. J.H.M. Schobben
Head of the Fish department

Signature:

Date: 27 February 2013