Migration behaviour and habitat preference of 3-5 year old European Sturgeon (*Acipenser sturio)* in the Rhine River 2015

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Appendix

Summary

The critically endangered European sturgeon (Acipenser sturio) was extirpated in the Rhine River by 1950. As a prerequisite for any rehabilitation of the species a sound scientific assessment of reintroduction of this species as well as the census of the impacts acting upon the species during its migration is paramount.

First steps towards a possible reintroduction were taken in 2012 with an experimental tracking study that focused on the downstream migration of stocked juvenile sturgeon to the North Sea from the Rhine system. For this the migration behaviour were studied of 47 European sturgeons (A. sturio) of 76 ± 4.4 cm (total length) and 1 656 ± 258 gram. Recapture data were collected and the environmental characteristics of the habitats used were assessed. The release took place at the Rhine delta near the towns of Kekerdom (n=43) and Rotterdam (n=4).

In 2015 a comparable study (this present report) was carried out with 44 sturgeons of 80.9 ± 10.2 cm (total length) and 2 394 ± 907 gram. Based on the results of 2012 a new location near the German border, situated 15 km higher upstream, was picked for the release in 2015. This new location was chosen to verify the hypothesis if the sturgeons would choose a different route that would lead them downstream through Nederrijn - Lek and IJssel.

All sturgeons were implanted with transponders of the NEDAP TRAIL system®. Additionally, WOT-tags were inserted at the base of the dorsal fins to provide external recognition. The sturgeons were released at the 10th of June 2015.

After their release, none of the sturgeons showed upstream migration behaviour. Of all 44 sturgeons, 31 (71%) were registered by the NEDAP detection system. Additional observations thanks to WOT tags were reported. Two sturgeons were found dead on the river bank and reported. Both were severely damaged, plausibly as a result of collisions with ship propellers. Three other sturgeons were recaptured and reported by commercial fishermen from the North Sea. One sturgeon was caught by an angler. All four sturgeons were released alive.

In total, 23 of the 44 (52%) sturgeons were documented to reach the North Sea. Three sturgeons entered the Sea by passing the Haringvliet dam and 19 took the route through the Nieuwe Waterweg. The route of one sturgeon is unknown, but the sturgeon was detected in the Noord and probably must have reached the North Sea through the Nieuwe Waterweg as well.

The sturgeons migrated from the release site in the downstream direction and after 9,5 kilometres they reached the Y-junction at the Pannerdensch kanaal. Because no detections were collected at the stations in the downstream area of the Pannerdensch Kanaal, including the Nederrijn system, it is suggested that all sturgeons followed the route through the Waal. At 102 km from the release location there is a second Y-junction, were the sturgeons were observed to take the route through the Beneden Merwede above the Nieuwe Merwede.

The average time between their release at the German border and the first detection at the Haringvliet dam (n=3, 11 ± 3 days) and the Nieuwe Waterweg (n=19, 13 ± 12 days) was comparable. The distance from the release location to the Haringvlietdam is 171 km and to the detection station in the Nieuwe Waterweg 167 km.

The percentage of sturgeons that reached the North Sea in 2015 was 52%. This is slightly more than the outmigration in 2012 (44%).

1 Introduction

1.1 General

In the beginning of the 20th century, the European sturgeon (*Acipenser sturio)* became extinct in the Rhine River system and the North Sea most likely due to overexploitation, deterioration of water quality, loss of habitat and river regulation (damming, channelling). Around 1900, a number of 350-500 sturgeons were sold on the markets in the South of the Netherlands. Between 1920 and 1950 a maximum 20 sturgeons were sold each year (Ouak, 2016 in prep.). The last recording has been from the Waal near Tiel in 1952.

Till 2007 adults were rarely observed in the Gironde-Garonne-Dordogne basin and till the nineties spawners were still reported in the basin of the Rioni river in Georgia. The last confirmed catch in the Rioni river was in 1991 (Debus 1996). Currently, in Western Europe the survival of the European sturgeon is almost entirely dependent on stocking programs. The last natural reproduction known from the Gironde-Garonne-Dordogne basin has been in 1994 (Ludwig et al. 2004). The French and German governments perform National action plans and stocking programs in the Gironde and in the Elbe rivers (Gessner et al. 2010; MEDDTL, 2011).
Until the late 19th century, the sturgeon was present in almost all rivers of Western Europe. Possibly global warming may force future populations to rivers with suitable water temperature conditions (Lassalle et al. 2010). The Rhine River could function as a suitable habitat for the European sturgeon. Water quality is not a limiting factor anymore (Van der Veen 1981; Jakob 1996; De Villeneuve 1996). Much effort was put into habitat restoration of riverbanks and side channels and the positive effects of nature restoration in the river on fish populations are substantial (Buijse and Cazemier 1998; Raat 2001; Reeze et al. 2005).

There are a number of factors that show that the Rhine River system could be suitable for the re-introduction of the European sturgeon in the near future, as listed below.

- In the Dutch part of the main stem of the Rhine River (the Waal) there are no longitudinal barriers like dams.
- In 2018, longitudinal connectivity between the Rhine River estuary (Haringvliet) and the North Sea will be further improved by the “de Kier”, which means that the Haringvlietdam will be opened more often and also during high-tides. However, during low river discharges (less than 1500 m^3 at Lobith), the dam will still be closed. Therefore the water board intends to create an additional migration route within the Zuiderdiep, a former major gully of the Haringvliet estuary. With both measures it is believed that both up- and downstream migration of anadromous fish will be facilitated.
- During the last 30 years, the water quality of the Rhine River has distinctly improved. This is a positive result due to many measures taken in relation to (above all) the implementation of the International Commission for the Protection of the Rhine. The pollution of the Rhine River with heavy metals and other pollutants has been strongly reduced. The oxygen contents of Rhine water and the species number of benthic micro-organisms have again risen (ISKR, 2006).
- Habitats in the Rhine River are being restored in Germany and the Netherlands.
- Sturgeon are vulnerable to high water temperatures. Due to global warming, the Northern position of the Rhine River, compared to Mediterranean rivers, could represent a more suitable habitat to sturgeon.
- The Rhine is located between the populations of the Gironde and Elbe rivers. As such it could become a link in the chain of sturgeon sources for repopulating other catchments.
- Sturgeon are diadromous migratory fish species. They depend upon a free migration between the river and sea to maintain a self-sustainable population. Therefore the (possible) rehabilitation of *A. sturio* in the Rhine River can be regarded as a signal for a healthier river system.

On the other hand, there a some threats for reintroduction of the European sturgeon in the Rhine River.

- Tidal area offers essential habitat for two and three year old sturgeons. However, this type of area is rather limited in size in the Lower Rhine River system in the Netherlands (Winter et al., 2015).Migration studies with juvenile sturgeons should help to give more insight in the availability of (and free routes within) these crucial habitats.
- The Rhine River is intensively navigated. Sturgeons are vulnerable to propeller strikes, as is shown in studies in the Delaware River (Brown and Murphy (2010). The influence of navigation on the survivability of sturgeons in the River Rhine must be further investigated.
- The North Sea is intensively fished (Winter et al., 2015) which may hamper the rehabilitation of *A. sturio*.

Thus, it could be that the Rhine River system is ready again for a reintroduction of *A. sturio*. As a prerequisite for any rehabilitation of the species in the Rhine River, a sound scientific assessment of reintroduction of this species, as well as a census of the impacts acting upon the species during its migration, is paramount. Knowledge of key factors such as: habitat quality, the carrying capacity of the available habitat along the Rhine for juvenile, the migration road and associate survival to reach the sea are essential. They provide the scientific basis for a decision of the restoration potential for the species in the Rhine system. Based upon this assessment, a political commitment within the catchment has to be reached. This should also include the potential countermeasures to circumvent adverse conditions for the species before actually considering implementing a stocking program.

First step was taken in 2012 with an experimental tracking study that focused on the migration road of stocked juvenile sturgeon to the North Sea from the Rhine system. For this research the migration behaviour of 47 tagged European sturgeons in the spring and summer of 2012 were studied. In 2015 a similar study (this present report) was carried out, where 53 sturgeons were released more upstream at the German border. This was done to study the importance of the more Northern part of the Rhine Delta and to identify a preferred migration corridor, consisting of the Nederrijn-Lek, IJssel and Ijsselmeer.
The NEDAP TRAIL System® of Rijkswaterstaat was used in both studies to locate the sturgeons.

1.2 Aims

The main objective of this study is to observe the migration behaviour of stocked juvenile European sturgeon (A. sturio) in the Rhine River system. For 2015, the following research-questions have been formulated:

1. Are European sturgeon (A. sturio) able to migrate downstream and/ or upstream along the Rhine River and where they encounter migration barriers (such as hydropower stations, dams, weirs and sluices)?
2. Can they reach (escape into) the North Sea?
3. What is their preferred migration route?
4. What is the daily and migratory behaviour in the Rhine system?
5. Do they use the Lower Rhine River over extended periods of time? And if so, what are the specific conditions under which this takes place?

1.3 Sturgeon project group

The project is accompanied by a scientific comity which consists of a group of fixed and temporary members:

- The Netherlands:
    - The Royal Dutch Angling Organisation (Sportvisserij Nederland);
    - WWF-NL (Worldwide Fund for Nature, Netherlands);

    - ARK Nature;
    - RWS (Rijkswaterstaat);
    - IMARES (Institute for Marine Resources & Ecosystem);
- France:
    - IRSTEA (French National Research Institute of Science and Technology for Environment and Agriculture);
- Germany:
    - GRS (Gesellschaft zur Rettung des Stors);
    - Leibniz Institute of Freshwater Ecology and Inland Fisheries;
    - Biologe des Rheinischen Fischereiverbandes von 1880 e.v.

Finances:
In 2012 the research was supported financially by the “Living North Sea” programme and Sportvisserij Nederland. In 2015 the study was financially supported by the Postcodeloterij Droomfonds and by a consortium of WNF, ARK and Sportvisserij Nederland.

2 Material and methods

2.1 Material

2.1.1 Study area

The study area includes the Lower Rhine River and the Dutch Delta (figure 2.1), from the German border in the east to the port of Rotterdam in the west (Nieuwe Waterweg), Europe's largest seaport and the terminus of all Rhine navigation. The Lower Rhine and the Dutch delta are heavily modified waters, characterized by a network of man-made channels and intensive navigation. Natural habitats are strongly modified by hydraulic engineering including some of the largest sea locks in the world. There are no fish migration-barriers in the main stem of the Lower Rhine River. Nevertheless the Meuse river, Neder-Rijn and lake IJsselmeer do contain several migration barriers such as hydro power plants and main sluice-weir complexes.

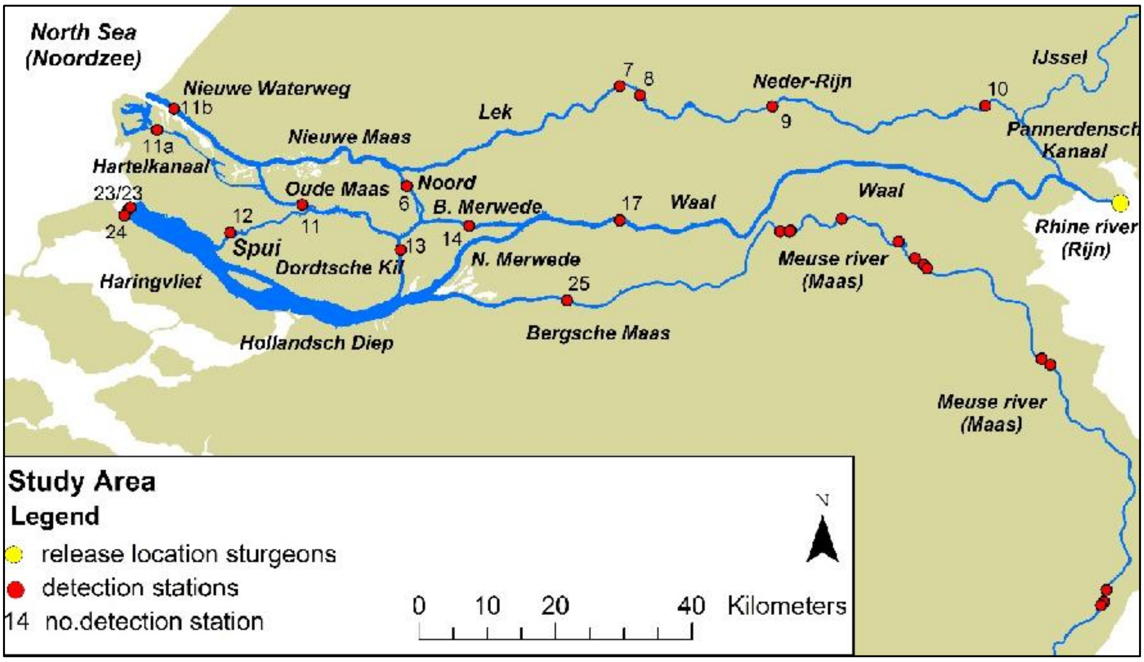
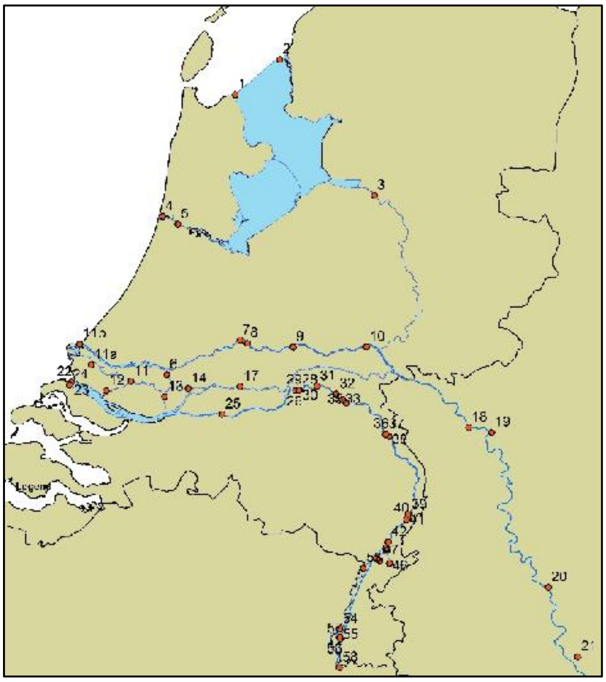


figure 2.1 *The network of water ways as part of the Rhine and Meuse River delta.*

2.1.2 NEDAP TRAIL system®

The migration behaviour of the sturgeons were tracked by means of the NEDAP TRAIL System®, as is described in By de Vaate & Breukelaar (2001). This technique is based on inductive coupling between a fixed array of receivers (detection stations), strategically positioned in the Lower Rhine River system (figure 2.2) and transponders (surgically implanted in the test-fish). Part of each receiver is the antenna, each antenna is positioned on the bottom of the water way and reaches from shore to shore. For the transmission of signals, a narrow low frequency band (33.25 kHz) was chosen, resulting in a high-sensitivity receiver with low probability of interference from radio signals and other possible disturbances.

The chosen NEDAP transponders consist of a battery with an ensured lifetime is at least four years, obviously depending on the number of registrations. The transponders weigh 26.5 grams in air, 17 g. in water, and are enclosed in a glass tube: diameter = 15 mm, length = 70 mm (figure 2.4). Field tests showed that the NEDAP detection system still functions properly in fresh and salt water at a maximum antenna length of 3 000 m, a water depth of 30 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 will be interrupted. The maximum tolerable conductivity of the river water was not tested. However, calculations showed that a conductivity of less than 6 000 µS cm-1 did not affect transmission when the distance between the antenna and the transponder does not exceed 15 m. When a tagged fish passes a detection station its unique ID-number (amongst other information) is logged onto the NEDAP data storage system.



nr	name	nr	name
1	IJsselmeer_Den Oever	30	Maas_Alphen_wkc_bov
2	IJsselmeer_Kornwerderzand	31	Maas_Megen
3	IJssel_Kampen	32	Maas_Niftrik_Loonsewaard
4	NZK_IJmuiden_gemaal	33	Maas_Balgoij
5	NZK_Velsen	34	Maas_Grave_vispass.
6	De Noord_Kinderdijk	35	Maas_Grave_bov
7	Lek_Nieuwegein	36	Maas_Sambeek_ben_stu
8	Nederrijn_Hagestein	37	Maas_Sambeek_vispass
9	Nederrijn_Maurik_bov	38	Maas_Afferden
9a	Nederrijn_Maurik_ben	39	Meuse_Steyl
9b	Nederrijn_Maurik_wkc_ben	40	Meuse_Belfeld_vispass.
10	Nederrijn_Arnhem	41	Meuse_Belfeld_bov
11	Oude Maas_Spijkenisse	42	Meuse_Buggenum
11a	Hartelkanaal_Europoort	43	Meuse_Linne_vishevel
11b	Nieuwe Waterweg_Europoort	44	Meuse_Roermond_vispass.
12	Spui_Zuidland	45	Meuse_Roermond_bov
13	Dordtsche Kil_s'Gravendeel	45a	Roer Roermond_ECI_bov
14	Ben Merwerde_Sliedrecht	46	Roer_Sint_Odiliënberg
17	Waal_Brakel	47	Meuse_Linne_dorp
18	Rhine_Xanten	48	Meuse_Linne_vispass.
19	Lippe_Wesel	49	Meuse_Linne_wkc_ben
20	Wupper_Burrig	50	Meuse_Linne_stuw_ben
21	Sieg_Menden	51	Meuse_Linne_wkc_bov
22	Haringvliet_Stellendam_noord	52	Meuse_Linne_stuw_bov
23	Haringvliet_Stellendam_zuid	53	Grensmaas_Stevensweert
24	HV_Stellendam_scheep	54	Grensmaas_Itteren
25	Bergsche Maas_Cap. Veer	55	(expired)
26	Meuse_Lith_dorp	56	Grensmaas_Bharen_vis
27	Meuse _Lith_vispass.	57	Meuse_Maastricht
28	Meuse _Alphen_wkc_ben	58	Berwijn_Moelingen
29	Meuse _Lith_stuw_ben		

figure 2.2 *Overview of detection stations in the lower Rhine- an Meuse River Systems (Ben: lower; Bov: top; vispass.:fish facility). (situation 1st of June 2015).*

2.2 Length and weight of the sturgeons

53 test-fish (European sturgeons, *A. sturio)* were provided for the present study, thanks to the authorisation of the French ministry of environment by the French research institute IRSTEA and MIGADO association. The test-fish used (further called ‘sturgeons’) were bred at the IRSTEA experimentation station in Saint Seurin sur Isle in 2011. The length of the sturgeons varied between 64 and 102 cm (80.9 ± 10.2 cm, total length) and a weight between 1 100 and 4 410 gram (2 394 ± 907 g) (figure 2.3 and Annex 1).

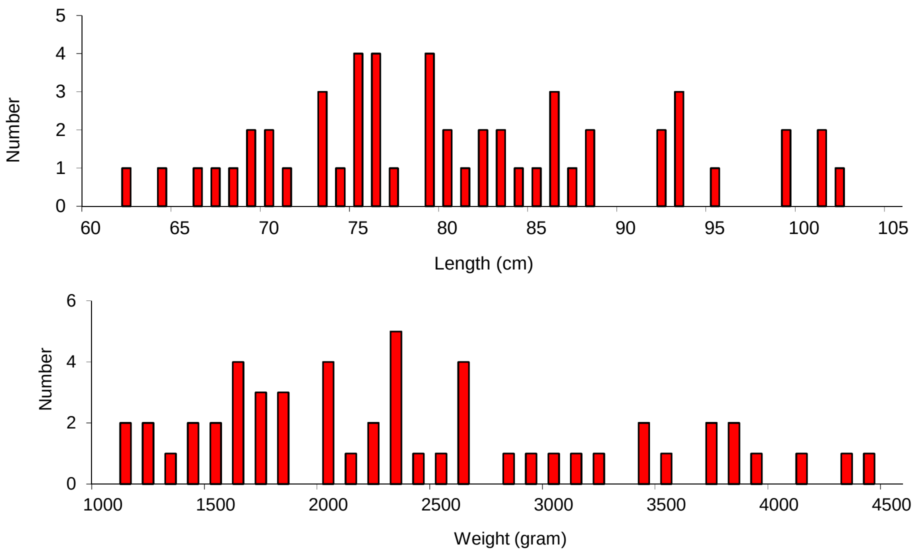


figure 2.3 *Length frequency (above) and weight frequency (below) of the tagged sturgeons.*

2.3 Tagging

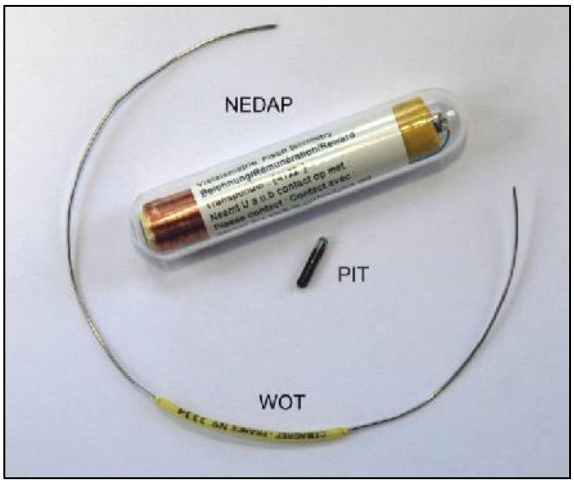


figure 2.4 *Marks utilized to tag sturgeon for the experiment: PIT - tag, 12 mm long, NEDAP transponder, 70 mm long and WOT- tag.*

All sturgeons were tagged with NEDAP transponders on the 28th and 29th of April 2015 at the IRSTEA experimentation station in France. The sturgeons were also previously tagged with a Passive Integrated Transponder (PIT, diameter: 2 mm, length 12 mm). The reading range of PIT tags is limited, but their duration is near infinite. Individual sturgeons can be recognized using a handheld PIT reader.

The tagging procedure was similar to the one used, as described in Acolas *et al.* (2012). The sturgeons were anaesthetised using eugenol (clove oil, 0.5 ml diluted in 5 ml of ethanol per 10 l water). During surgery a less concentrated anaesthetic solution (60% of the initial concentration) was provided to the sturgeons positioning a tube in their mouth for water flow through their gills. During operation gloves and disinfected surgical materials were used. An incision of approximately 2 - 2.5 cm along the linea alba between pectoral and anal fins was made and special attention was paid to prevent damages to internal organs. After internal control, the transponder was inserted in the abdominal cavity (figure 2.5). The incisions were closed with sterile sutures (Ethicon Polydioxanone absorbable monofilament, cutting needle 2/0 and 3/0) and treated with a surgical glue (Vetbond). After surgery the sturgeons were imparted in a basin with running water, where they were observed until the sturgeons showed the correct swimming behaviour. All sturgeons recovered well.

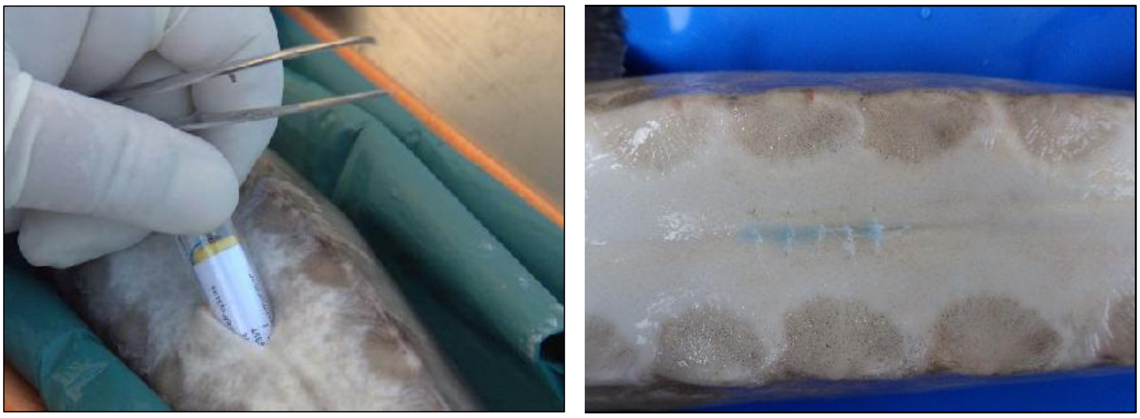


figure 2.5 *Insertion of the NEDAP transponder in the abdomen cavity of the sturgeon (left) and the closure of the incision with sutures (right).*

In the period between tagging (in France) and their release (in the Netherlands) the sturgeons were frequently checked for abnormal behaviour. In addition, wound-healing was checked by the staff of IRSTEA on the 29th of April, the 19th of May and the 9th of June. In general, the condition of the wounds were determined to be good or even very good. All 53 tagged sturgeons were transported to the Netherlands by a specialised company (Viskweekcentrum Valkenswaard) on the 4th and 5th of June. During transport the oxygen supply was checked regularly, and the sturgeons were checked for any possible abnormal behaviour.

figure 2.6 *This floating live well was used to stock the sturgeons in de Kaliwaal.*

After arrival the water of the fish tank was slowly replaced (within two hours) by water from the river to acclimatize the sturgeons. The sturgeons were stored in a floating live well, located in lake Kaliwaal near the town Kekerdom (figure 2.6). The Lake Kaliwaal is in open connection with the river Waal. Twice a day, the sturgeons were fed with a mixture of shrimp and krill as subscribed by the hatchery Migado. During their stay for five days in the live well, no deviant behaviour was observed. The sturgeons showed healthy and active.
On the 9th of June the sturgeons were provided with a WOT-tag (figure 2.4). The tag consists of a metal wire with a yellow rubber tube with a laser printed unique number and phone number. To attach the WOT, a hollow needle was inserted through the musculature just below the dorsal fin (figure 2.7).

figure 2.7 *Tagging a sturgeon with a wire on tag (WOT).*

2.4 Tag checking

A single sturgeon (no. 15385) must have lost the transponder during transportation to the Netherlands. The transponder was found in a tank on the lorry and was again surgically inserted in the sturgeon on the 9th of June. No other transponder was found in any tank placed on this lorry. In addition, all tanks at the hatchery in France were thoroughly cleaned and checked for any other possible left transponders, but none were found.
The correct functioning of all transponders had been checked before delivery by the NEDAP factory. However because there is always a chance that transponders can be damaged and their functioning compromised, *e.g.* during transport to and from France. Therefore on the 9th of June, during implementation of the WOT-tags, while the sturgeon were under sedation, each individual was held against a mobile NEDAP detection station. Of the 53 tagged sturgeons, 44 of their transponders were detected. The non-identifiable nine sturgeons were released in the river but excluded from this study. No data was collected after their release by the NEDAP System and also no recapture or finds of these nine sturgeons were reported afterwards.
On the 9th of June all 53 sturgeons were also checked for a PIT tag signal response by means of a handheld PIT tag identifier and all PIT tags were identified.

2.5 Release

On the morning of the 10th of June 2015, the sturgeons were transported (by the same company) to their release site at the German border near the town Spijk. Again the sturgeons were transported with the same oxygen supply and were checked regularly for any abnormal behaviour. Nothing was out of the ordinary, the sturgeons were healthy and fit. A first group of four sturgeons were released during a media event held at 01:00 PM. The other 49 sturgeons were released at 6:00 PM. The sturgeons were released from the riverside.

2.6 Mobile survey

Three mobile surveys were carried out with a mobile NEDAP detection station. The aim was to find any sturgeons that might not have left the release site or that would linger in the river stretch of 85 km between the release site and the first downstream NEDAP detection station at Waal_Brakel (nr. 17, figure 2.2). The mobile detection station was temporarily installed on board of a research vessel. This mobile station had a detection range of 12 m in diameter around the antenna. In the afternoon of the 11th of June 2015 a short mobile survey was carried out at the release location. Two other mobile surveys were carried out on the 19th of June and 2nd of July, further downstream at strategically chosen locations. *I.e.* the survey was especially carried out close to the shore and in the outside corners of the river. By doing so, it should have been possible to detect any dead sturgeons that could have been washed upon the shores of the river bank. During these surveys also special attention was paid to locate dead sturgeon by sight.

3 Results

3.1 Registrations

3.1.1 Tag data

In total 53 sturgeons were tagged in France. After subtraction of the sturgeon with non-responding tags (§ 2.4), 44 sturgeons were used in the tracking experiment. Of the 44 successfully tagged and released sturgeons at Spijk, no tracking data could be collected of 11 individuals were never registered or recaptured.

Several NEDAP detection stations showed a decrease in detection rate during this present study, therefore not all tagged sturgeons could be detected at each station (table 3.1). Therefore the performance of the stations is taken into account in the data-analysis. The performance of the tracking system is discussed § 4.1.1).

table 3.1 *Performance of NEDAP detection stations during the study period (11th of June till 30th of September).*

Period	Name detection station	Description
10-06 - 04-09	Waal Brakel	estimated detection rate: 80%
10-06 - 04-09	Beneden Merwede Sliedrecht	estimated detection rate: 10%, cables moved ahead only poor detection possible
14-07 - 30-09	IJssel Kampen	station offline, cables disconnected
04-08 - 17-08	Hartelkanaal Europoort	station offline, cables disconnected
10-06 - 30-09	Oude Maas Spijkernisse	less detection, one cable disconnected

table 3.2 *Overview of registrations per station. * Number of passes based on other stations downstream registrations and finds.*

Release location→		**Spijk June 2015 (*n*=44)**	
No	**Name detection station**	**N sturgeons**	**N Regis-trations**
17	Waal_Brakel	25 (31)*	34
14	Beneden Merwede_Sliedrecht	2 (18)	10
13	Dordtsche Kil_s'Gravendeel	5	6
06	Noord_Kinderdijk	4	5
12	Spui_Zuidland	1	2
11	Oude Maas_Spijkenisse	14	18
11a	Hartelkanaal_Europoort	-	-
11b	Nieuwe waterweg_Europoort	19	182
22/23	Haringvlietdam	3	6
	Total	31	263

All tracking data collected of the 44 tagged sturgeons from the 10th of June, 2015 until the 29th of September 2015 were included in the data-analysis (*n*=263) (table 3.2).

After their release, none of the tagged sturgeons were detected in the upstream direction. Of all 44 tagged sturgeons, *n*=31 (71%) were registered. At the first station downstream from the release location ("Waal_Brakel"), 25 sturgeons were registered. However, downstream from "Waal_Brakel", six additional sturgeons were registered, but those sturgeons had not been recorded at "Waal_Brakel". Therefore in total 31 sturgeons must have passed the station "Waal_Brakel" alive. The same principle applies to the station "Beneden Merwede_Sliedrecht", were 16 sturgeons passed un-detected.

The majority of registrations (69%) were collected from the station "Nieuwe Waterweg_ Europoort". Only when sturgeons were detected on the last detection station nearing the North Sea or captured in the North Sea, they were counted as sturgeons that had reached the North Sea. Three sturgeons were registered at the station "Haringvliet_dam" and 19 were registered at the station "Nieuwe Waterweg_ Europoort". One sturgeon that was recaptured in the North Sea was not detected by one of these detection station situated near the North Sea. In total, at least 23 of the 44 (52%) sturgeons reached the North Sea.

3.1.2 Additional observations

<u>Mobile survey</u>

No sturgeons were detected during three mobile surveys held after the 10th of June 2015 (figure 3.1).

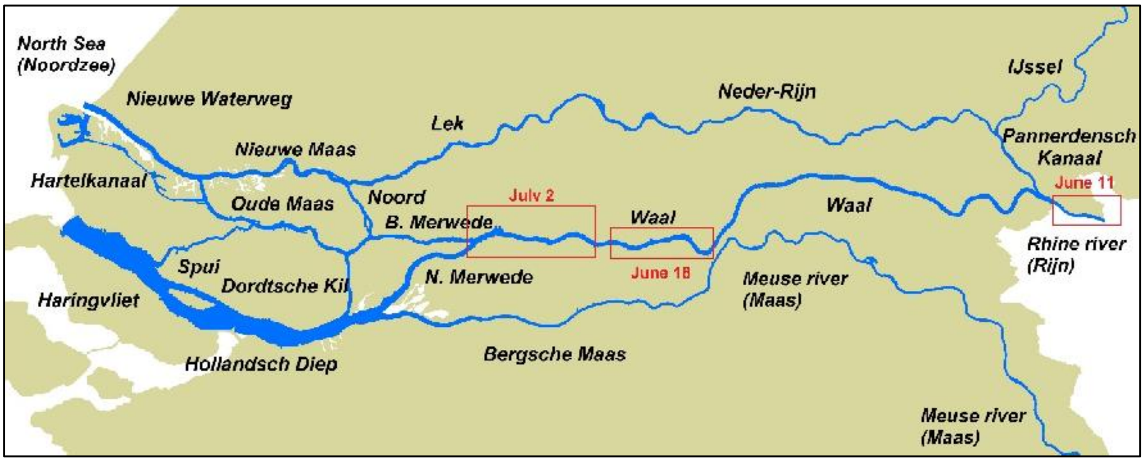


figure 3.1 Overview of the three areas that have been surveyed by mobile tracking.

<u>Finds</u>

Two dead sturgeons were found on river banks and reported (figure 3.2). One was found at the Waal (Rhine River main stem) near the town Ewijk on the 15th of June. Based upon the observed decomposition of its body this sturgeon had probably been dead for several days, this sturgeon was almost decapitated. The second sturgeon was found on the river bank in the Beneden Merwede near Werkendam on the 17th of June. This sturgeon had also been dead for several days. The transponder was broken and this sturgeon had probably already been dead when it passed the detection station "Waal_Brakel" unseen. The sturgeon had a broken tail, a broken dorsal spine, and a sharp but shallow cut at the beginning of the belly. These type of damages (sharp cuts perpendicular to the body) were also found in the previous tracking study held in 2012 when one decapitated sturgeon was found in the Waal (Vis & de Bruijn, 2012; Brevé et al., 2013).

Between the 28th of June 2015 and the 31st of December 2015 four other sturgeons were recaptured and reported to Sportvisserij Nederland. Three sturgeons were recaptured in the North Sea by commercial fishermen and one was caught by an angler in the Oosterschelde (figure 3.2). All sturgeons were released alive again.

- Two sturgeons were caught along the coast with gill nets.
- One sturgeon was reported by beam trawl fisheries.
- On December 19th one sturgeon was caught by an angler in the Oosterschelde, near the "Zeeland" bridge.

These four recaptured sturgeons comprise 8% of all released sturgeons (*n*=53) and 17% of the sturgeons that reached the North Sea based on registrations on the NEDAP system (*n*=23).

Date	No.	Remarks
14-6-2015	14363	Found dead on shore of the Waal near Ewijk
17-6-2015	14393	Found dead on shore of the Boven-Merwede near Werkendam
28-6-2015	NA	Recaptured in the North sea, along the coast near Katwijk, released alive. Caught with gill nets.
29-6-2015	14386	Recaptured in the North sea, along coast near Kijkduin, released alive. Caught with gill nets
3-9-2015	14361	Recaptured in the North sea, along the coast near Goedereede, released alive. Caught with trawling fishery.
19-12-2015	14359	Recaptured in the Oosterschelde near the “Zeeland” bridge, released alive. Caught by an angler.

figure 3.2 *Location of found, dead sturgeons (red dots) and recaptures along the Dutch coast (yellow dots).*

3.2 Migration routes

The migration routes of the sturgeons were deduced by a combination of the registrations of the NEDAP transponders and the two found and four recaptures. As mentioned in § 3.1.1, several sturgeons passed detection stations without being registered, due to problems with the detection cables. Nevertheless their migration route downstream could be deduced from other detections of these individuals at stations located further downstream. The number of individual sturgeons that must have passed a specific station was calculated and presented in parentheses in figure 3.3.

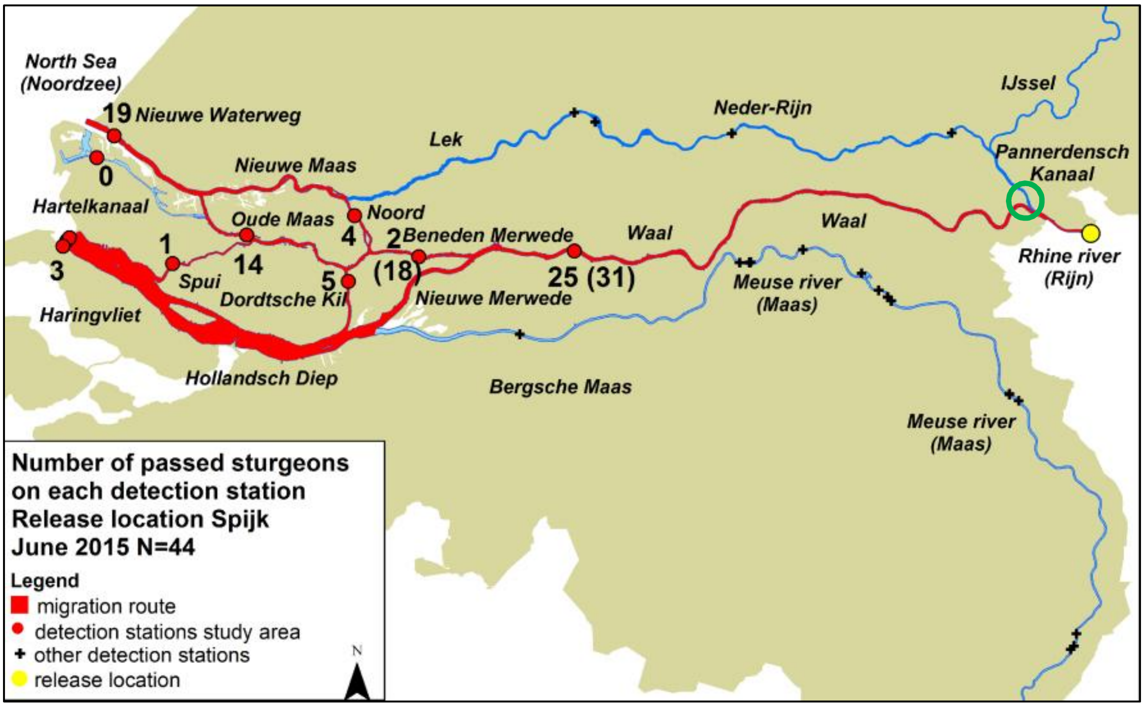


figure 3.3 *Overview of migration routes and number of registrations per station. No data was collected from stations situated in the Rhine River system downstream from the Y-junction at the Pannerdensch Kanaal (green circle), although a third of the Rhine River discharge flows into this channel.*

There are several alternative routes for sturgeons to reach the North Sea. These are the route through the:

- Nieuwe Waterweg;
- Haringvliet (figure 3.3);
- IJssel and IJsselmeer (Kornwerd and Den Oever).

The sturgeons migrated from the release site in the downstream direction. After 9.5 km they reached the Y-junction where the Rhine River divides into the Waal and the Pannerdensch kanaal (green circle figure 3.3). Since no detections were collected at the stations in the Nederrijn, IJssel and Afsluitdijk. Probably most (if not all) sturgeons followed the route through the Waal.

At 102 km from the release location there is a second Y-junction between the:

- Nieuwe Merwede;
- Beneden Merwede (figure 3.3).

Data from 25 sturgeons were collected downstream of the junction Nieuwe Merwede / Beneden Merwede. Three reached the North Sea by passing the Haringvliet dam. The other 22 sturgeons migrated towards the Nieuwe Waterweg. This area can be reached by the Beneden Merwede, Dordtsche Kil or Spui. Six sturgeons were detected on these stations and 16 passed un-detected. It later became evident that the detection cables of the station in the Beneden Merwede were malfunctioning at the time of the experiment. As a consequence, the other stations on this route were checked but no further malfunctions were detected. It can be concluded that the sturgeons migrated mainly through the route:

The Beneden Merwede ⇨ Oude Maas ⇨ Nieuwe Waterweg.

From all data collected the routes were deduced (figure 3.4).

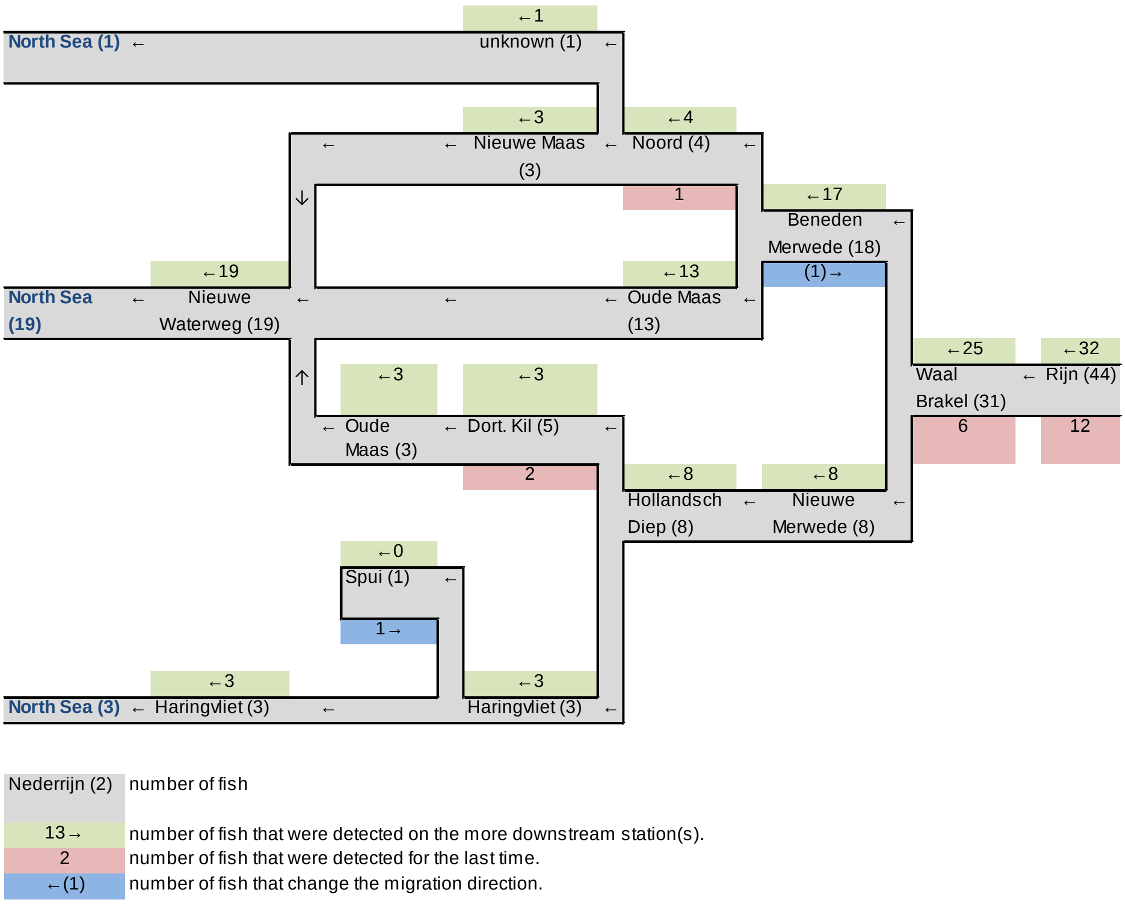


figure 3.4 *Overview of the downstream migration pattern followed by the sturgeons, released in the Rhine River near the German border on the 10th of June. *possible other routes that not were used by the sturgeons (e.g. Hartelkanaal and Neder-Rijn) are not shown in this figure.*

3.3 Migration and a-biotic parameters

3.3.1 Rhine River discharge

There seems to be a clear connection between the chosen pathways of the sturgeons released and the management of the Rhine River discharge in the Netherlands. To understand this relationship better, a short description of this water management scheme is given. The objective of the water management is to facilitate navigation and to prevent excessive salt water intrusion in the harbour of Rotterdam. Therefore the mainstream of the Rhine River is redirected into the harbour and out into the North Sea via the Nieuwe Waterweg. Furthermore, the management of the 17 discharge sluices within the Haringvliet dam (situated outside the harbour of Rotterdam) is based upon the river discharge of the Rhine, measured at the town Lobith, situated near the German border (figure 3.5). The relative discharge through the Haringvliet dam is expressed in the opening of the discharge sluices in square meters, whereas one sluice door opened = 25 m^2 . The sluice doors are closed with a Rhine discharge of less than 1 100 m^3/sec. And with a river discharge of 1 100 – 1 700 m^3/sec, the discharge through the Haringvliet dam is still at a minimum opening of 25 m^2 (one door open). From a Rhine discharge over 1 700 m^3/sec the Haringvliet sluices are opened up proportionally.

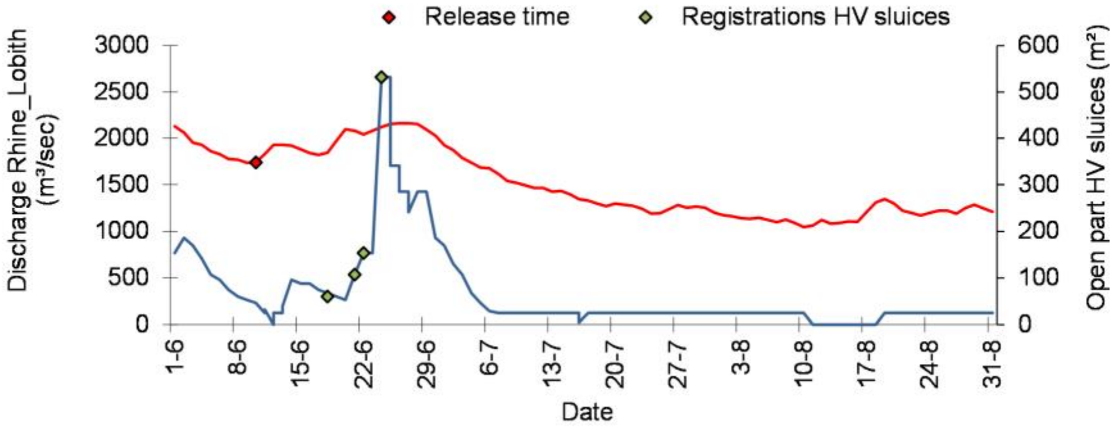


figure 3.5 *Discharge of the Rhine River (red line) and opening (m²) (blue line) of the Haringvliet discharge sluices in the period of 1st of June till 31st of August (Source: RWS Operationele bedieningsstaat Haringvliet dam June-August 2015).*

The sturgeons were released at a river discharge of 1 750 m³/ sec with a mean discharge in the first week (10th-16th of June) of 1 868 m³/ sec (figure 3.5). Between the 23rd of June and the 2nd of July, the opening of the Haringvliet sluices was not in correspondence with the normal management of the sluices, which is based on the discharge of Rhine River. In this period the dam was opened further than usually for unknown reasons. In the first week after the release of the sturgeons (10th-16th June) the average opening of the discharge sluices of the Haringvliet dam was about 65 m². By then most of the sturgeons had reached the Y-junction of the Beneden Merwede and the Nieuwe Merwede. Of those, most sturgeons took the route through the Beneden Merwede. This is also in accordance with the low number of sturgeons that were detected at the Haringvliet dam (*n*=3). After the release of sturgeons in the second week (17th-23rd of June) the opening of the sluices was approximately 161 m². In addition, six registrations of three different sturgeons were recorded in the period of the 18th-23rd of June.

table 3.3 *Registration of sturgeons at the station in the Haringvliet dam and the discharge management of the dam.*

ID no.	Date/time registration sturgeon	Date/time dam opened	Duration open dam	Open part dam (sqm)	Time between registation and opening	Time between registation and closing
14344	22-6-2015 15:07	22-06-15 9:23	7:24:00	153	5:44	1:40
14346	18-6-2015 8:44	18-06-15 6:59	7:07:00	60	1:45	5:22
	18-6-2015 8:57	18-06-15 6:59	7:07:00	60	1:58	5:09
	18-6-2015 9:09	18-06-15 6:59	7:07:00	60	2:10	4:57
	20-6-2015 22:40	20-06-15 19:51	8:11:00	107	2:49	5:22
14396	23-6-2015 22:34	23-06-15 21:54	8:09:00	532	0:40	7:29

3.3.2 Water temperature

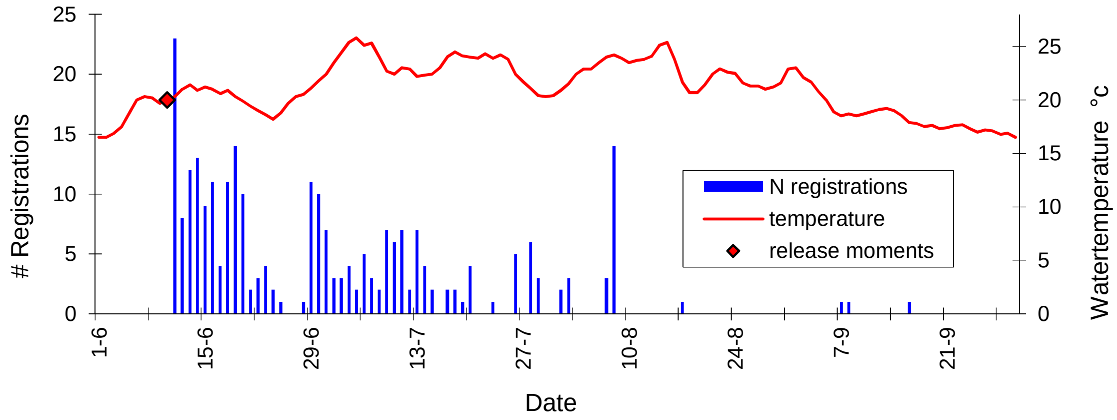


figure 3.6 *The number of registered sturgeons and the water temperature in de Rhine River near the town Spijk, in the period 1st of June till 31st of September 2015.*

There seems to be no connection between the water temperature and the number of sturgeons registered (figure 3.6). The data were not further analysed. During the release of the sturgeons the water temperature was around 18 ºC. A maximum of 23 º C was recorded at the beginning of July.

3.3.3 Tide

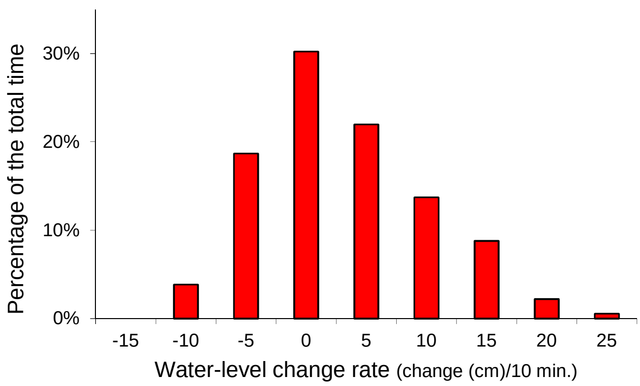


figure 3.7 *Classification of the 'water-level change rate;, during the research period 10th of June till 30th of September*

The majority of registrations were collected at the station Nieuwe Waterweg (69%). At this location the salinity of the water varies depending on the tide and the river discharge. Sturgeons probably use this area to adapt to the changing salinity.

Several sturgeons were registered only once (*n*=3) while others (*n*=16) were registered between two and 41 times. The duration between the first and the last registration of these individuals was 1-82 days, with an average of 22 days. The relationship between the water-level changes within this tidal area and the collected data on the activity of sturgeon was studied as follows.

The average difference between high-tide and low-tide in the area at the station Nieuwe Waterweg is 1.74 m. The tidal changes within the Nieuwe Waterweg were compared with the time-recordings of the sturgeons at detection station *"Nieuwe Waterweg_Europoort"*. The water level is monitored every 10 minutes at a measuring buoy (facilitated by Rijkswaterstaat) located a few kilometres downstream from the detection station. The delay is limited to a few minutes. With this information the '*water level change rate*' (*wlcr*) was calculated, defined as the change in water level within 10 minutes. All the *wlcr* data in the period between 10th of June and 31st of September 2015 was divided in 5 cm classes. This resulted in a bar graph (figure 3.7) representing the time during which a certain *wlcr* occurs. For example: in 22% of the time there is an incoming tide with a raise in water level of 5 cm per 10 minutes.

Per class the time duration (in %) was calculated. The most common *wlcr* occurs at a decrease in water level of -5 to 0 cm (during 34%of the time).

The *wlcr* was determined for all sturgeons within the area registered at the station in the Nieuwe Waterweg. The resulting *wlcr* data was classified in the same way as before and presented in figure 3.8.

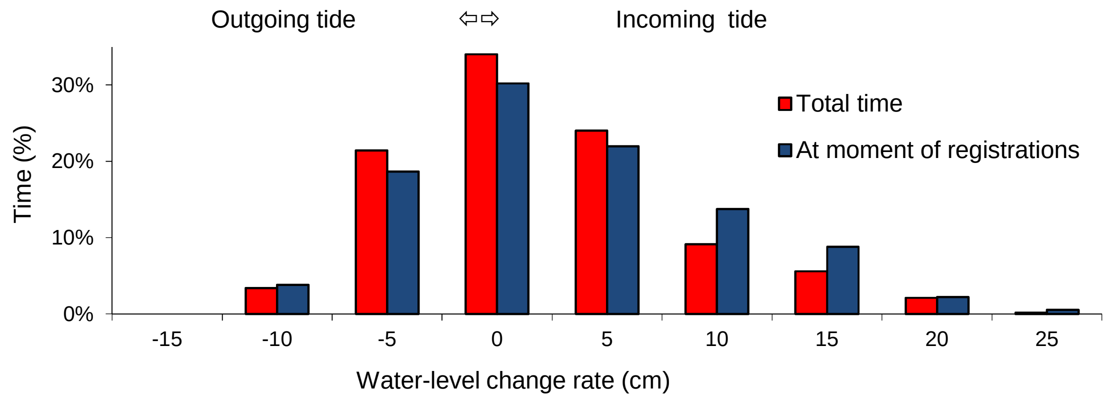


figure 3.8 *Red bars: Water-level-change–rate (wlcr) between 10^{th} of June and 31^{s} of September 2015. Blue bars: (wlcr) at the moments that sturgeons were detected.*

Based upon the outcomes of this exercise it seems that the sturgeons were more active during high-tide, *i.e.* incoming (rising) sea water. However, the differences are minor and on average the sturgeons were registered under all tidal circumstances.

In a second approach the detections of individual sturgeons were studied in more detail. Several sturgeons were often registered within a short period before or after the turn of the tide. *E.g.* the sturgeon with transponder no. 14368 shows that the registrations occur just around high-tide (figure 3.9 upper graph). This may have been a coincidence because of the limited number of registrations. In the second example the sturgeon with transponder no. 14337 showed no preference in relation to tidal influences (figure 3.9 lower graph). The data from this sturgeon was collected during all phases between high- and low-tide.

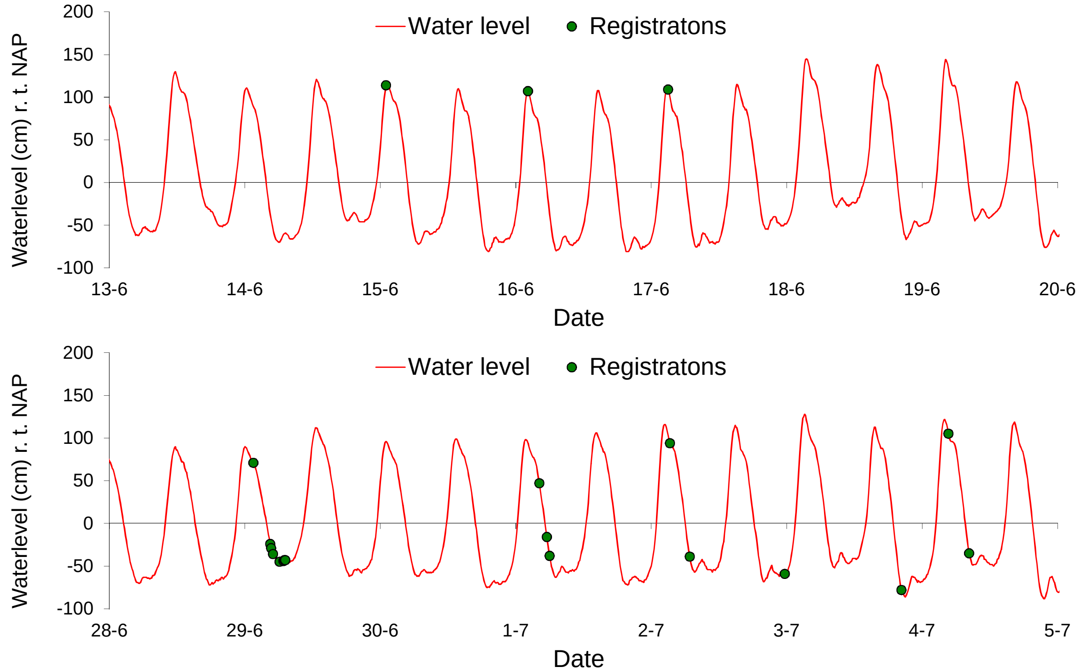
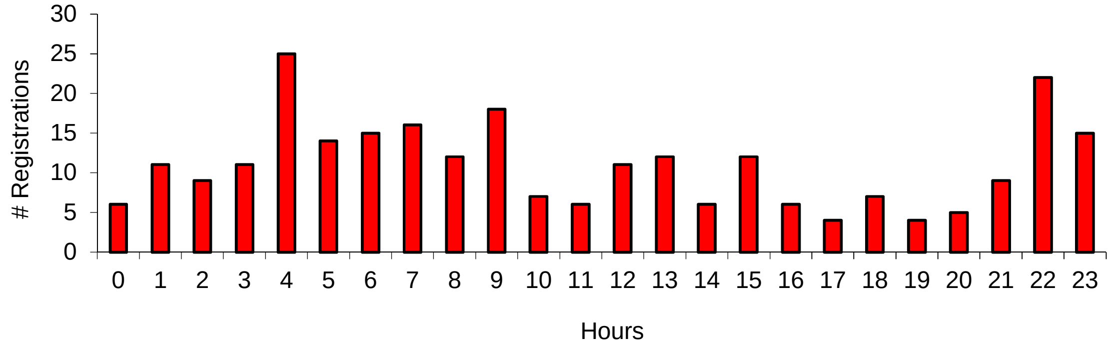


figure 3.9 *Upper graph: Tide and registrations of sturgeon no. 14368 in the Nieuwe Waterweg (11^{th} of June - 22^{nd} of June 2015). Lower graph: sturgeon no. 14337 (28^{th} of June – 5^{th} of July 2015).*

3.4 Registrations in time

3.4.1 Registrations during the day

About 60% of all registrations were collected in the period between sunrise and sunset (figure 3.10). On the registration days the average length of the day and night was approximately 16 and 8 hours, respectively. Adjusted for the length of the day sturgeons showed a slight preference for migration during the night.



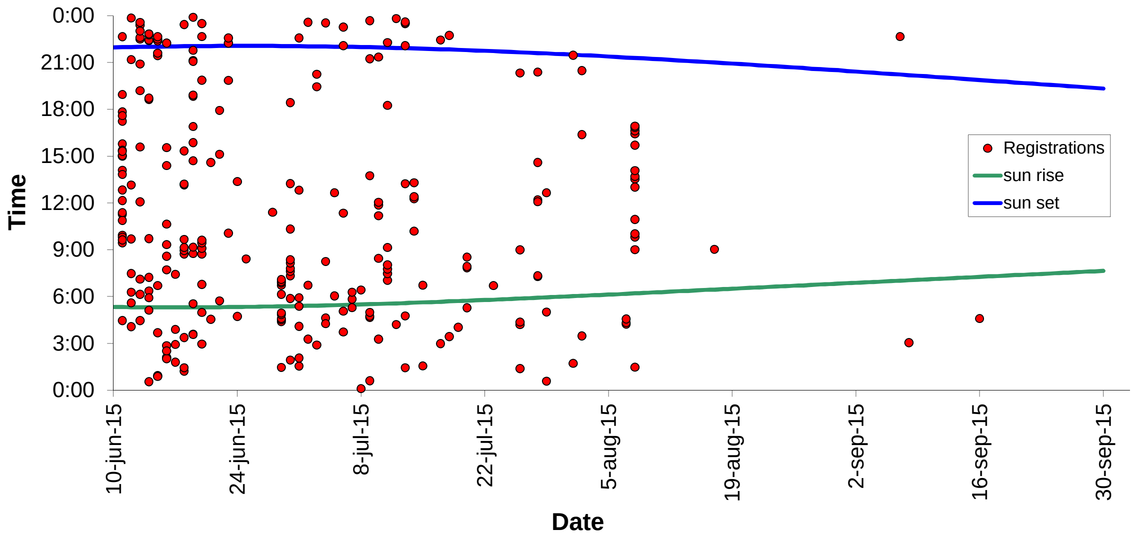


figure 3.10 Overview of registrations per hour (upper graph) and the registrations in relation to sunset and sunrise (lower graph).

3.4.2 Migration velocity and duration

<u>Release site to station Brakel</u>

To get an idea of the speed at which the sturgeons moved along the river, the duration between the moment of their release and their first registration at station "Waal_Brakel" (87.3 km) was calculated.

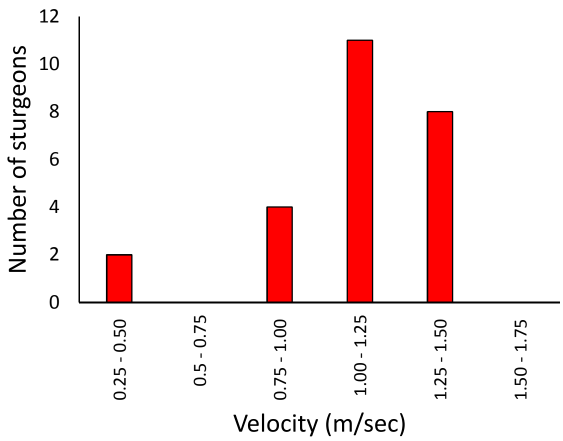


figure 3.11 *Migration velocity of sturgeons (n=25) at the section of the Waal between the release location near Kekerdom and the detection station near Brakel.*

The individual velocity (swimming- + water velocity) of the registered sturgeons was classified into six groups(figure 3.11). The average migration of the sturgeons in this river-section was 1.1 m/s (96 km/day). The fastest sturgeon moved approximately 1.5 m/s (127 km/day). There is no data of water-velocity available but the velocity within this river-trajectory was roughly estimated to be around 1 m/s (pers. comment André Breukelaar). This would suggest that the sturgeons drift with the river flow and only display minimal swim movement in the downstream direction. Possibly the sturgeons positioned themselves oblique, or even backwards to the current.

Release site to North Sea

The distance from the release location to the Haringvlietdam is 171 km and to the detection station in the Nieuwe Waterweg 167 km. The detection in the Nieuwe Waterweg is located in the brackish zone, while the station at the Haringvlietdam is located at the upstream site of the dam where the water is permanently fresh. The sturgeons reached the Nieuwe Waterweg via multiple routes with different distances. The migration time to the Nieuwe Waterweg ranged between 3 - 52 days, with an average of 13 days (figure 3.12). Most sturgeons passed the station in the Nieuwe Waterweg within fourteen days after their release. The migration time from the release site to the Haringvliet sluices ranged between 8 - 13 days, with an average of 11 days.

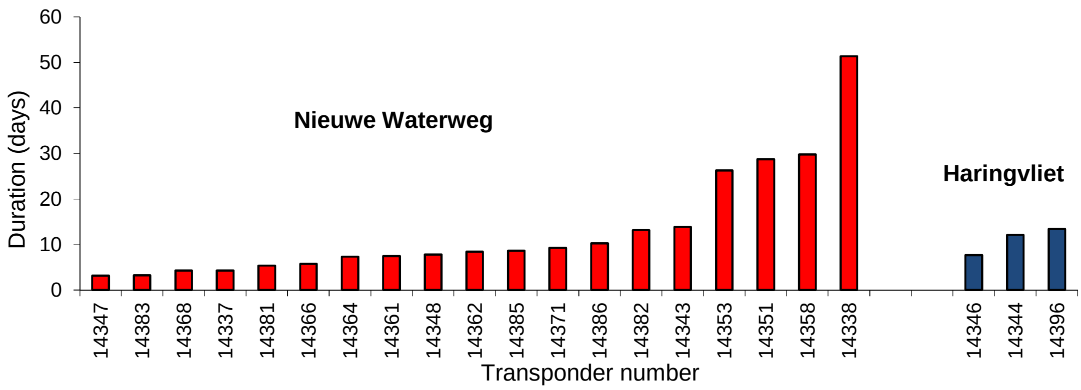


figure 3.12 *Migration duration between the moment of release and the first registration (a) at the Nieuwe Waterweg near Europoort and (b) at the Haringvliet sluices.*

4 Discussion

4.1 Study 2015

4.1.1 Tracking system

Transponders

On the 9th of June all implanted transponders (PIT and NEDAP) were checked with a handheld and mobile detection station. All PIT tags responded. Nine NEDAP transponders failed to respond to the signal of the detection station. There are two possible explanations for this.

1. There is always a possibility that sturgeons could lose their transponder during the period between marking on the 29th of April and the check on the 9th of June, just as happened with one of the sturgeons during the transport to the Netherlands. When stiches are placed too loose, the transponders can get out. However, there is no reason to believe that more sturgeons than the one mentioned had lost their transponder. The accommodation in France, the transportation tanks and the storage facility in the Kaliwaal were thoroughly checked and no transponders were retrieved from any of these locations. In addition the wounds of the sturgeons with no responding transponders were checked and photographed. All wounds were still holding 4-6 stiches and wounds were closed. Thus any further loss of transponders seems improbable.
2. Therefore the most obvious explanation for no detection of a transponder in nine sturgeons is that the transponder was malfunctioning (or the battery was empty) on the 9th of June. Nevertheless, all transponder had been double checked at the NEDAP factory before delivery.
   The most likely explanation is that the malfunction occurred between the delivery and the final check on the 9th of June. It is possible that the transponders were unintentionally activated during transport or surgical implantation and have been emitting signals permanently, which can certainly result in an empty battery. Activation of a NEDAP transponder can occur when a device is sending a signal that is similar to the NEDAP frequency (33,25 kHz). There is no reason to assume that the NEDAP signal was compromised after the transponder had been incorporated in tissue.

Detection stations

Several transponders were not detected at certain NEDAP detection stations, while they did pop-up at a more downstream detection station. There are two explanations that may account for an *ad hoc* recording of the tagged sturgeons;

1. Sturgeons might have passed the detection cable sideways. It is reported by the manufacturer that the response of the transponder may fail in case it is not perpendicular to the detection cables. This could be the case when a sturgeon drifts along the river flow and positons itself oblique in the current.
2. The detection station was temporarily offline or showed somehow a lesser detection range for a period of time (see also §3.1.1).

Misdetections at several stations

1. Backtracking all detections it can be concluded that 19% of the sturgeons which must have passed station “Waal_Brakel” were not registered at this station. Nevertheless according to Rijkswaterstaat, this station was fully functional during the study period. This makes the assumption 1 (above) more plausible, probably the sturgeon must have passed the antenna cables of this station in an oblique position.
2. Station Beneden Merwede performed quite poor due to problems with the antenna, the cables where move aside the river bed. Based on tracking data of more downstream located detection stations, it seems that most sturgeons could have passed this station un-detected.
3. Of all stations the station in the Hartelkanaal is positioned at the closest range towards the North Sea. This station had been offline for nearly two weeks (between 4 - 17 August) but based on the

detections of other upstream located stations it's unlikely that sturgeons passed the Hartelkanaal station during the period when it was offline.

4. Of the station in the Oude Maas two cables were in operational status, instead of three. Nevertheless, based on the collected data from the sturgeons it seems that it must have operated quite well.
5. The station in the IJssel had been offline after the 14 th of July. Based on the fast swimming speed of the sturgeons, it seems unlikely that sturgeons passed this station in the period when it was offline.

4.1.2 Outmigration

It is estimated that 52 - 70% of the released sturgeons made it into the North Sea. The minimum number is estimated to be 23 (out of 44). However many aspects have to be taken into account. Even the minimal percentage of 52% of the sturgeon that reached the Sea is quite high as compared to the Gironde population which use the estuary for several years. In the Rhine Delta, the condition are probably more suitable on the coast (food and habitat). The upper limit of 70% is based upon the following considerations (expert judgement) and open to discussion.

- The sturgeon could have moved upstream from the release site to the detection station in the Rhine River near Xanten (Germany). But no sturgeons were detected in the upstream direction. Thus it seems that all sturgeons attempted to migrate downstream.
- It can not be excluded that sturgeons stayed between the release location and the first detection station, waiting for another moment to move downstream. However, the measured average movement speed of the sturgeons in the Waal was relatively high (96 km/day) and there were only minor differences in velocity between all detected individuals. Almost all detected sturgeons passed the station near Brakel on the 11th of June, thus within one day after their release near Spijk. Therefore, it seems highly unlikely that several sturgeons stayed upstream of Brakel. They could also have moved unseen into the Pannerdensch kanaal and the IJssel river but in that case they should have been detected on the station in the IJssel near Kampen of at the Afsluitdijk on their way into the Wadden Sea. Thus, after three quarters of a year without any further detections in the Lower Rhine River system it seems unlikely that there are still sturgeons between the release location and the first detection station.

4.1.3 Sturgeons found dead

In addition to the above, the sturgeons that were not detected could also be dead. This is to a certain extend confirmed with two dead sturgeons found on the banks of the Waal river.
It is of importance to this present study to consider the reasons that sturgeons might not reach the sea. For two sturgeons it is obvious why they did not. They were mutilated and found dead on the river bank. One sturgeons had probably been dead for several days and was almost decapitated. The other sturgeon had a broken tail, a broken dorsal spine, and a sharp but shallow cut at the beginning of the belly. Based upon the visible sharp cuts that were seen in the bodies of those two sturgeons it might be that they were hit by a ship propeller. Because these sturgeons were found shortly after their release, it is supposed that they did not die due by natural causes, although this can not be excluded. It is plausible that both sturgeons were killed by a ship collision or propeller. Brown and Murphy (2010) observed decapitated and severely damaged sturgeons on the Delaware river banks. In the estuary of the Delaware River, which flows on the border of the U.S. state of New Jersey 28 dead sturgeons *(Acipenser oxyrinchus)* were found between 2005 and 2008. For 50% of these sturgeons it could be established that these were slain by propellers. The other sturgeons were so badly damaged that the cause of death could not be determined. Of all sturgeons that were slain by propellers, 71% were cut in two near the torso or the head. De Rhine Delta is intensively navigated. Given the findings in the Delaware River it is not inconceivable that the other sturgeons in the Rhine River that were not detected could also have been killed by ships.

4.1.4 Recaptures

All locations of reported recaptures were scattered along the Dutch coast. The first sturgeon was recaptured in the North Sea near Katwijk, 17 days after the release in the Rhine River. A second sturgeon was recaptured in the North Sea near Kijkduin, nine days after the last registration at the station in the Nieuwe Waterweg. The third sturgeon was reported in the North Sea near Goederee, 16 days after the last registration at the station in the Nieuwe Waterweg and 85 days after the release. In December a fourth sturgeon was recaptured in the Oosterschelde by an angler, 190 days after the last registration at the station in the Noord and 192 days after the release.

4.1.5 Haringvliet dam as migration barrier

Three sturgeons were registered at the station in the Haringvliet dam. Two of these were registered only once. One sturgeon was registered three times between the 20th and 23rd of June, when the dam was partly opened. This sturgeon wandered (and had been delayed for a minimal of five days) since it was also registered on the 16th of June in the Spui after which it returned to the Haringvliet on the same day. In a situation with a Rhine River discharge at Lobith (close to Spijk) of over 1 100 m^3/s the Haringvliet dam opens up for at least 25 m^2 per low-tide period. Within this period, the sturgeons could have passed this location and swam into the North Sea. The sturgeons could also use one of the six fish sluices in the dam. These are in continuous operation between February and May and for the rest of the year only during the low-tide periods.

Due to the management of the Haringvliet discharge sluices the transition from salt to fresh water in the area depends upon the location of the sluices that are opened up. Lake Haringvliet contains permanently fresh water. However, the water just outside the Haringvliet dam shows varying circumstances of brackish, fresh and salt water, depending on the river water flowing through the discharge sluices. Only at a high discharge there is a gradient from fresh to salt water at the seaside of the Haringvliet dam. A zone with fresh water will occur seaward-behind the Haringvliet dam (Van Vessem, 1998). And this might help the sturgeon to get used to the saltier water.

At low river discharges (to approximately 2 000 m^3/s) there will be no fresh/salt gradient in the estuary (Lake Haringvliet). During these discharges the entire area outside the dam comprises a euhalinicum (saline zone 17 ppt) which occurs for approximately 50% of the year (Paalvast *et al*., 1998). The salinity of the water near the bottom on the inside and the outside of the dam differs by about 30 ‰. Sturgeons of 4-5 years can tolerate a difference in salinity ranging from 15 to 31 ‰ and can endure a surge of 10.5 ‰ per day (Taverny *et al.*, 2002).
In relation to this salt/fresh water transition it might be that younger sturgeons than the sturgeons used (approximately 1-3 years) would experience problems when they would reach the North Sea trough the Haringvliet dam at low river discharges. Whereas individuals of seven years or older could more easily adapt when they swim from freshwater into salt water or vice versa (Magnin, 1962).

4.1.6 Growing and foraging habitat

One of the objectives of this present study was to gain insight into a possible foraging habitat for sturgeon (*A. sturio)* in the Lower Rhine River system. In this context it is important to state that four-year old sturgeons were used. After their release most sturgeons migrated in a relatively short time span (about 3 weeks) towards the North Sea. Based on the recapture reports from the North Sea in 2015 it seems that sturgeons of this age do forage along the North Sea coast and in the tidal zone of the Nieuwe Waterweg (figure 3.2).

The battery duration of the transponders used is at least four years under normal circumstances. This implies that the sturgeons could be registered again in the upcoming years at detection stations situated at river outlets such as the Haringvliet, Nieuwe Waterweg or IJsselmeer. Future registrations may give more insight about the foraging behaviour of the sturgeons.

At present, several natural transitions between fresh and salt water exist in the Lower Rhine River system, namely in the Nieuwe Waterweg, the Hartelkanaal and the surrounding waters within the Port of Rotterdam. In the future the Haringvliet dam will also be opened at high-tides (in +/- 70% of these situations). It is suggested that this will provide better opportunities for sturgeon in the Netherlands to migrate between fresh and salt water. Traditionally Lake Haringvliet was the main estuary of the Rhine and Meuse rivers, and was used by sturgeon and other migratory fish (Winden et al, 2000). It must be noted that there are also plans for the construction of a fish passage at the Afsluitdijk to open up a migration route between Lake IJssel and the Waddenzee.

4.2 Comparison between migration in 2012 and 2015

The tracking technique used in 2012 and 2015 and the number and age of the sturgeons were identical. The tracking results were quite similar, although several slight differences in migration patterns could be observed and these results are highlighted in this paragraph.

4.2.1 Method and release strategy

In May 2012, 13 sturgeons were released in the Waal near Kekerdom (table 4.1). In June 2012, another 30 sturgeons were released at the same location. In comparison to 2012, in 2015 the 44 sturgeons were released more upstream (15 km) in the Rhine River near Spijk at the German border. A release at this site enabled a test to see whether or not the sturgeons would take the opportunity to migrate via the Pannerdensch kanaal. From this Y-junction the water flows towards the Nederrijn- Lek (another route leading to the Nieuwe Waterweg) and via the IJssel river that leads to the Waddenzee by the passing the Ketelmeer, IJsselmeer and the Afsluitdijk (figure 2.2). Because no sturgeons were detected at stations situated within the Nederrijn- Lek, Ijssel or at the Afsluitdijk, it became clear that the sturgeons preferred the route through the Waal, following the main river discharge. This is remarkable because approximately 1/3 of the Rhine discharge flows through the Pannerdensch Kanaal.

From literature (Williot et al. 1997) it is known that sturgeons can migrate to the Sea at an age of about two years. In 2012 the sturgeons were three and five years old (76 ± 4.4 cm total length, 1 656 ± 258 gram) and in 2015 four years old (80.9 ± 10.2 cm total length, 2 394 ± 907 gram). Both cohorts used in 2012 showed no significant difference between the movement velocities (1,23 and 1,24 m/s). In addition, the percentage of sturgeons that reached the North Sea in 2012 also didn't differ significantly between both cohorts (46 and 48%) Therefore it is suggested that the results from 2012 can be compared with those from 2015.

4.2.2 Registrations and deducted migration routes

To estimate the differences in migration route between 2012 and 2015 registrations of the groups that were released in Kekerdom (2012, *n*=43) and Spijk (2015, *n*=44), are compared. Some sturgeons passed the detection stations Brakel (2012/2015) and Sliedrecht (2015) unseen. Several sturgeons were nevertheless detected or found dead further downstream.

The number of sturgeons that passed stations Brakel in 2012 and 2015 was comparable: *n*=29 and *n*=31, respectively. In addition, the number of sturgeons that were registered at the detection station in the Nieuwe Waterweg was slightly more in 2015 than in 2012: *n*=19 and 16, respectively. Remarkably, the registrations collected at this station showed a big difference between both years: *n*=1 171 in 2012 and *n*=182 in 2015 (table 4.1). This could be related to the differences in river discharge and the influence of the position of the zone between fresh and salt water. In 2015, the average river discharge in the first week after the release was quite low (1 868 m^3/sec), compared to 2012 (2 221 m^3/sec).

table 4.1 *Comparison of registrations between 2012 and 2015.*
** = number of sturgeons that must have passed this station as well, these numbers were deduced by back-tracking other registrations of the same individuals at NEDAP stations located further downstream.*

Release site→	Kekerdom May/June 2012 (*n*=43)		Spijk June 2015 (*n*=44)	
Name station	***n(*)* sturgeons**	***n* registrations**	***n(*)* sturgeons**	***n* registrations**
Waal_Brakel	20 (29)	20	25 (31)*	34
Beneden Merwede_Sliedrecht	2	2	2 (18)	10
Dordtsche Kil_s'Gravendeel	8	8	5	6
Noord_Kinderdijk	1	1	4	5
Spui_Zuidland	-	-	1	2
Oude Maas_Spijkenisse	9	13	14	18
Hartelkanaal_Europoort	2	4	-	-
Nieuwe Waterweg_Europoort	16	1171	19	182
Haringvlietdam	-	-	3	6
Total	**26 (29)**	**1242**	**31**	**263**

There is a difference between detections at the Haringvliet dam station, which can be explained by technical problems of the station in 2012.
In 2015, the percentage of sturgeons that reached the North Sea (52%), was slightly higher than in 2012 (44%) (table 4.2).

table 4.2 *Comparison of route and number of sturgeons that reached the North Sea.*

Release site→	Kekerdom May/June 2012 (*n*=43)	Spijk June 2015 (*n*=44)
Name Station	***n* sturgeons**	***n* sturgeons**
Hartelkanaal_Europoort	1	0
Nieuwe Waterweg_Europoort	15	19
Haringvliet	0*	3
Unknown (recaptures North Sea)	3	1
Reached North Sea	19 (44%)	23 (52%)

The migration routes taken by the sturgeons in 2012 and 2015 were different. In 2012 the sturgeons preferred the route through the Nieuwe Merwede and Dordtsche Kil above the route through the Beneden Merwede. In 2015 this was reverse. Possibly the opening of the Haringvliet dam in 2012 could be the main reason for this. Because the management of the Haringvliet dam is intended to redirect the distribution of the discharge in Rhine delta. With a larger opening of the dam more water flows through the Haringvliet and Hollandsch Diep towards the North Sea.

4.2.3 Reported recaptures

In 2012 six tagged sturgeons was reported by beam trawl fisher (shrimpers) from different locations: from the North Sea (*n*=4) and the Wadden Sea (*n*=2). This is 13% of all released sturgeons and 27% of the sturgeons that were registered to reach the North Sea. In 2015, three tagged sturgeons were reported by commercial fisheries from the North Sea. This is 7% of all released sturgeons and 13% of the sturgeons that reached the North Sea. Two of those were caught with gill nets and one by beam trawl fisheries.
The Dutch coast is intensively fished (Winter et al., 2015) which supposedly hampers *A. sturio* rehabilitation. Since September 2012 the by catch in beam trawl fisheries is most likely reduced by

the obligatory appliance of a sieve net. This net allows for most fish other than shrimps to be released under water (*e.g.* Polet et al., 2004; Revill and Holst, 2004). In 2012, five out of six recaptures were collected when no sieve nets were installed. Because only one recapture was reported in 2015 by a shrimper it seems that sieve nets are functional. However, with these low numbers of sturgeon entering the North Sea this can not be confirmed within the present study.;

5 Conclusions and recommendations

5.1 Conclusions

Related to objective 1: **Are European Sturgeon (*A. sturio*) able to migrate downstream and/ or upstream along the Rhine River and where they encounter migration barriers (such as hydropower stations, dams, weirs and sluices)?**

- Of all 44 tagged sturgeons, 33 (75%) were observed or reported back. It is unclear what happened to the other 11 sturgeons (25%). This could be a representation of mortality, although this can not be confirmed.
- All registered sturgeons migrated downstream and after 9,5 kilometres they reached the Y-junction at the Pannerdensch kanaal. Because no detections were collected at the stations in the Nederrijn, IJssel and Afsluitdijk it is probable that all sturgeons followed the route through the Waal.
- The majority of sturgeons utilized the route through the Beneden Merwede, (instead of another possibility leading the sturgeons through the Nieuwe Merwede.
- Three sturgeons were registered at the detection station in the Haringvliet dam. Two of these passed the dam immediately after their arrival, whereas a third sturgeon was delayed for at least five days.

Related to objective 2: **Can they reach (escape into) the North Sea?**

- In total, 23 of the 44 (52%) sturgeons reached the North Sea. Three did so by passing the Haringvliet dam and 19 choose the route through the Nieuwe Waterweg. The route of one sturgeon is unknown, but the sturgeon was detected in the Noord and probably must have reached the North Sea through the Nieuwe Waterweg as well.
- It can not be excluded that more sturgeons reached the North Sea unseen. This hypothesis is supported by the fact that several sturgeons were missed on one or more detection stations.
- Two sturgeons were found dead at the Waal near Ewijk and the Boven Merwede near Werkendam, 36 and 102 km respectively downstream from the release location. Both were severely damaged, plausibly as a result of a hit by a ships propeller. This kind of damage has been reported in other studies, *e.g.* in the Rhine and Delaware rivers. It can not be excluded that other sturgeons died as well.
- It seems unclear to what happened with the 11 sturgeons that were never registered. In addition it is unclear whether or not the 10 sturgeons that were detected at NEDAP stations but not at the Haringvliet dam or the Nieuwe Waterweg. They might not have reached the North Sea as well. The differences in migration movement between individuals were quite small. Because nearly all sturgeons passed the detection station Brakel on the 11th of June, one day after their release at the German border it seems unlikely that sturgeons swam upstream.

Related to objective 3: **What is their preferred migration route?**

- The sturgeons migrated mainly through the route: Rhine ⇨ Waal ⇨ Beneden Merwede ⇨ Oude Maas ⇨ Nieuwe Waterweg.

Related to objective 4: **What is the daily and migratory behaviour in the Rhine system?**

- Adjusted for the length of the day sturgeons showed a slight preference for migration during the night.
- The average movement speed (own swimming speed + speed river flow) of the sturgeons in the river section between the release site and station Brakel was 1.11 m/s (96 km/day). Here the fastest sturgeon moved 1.47 m/s (127 km/day).
- The migration time from the release site to the Nieuwe Waterweg ranged from 3.2 to 52 days. Most sturgeons passed the station in the Nieuwe Waterweg within fourteen days after their release. The migration time from the release site to the Haringvliet sluices ranged from 7.7 to 13 days.
- Four sturgeons were recaptured and reported to Sportvisserij Nederland. This is 8% of all released sturgeons and 17% of the sturgeons that reached the North Sea. Three sturgeons were recaptured in the North Sea by commercial fishermen and one was caught by an angler in the Oosterschelde. All sturgeons were released alive again.
- None of the released sturgeons were registered in the upstream region of the release site. Given the speed and uniformity with which the sturgeons migrated in the downstream direction it seems unlikely that many (if any) sturgeons migrated (temporarily) upstream after their release.

Related to objective 5: **Do they use the Lower Rhine River over extended periods of time? And if so, what are the specific conditions under which this takes place?**

- Most (69%) registrations have been received at the station Nieuwe Waterweg. This is a major channel within the Port of Rotterdam and a location where the water is salt or brackish, depending upon the tide and river discharge. Here the sturgeons could have spent some time to acclimatize.
- It is suggested that the sturgeons would show stronger movements during incoming (rising) tide. However, the differences are minor and on average the registrations took place under all tidal circumstances.

Related to: **The comparison between the results of 2012 and 2015.**

- The results were quite similar, although several slight differences in migration patterns could be observed.
- The migration routes taken by the sturgeons in 2012 and 2015 showed several differences. In 2012 the sturgeons strongly preferred the route through the Nieuwe Merwede and Dordtsche Kil above the route through the Beneden Merwede. In 2015 reversed slight alteration was noted with three sturgeons utilizing the Haringvliet. The main difference between the two pathways is thought to be due by a difference in opening of the Haringvliet dam, in 2015 the Haringvliet dam was only opened by a minimum of 25 m^2.
- The percentage of sturgeons that reached the North Sea in 2015 (52%), was slightly higher than in 2012 (44%).
- There was a difference between the number of recaptures in 2012 and 2015. In 2012 the capture of six tagged sturgeons was reported by commercial fishermen in the North Sea (*n*=4) and the Wadden Sea (*n*=2). This is 13% of all released sturgeons and 27% of the sturgeons that reached the North Sea. These sturgeons were captured and reported by beam trawl fisheries. In 2015, three tagged sturgeons (6%) were reported by commercial fishermen from the North Sea and one sturgeon (2%) was reported by an angler.
- In 2012, five out of six recaptures were collected when no sieve nets were installed. It might be that sieve nets are functional; but because these are at present permanently installed and numbers of sturgeons used are low there is no possibility to compare by-catch between 2012 and 2015.

5.2 Recommendations

- The battery-life of the transponders is guaranteed for at least 4 years by normal use. There is a possibility, until 2018, that the NEDAP TRAIL system® picks up more detections when sturgeons might enter the Dutch Delta. It is recommended to analyse the detections and back reports of sturgeons that were released in 2012 and 2015 again in the autumn of 2016. For now it's unclear if any detections has been recorded.
- It is recommended to build an additional detection station in the upstream part of the Waal, just downstream of the Y-junction where the Rhine divide in the Pannerdensch kanaal and Waal. The first downstream detection station from the release site was located at 87 km. Therefore it is unclear what happened with the sturgeons in this (quite long) river-stretch.
- It is recommended to check with a mobile NEDAP station for possible signals that can activate transponders at the IRSTEA experimentation station in France.
- It is recommended to further study the survival of sturgeon in the North Sea because the percentage of catch reports by commercial fisheries in this study is quite high (6%).
- It is recommended to improve any communication towards sport- and commercial fisheries about the work on rehabilitation of the European sturgeon. E.g. it should be known amongst fishers that there is a reward of 100 euro per recapture. This could help to obtain more recapture reports of tagged sturgeon and other tagged fish.
- According to Winter *et al.* (2015) the available habitat in the Netherlands for two and three year old sturgeons is rather limited[1]. It is therefore suggested to additional study the survival, behavior and dispersion of these younger sturgeons in the Lower Rhine River system to estimate how well these juvenile sturgeon are able to adapt to the downstream freshwater sections of the Lower Rhine River system and more marine habitats within the Dutch Delta.

[1] *"If juvenile European sturgeons need brackish estuarine habitats during part of their life-cycle, e.g. during their 2nd and 3rd year as the Gironde data suggest, then the lack of estuarine and brackish habitats in the lower sections of the Rhine basin are important bottlenecks for especially juvenile sturgeons. Foreseen future scenarios in the Haringvliet are most probably insufficient to lower this population bottleneck. However, if juvenile European sturgeons are more flexible in selecting either marine habitats at an earlier stage already after the first growing season as preliminary results from the Elbe suggest or if they can remain feeding in the downstream sections of the freshwater systems in the lower Rhine, e.g. the large freshwater lakes Haringvliet, Hollands Diep and IJsselmeer then the scarcity of brackish estuarine habitats in the future Rhine system proves to be less restrictive for a successful reintroduction of European sturgeon in the Rhine basin" (from Winter et al. 2015)*

6 References

Acolas, M. L., E. Rochard, C. Pichon & E. Rouleau (2012). "Downstream migration patterns of one-year-old hatchery-reared European sturgeon (Acipenser sturio)." J Exp Mar Biol Ecol 430–431.

Brown J. & G.W. Murphy (2010). Atlantic Sturgeon Vessel-Strike mortalities in the Delaware Estuary, Fisheries, p. 72-83.

Buijse T. & Cazemier W. (1998) Fischbestandserhebungen im Rhein im Rahmen des landesweiten Ökosystem-Monitorprogramms. LÖBF- Mitt 23:47–56

Debus L. (1996) The decline of the European sturgeon Acipenser sturio in the Baltic and North Sea. In: Kirchhofer A, Hefti D (eds) Advances in life sciences: conservation of endangered freshwater fish in Europe (July, 1994. Bern, Switzerland). Birkhaeuser Verlag, Basel- New York, pp 147–156, XII + 341 pp.

Gessner, J., M. Tauteman, H. Von Nordheim & T. Borchers (2010). Plan national d'actions pour la protection et la conservation de l'Esturgeon eupéen (Acipenser sturio) en Allemagne. Ministère fédéral de l'environnement de la protection de la nature et de la sureté nucléaire. 83p.

Jakob E. (1996). Das Potential des Unteren Niederrheins als Laich- und Bruthabitat des europäischen Stör Acipenser sturio. LÖBF (Landesanstalt für Ökologie, Bodenverordnung und Forsten Nordrhein Westfalen). Kirchhundem, Duitsland

Ludwig A., P. Williot, F.Kirschbaum & D. Lieckfeldt (2004). Genetic variability of the Gironde population of Acipenser sturio. Institute for Zoo and Wildlife Research, Leibniz-Institute of Freshwater Ecology and Inland Fisheries, Cemagref, Inland Living Aquatic Resource**.**

Magnin, E. (1962). Recherches sur la systématique et la biologie des acipenséridés: Acipenser sturio L., Acipenser oxyrinchus Mitchell et Acipenser fulvescens Raf. Parijs: Station Centrale d'Hydrobiologie Appliquée.

Ministère de l'écologie du développement durable des transports et du logement (2011). Plan national d'actions en faveur de l'esturgeon européen Acipenser sturio 2011-2015: 69p.

Paalvast, P., W. Iedema, M. Ohm & R. Posthoorn (1998). MER beheer Haringvlietsluizen. Over de grens van zoet en zout. RIZA rapport 98.051.

Polet, H., J. Coenjaerts & R. Verschoore, (2004). Evaluation of the sieve net as a selectivity-improving device in the Belgian brown shrimp (Crangon crangon) fishery. Fisheries research, 69(1), 35-48.

Quak, J. (2016, in prep.). Van Aal tot Zalm tussen zoet en zout. Een beschouwing over de visstand in Haringvliet, Hollands Diep en Goereesche Gat tussen 1870-1970**.** Sportvisserij Nederland**.** Concept 01 9 februari 2016**.**

Raat A.J. (2001) Ecological rehabilitation of the Dutch part of the River Rhine with special attention to the fish. Regul Rivers Res Manag 17(2):131–144

Reeze A.J.G, A.D. Buijse, W.M. Liefveld & R. Postma (2005) Weet wat er leeft langs Rijn en Maas: ecologische toestand van de grote rivieren in Europees perspectief. Ministerie van Verkeer en Waterstaat, Rijkswaterstaat

Revill, A., & R. Holst (2004). The selective properties of some sieve nets. Fisheries Research, 66(2), 171-183.

RWS. (2015). Operationele bedieningsstaat Haringvlietsluizen, juni-augustus 2015.

Taverny, C., M. Lepage, S. Piefort, P. Dumont, & E. Rochard (2002). Habitat selection by juvenile European sturgeon Acipenser sturio in de Gironde estuary (France). Journal of Applied Ichthyology 18, 536-541.

Vaate, A. bij de & A.W. Breukelaar (2001). De migratie van zeeforel in Nederland. Rijksinstituut voor Integraal Zoetwaterbeheer & Afvalwaterbehandeling, rapport nr. 2001.046. ISBN 9036954037.

Van der Veen C. (1981). Facts and figures on Rhine pollution. Int'l Bus Law 9:41

Vessem, P. van (1998). Morfologie monding Haringvliet. MER beheer Haringvlietsluizen. Rapport RIKZ-98.016.

Vis H. & Q.A.A. de Bruijn (2012). Migration behaviour and habitat preference of the Atlantic Sturgeon (Acipenser sturio) in the Rhine. VisAdvies BV, Nieuwegein. Project number VA2011_43, 34 pag.

Williot P, Rochard E, Castelnaud G, Rouault T, Brun R, Lepage M, Elie P. (1997). Biological characteristics of European Atlantic sturgeon, Acipenser sturio, as the basis for a restoration program in France. Environmental Biology of Fishes 48: 359-372.

Winden, A. van, W. Overmars, W. Bosman & A. Klink (2000). De Atlantische steur: Terugkeer in de Rijn. Wereld Natuur Fonds /Stichting ARK, Hoog Keppel (Nederland). ISBN 90-74647-49-9

Winter H.V., L.R. Teal, K.E. van de Wolfshaar, A.B. Griffioen, B. Houben & N.W.P. Brevé (2015). Desk-study on habitat quality for the European Sturgeon in the Dutch Rhine and southern North Sea. IMARES Wageningen UR. Report number C044/15.

Attachments

Annex 1 Fish data

#	Pit tag number	NEDAP number	WOT number	year of birth	Tagging date transponder	Release date NL	Release location	Total length at tagging 28-29 April (cm)	Weight at tagging 28-29 April (gr.)
1	3420362	14337	8082	2011	28/29th April	10-06-15	Spijk	70	1410
2	3422962	14338	8055	2011	28/29th April	10-06-15	Spijk	79	2640
3	3422991	14340	8097	2011	28/29th April	10-06-15	Spijk	82	2560
4	3423304	14341	8079	2011	28/29th April	10-06-15	Spijk	75	1650
5	3419991	14342	8075	2011	28/29th April	10-06-15	Spijk	83	2430
6	3420115	14343	8072	2011	28/29th April	10-06-15	Spijk	64	1100
7	3423197	14344	8060	2011	28/29th April	10-06-15	Spijk	93	3400
8	3421282	14346	8048	2011	28/29th April	10-06-15	Spijk	69	1370
9	3419360	14347	8073	2011	28/29th April	10-06-15	Spijk	95	3740
10	3420064	14348	8014	2011	28/29th April	10-06-15	Spijk	73	1630
11	3419767	14350	8085	2011	28/29th April	10-06-15	Spijk	69	1150
12	3422950	14351	8069	2011	28/29th April	10-06-15	Spijk	86	2810
13	3423144	14352	8095	2011	28/29th April	10-06-15	Spijk	85	2300
14	3419683	14353	8083	2011	28/29th April	10-06-15	Spijk	67	1300
15	3420884	14354	8057	2011	28/29th April	10-06-15	Spijk	88	2960
16	3420230	14355	8078	2011	28/29th April	10-06-15	Spijk	62	1130
17	3420310	14356	8074	2011	28/29th April	10-06-15	Spijk	71	1660
18	3420131	14358	8061	2011	28/29th April	10-06-15	Spijk	76	1970
19	3419414	14359	8080	2011	28/29th April	10-06-15	Spijk	102	3900
20	3420523	14361	8087	2011	28/29th April	10-06-15	Spijk	68	1500
21	3420104	14362	8056	2011	28/29th April	10-06-15	Spijk	88	3420
22	3420338	14363	8071	2011	28/29th April	10-06-15	Spijk	93	3710
23	3422838	14364	8098	2011	28/29th April	10-06-15	Spijk	79	2330
24	3420336	14365	8058	2011	28/29th April	10-06-15	Spijk	83	2610
25	3422817	14366	8091	2011	28/29th April	10-06-15	Spijk	101	4100
26	3420714	14368	8063	2011	28/29th April	10-06-15	Spijk	76,5	1540
27	3423024	14369	8054	2011	28/29th April	10-06-15	Spijk	66	1230
28	3421095	14370	8049	2011	28/29th April	10-06-15	Spijk	87	2910
29	3419857	14371	8070	2011	28/29th April	10-06-15	Spijk	82	2200
30	3422830	14372	8100	2011	28/29th April	10-06-15	Spijk	84	2610
31	3419526	14374	8031	2011	28/29th April	10-06-15	Spijk	75	1770
32	3419681	14377	8084	2011	28/29th April	10-06-15	Spijk	92	3490
33	3421230	14379	8051	2011	28/29th April	10-06-15	Spijk	81	2260
34	3420047	14381	8099	2011	28/29th April	10-06-15	Spijk	80	2480
35	3420152	14382	8067	2011	28/29th April	10-06-15	Spijk	99	3830
36	3419559	14383	8089	2011	28/29th April	10-06-15	Spijk	75	1550
37	3420899	14384	8059	2011	28/29th April	10-06-15	Spijk	93	3800
38	3419410	14385	8066	2011	28/29th April	10-06-15	Spijk	92	3130
39	3420340	14386	8050	2011	28/29th April	10-06-15	Spijk	75	1830
40	3420545	14387	8053	2011	28/29th April	10-06-15	Spijk	73	1770
41	3423124	14392	8081	2011	28/29th April	10-06-15	Spijk	86	3150
42	3419831	14393	8090	2011	28/29th April	10-06-15	Spijk	101	4320
43	3420432	14395	8068	2011	28/29th April	10-06-15	Spijk	70	1630
44	3419789	14396	8062	2011	28/29th April	10-06-15	Spijk	80	2050
Sturgeons that were excluded from data-analysis, because of missing signal on 9th of June.									
#	**Pit tag number**	**NEDAP number**	**WOT number**	**year of birth**	**Tagging date transponder**	**Release date NL**	**Release location**	**Total length at tagging 28-29 April (cm)**	**Weight at tagging 28-29 April (gr.)**
45	3419573	14345	8065	2011	28/29th April	10-06-15	Spijk	79	2280
46	3423075	14349	8086	2011	28/29th April	10-06-15	Spijk	76	2010
47	3547363	14357	8093	2011	28/29th April	10-06-15	Spijk	73	2330
48	3421048	14360	8096	2011	28/29th April	10-06-15	Spijk	79	2000
49	3423190	14373	8077	2011	28/29th April	10-06-15	Spijk	75,5	1630
50	3420525	14375	8052	2011	28/29th April	10-06-15	Spijk	76	1720
51	3420767	14378	8088	2011	28/29th April	10-06-15	Spijk	86	2240
52	3420696	14388	8064	2011	28/29th April	10-06-15	Spijk	99	4410
53	3420644	14390	8092	2011	28/29th April	10-06-15	Spijk	74	1950

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