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# Outmigration pathways of stocked juvenile European sturgeon (*Acipenser sturio* L., 1758) in the Lower Rhine River, as revealed by telemetry

Niels W. P. Brevé<sup>1</sup>  | Hendry Vis<sup>2</sup> | Bram Houben<sup>3</sup> | André Breukelaar<sup>4</sup> | Marie-Laure Acolas<sup>5</sup>

<sup>1</sup>Koninklijke Sportvisserij Nederland, Bilthoven, Netherlands

<sup>2</sup>VisAdvies BV, Nieuwegein, Netherlands

<sup>3</sup>ARK Nature, Nijmegen, Netherlands

<sup>4</sup>Rijkswaterstaat (RWS), Rotterdam, Netherlands

<sup>5</sup>IRSTEA, National Research Institute of science and Technology for Environment and Agriculture, Gazinet-Cestas, France

## Correspondence

Niels W. P. Brevé, Koninklijke Sportvisserij Nederland, Bilthoven, Netherlands.  
Email: breve@sportvisserij nederland.nl

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## Abstract

Working towards a future Rhine Sturgeon Action Plan the outmigration pathways of stocked juvenile European sturgeon (*Acipenser sturio* L., 1758) were studied in the River Rhine in 2012 and 2015 using the NEDAP Trail system. A total of 87 sturgeon of 3 to 5 years old ( $n = 43$  in 2012,  $n = 44$  in 2015) were implanted with transponders and released in May and June in the river Rhine at the Dutch-German border, approximately 160 km from the sea. In total three sturgeons (3%) were found dead on river banks within seven days after the release. Based upon their wounds these sturgeons were likely hit by ship-propellers. Tracking results were obtained from 57 (66%) of the sturgeons, of which 39 (45%) indicated movement into the Port of Rotterdam. Here the sturgeons remained for an average of two weeks, which suggests they spent time to acclimatize to higher salinities before entering the North Sea. Of the 45 (52%) sturgeons that were confirmed to have entered the North Sea, ten (22%) were recaptured (mainly by shrimpers and gill-nets) close to the Dutch coastline; nine were alive and were released. From the results we obtained the preferred outmigration pathways, movement speeds and an indication of impacting factors (i.e. ship propellers and bycatch). Bycatches provided also localisations information in the coastal area. A next step to complete this work would be to assess habitat selection in freshwater and downstream migration of young of the year (YOY sturgeons) in the Lower Rhine.

## KEYWORDS

*Acipenser sturio*, Haringvlietdam, NEDAP Trail system™, North Sea, Port of Rotterdam

## 1 | INTRODUCTION

Around 1900 the European sturgeon (*Acipenser sturio* L. 1758) still spawned in all main European rivers (Holčík, 1989). However, at present the species faces a high risk of extinction according to the IUCN (Gessner, Williot, Rochard, Freyhof, & Kottelat, 2010); the species has nearly disappeared from all rivers including the Rhine basin (Rhine) (De Nie & Van Ommering, 1998). The last European population is originated from the Gironde basin in France and stocking in

Europe is currently supported by national action plans in the Gironde in France (MEDDTL, 2011) and in the Elbe in Germany (Gessner, Tautenhahn, Spratte, Arndt, & von Nordheim, 2011).

### 1.1 | Towards a Rhine sturgeon action plan

A possible re-establishment of European sturgeon in the Rhine could support the attempts towards effective prevention of extinction and recovery of the species in its Northern range. However, as a

prerequisite for a possible rehabilitation in the Rhine, a sound scientific assessment of the suitability of its current state of habitat is paramount: cited from Kirschbaum et al. (2009) "Natural populations can be established only if the most important factors that contributed to the decline of the species are no longer present in the rivers chosen for the re-introduction measures." As a result of water quality improvements and under the current scenarios for climate change the Rhine is suggested to provide again a potentially suitable basin for the species (e.g. Lassalle, Crouzet, Gessner, & Rochard, 2010; Williot, Rochard, Desse-Berset, Gessner, & Kirschbaum, 2011). Based upon this assessment, a political commitment and a realistic Rhine Sturgeon Action Plan within the catchment has to be reached that includes the potential countermeasures to circumvent adverse conditions for the species before actually considering to implement a reintroduction (Acolas, Gessner, & Rochard, 2011; De Groot, 2002). Due to certain biological features (e.g. females mature at 14–15 years old [yo] [Magnin, 1962]) the population recovery is a long-term process with an estimated minimum timeframe of 30–50 years (Jarić & Gessner, 2013).

Considering a future Rhine Sturgeon Action Plan, as is outlined in several studies (Gessner et al., 2011; RhFV, 2010; Williot & Kirschbaum, 2011), there are key aspects that need to be addressed:

1. Determination of the outmigration pathways of the species (if possible under different hydrological regimes) and the (adverse) impacting factors upon the species.
2. Assessment of availability, size/extent, stability and quality of critical habitats, such as spawning habitat and the identification of area for saltwater acclimatization.
3. Determination of the interference with navigation (current practice as well as the future development options). The Rhine is intensely navigated and the propulsions of these vessels cause strong and possible harmful water movements.
4. Monitoring the habitat use of juvenile sturgeons in the southern North Sea and investigating the effects and impacts of fisheries.
5. Assess the cooperation potential of fisheries.
6. Assess the usage of potential nursery areas in the Rhine in Germany.
7. Evaluate the effects of the temporal opening of the Haringvliet discharge sluices on sturgeon behaviour. This will only be possible after actual installed remediation management in 2018.

The outcomes of these assessments could provide the baseline information to verify the necessity and intensity of future habitat improvements and to help develop and deploy international cooperation on those subjects as is advised in related studies (Bölscher, van Slobbe, van Vliet, & Werners, 2013; IKS-R-CIPR-ICBR, 2009).

## 1.2 | Experimental releases

Within the project of a Rhine sturgeon action plan the present study focuses on key question 1, i.e. characterising the outmigration pathways in the lower Rhine, but some elements for questions 3, 4 and

5 were also acquired. Considering the configuration of this part of the Rhine, a complex network of channels and the Haringvlietdam that blocks the access to the sea at one stretch, it is important to identify if juvenile sturgeons are capable to reach the sea to fulfil their life cycle.

In the summers of 2012 and 2015 two tracking studies were carried out with marked juvenile European sturgeons to answer this question. The specimens were obtained from the French captive stock within intra-governmental agreement for a limited number of sturgeon for experimental releases. The results obtained in 2012 have been published in Brevé et al. (2013), the results obtained in 2015 and a comparison between both field studies are given in the present paper.

## 2 | MATERIALS AND METHODS

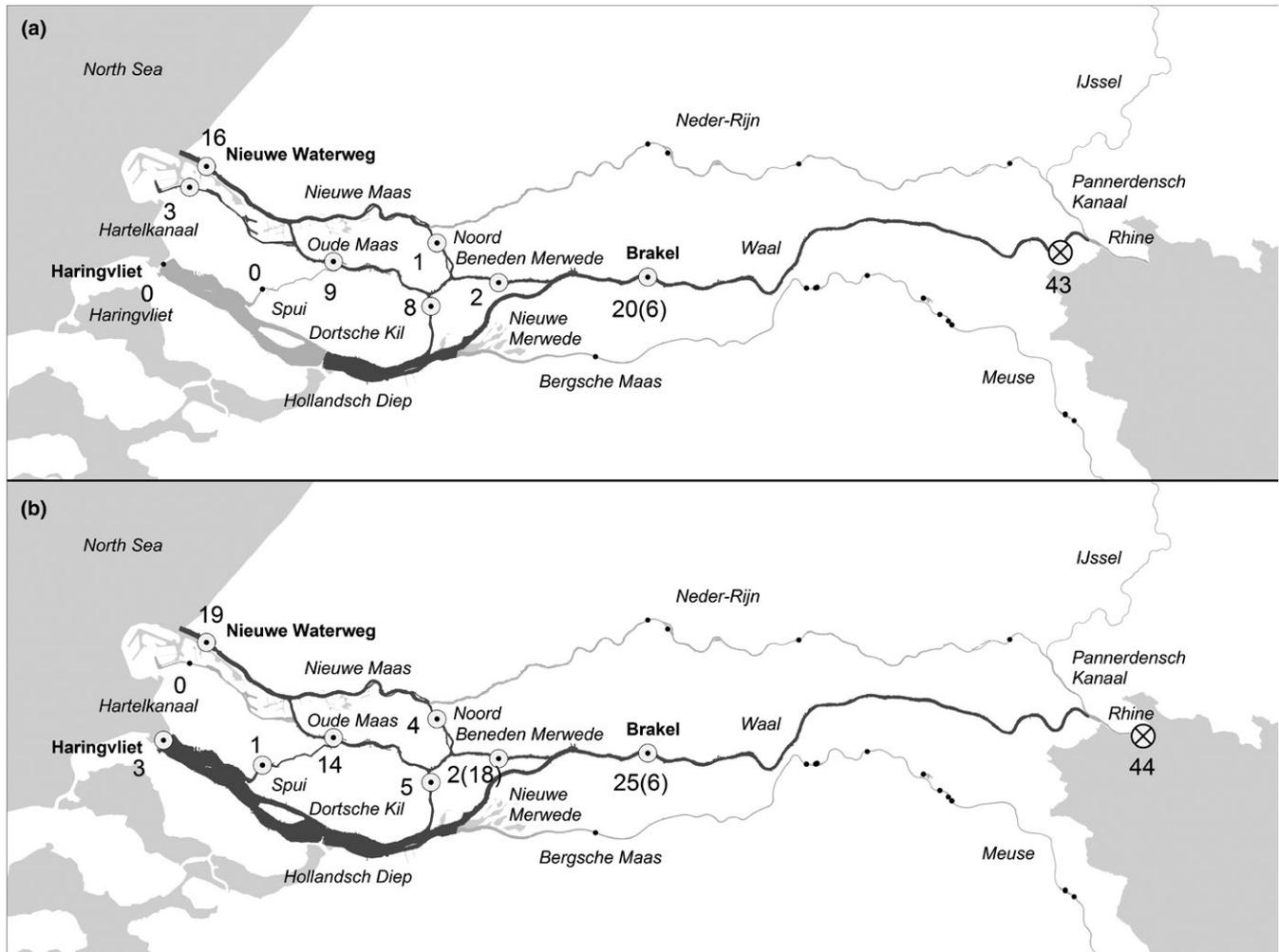
### 2.1 | Study area

The study area covers the Lower Rhine in the Netherlands, a mix of channels and natural habitats that are strongly modified by hydraulic engineering (Figure 1a and b). This includes the port of Rotterdam the terminus of all Rhine navigation, and some of the largest storm surge barriers in the world i.e. the Haringvlietdam and Afsluitdijk. During the study, the water temperature varied between 18 and 24°C for both years. The average Rhine flow velocity is estimated by RWS to be approximately 1 m/s at discharges of 2,000 m<sup>3</sup>/s. In 2015, the average Rhine discharge in the first week after the release was 1,868 m<sup>3</sup>/s and in 2012 it was 2,000 m<sup>3</sup>/s in May and 2,443 m<sup>3</sup>/s in June (Figure 2a and b).

## 3 | STURGEON TAGGING AND RELEASE

In 2012, 43 juvenile *A. sturio* from 3 to 5 yo ( $76 \pm 4.4$  cm in total length (TL),  $1.65 \pm 0.25$  kg) were released in the Rhine on May 10 ( $n = 13$ ) and June 21 ( $n = 30$ ) (Figure 1a). In 2015, on June 10, 44 conspecifics (4 yo,  $80.9 \pm 10.2$  cm TL,  $2.39 \pm 0.9$  kg) were released 15 km higher upstream at the Dutch/German border (Figure 1b) to identify if they would choose the Waal or the Pannerdensche channel to migrate downstream. In 2012 the tracking lasted 171 days and in 2015 97 days. All sturgeons originated of a controlled reproduction of the French broodstock (Williot & Chèvre, 2011). Notably, the three to five yo sturgeons were physically able to support the salinity of the sea (Acolas, Castelnaud, Lepage, & Rochard, 2011).

All sturgeons had been implanted into the abdominal cavity with transponders for the NEDAP TRAIL system® (Breukelaar, de Vaate, & Fockens, 1998). The telemetry system has detection stations installed at each main weir in the Rhine and Meuse Rivers in the Netherlands (Figure 1a and b). Surgery took place at the Irstea French experimentation station and the method of tagging and recuperation, transportation to the Netherlands and acclimatisation of the sturgeon to Rhine water followed the procedure described in Brevé et al. (2013). The transponders are contained within a shell of surgical glass (26.5 g in air;



**FIGURE 1** Study area and outmigration pathways (blue lines and areas). (a) 2012, (b) 2015. Yellow circles with crosses = release locations; black dots = Nedap trail stations with no detections; white dots with black centres = stations with detections; numbers = detections of individual sturgeons ( $n$ ); numbers between brackets = other individual sturgeons that passed this station without being recorded as deduced from detections collected further downstream

Ø: 15 mm; length: 70 mm; battery life of approximately 4 years). Their weight was less than 2% of the total weight of the lightest sturgeon which is an acceptable ratio for studies in underwater biotelemetry (Winter, 1983). WOT-tags were inserted on all released individuals at the base of their dorsal fin to provide external recognition.

The involvement of commercial fisherman was obtained by inviting their representatives at the release events and by providing a handling protocol, an Id-card and a 100 euro reward for reported recaptures. News during the study's progress (tracking and recaptures) was published in magazine *Visserijnieuws*.

## 4 | DATA ANALYSIS

Outmigration pathways were plotted in ArcMAP according to registrations (detections, finds and recaptures at sea) of the sturgeon.

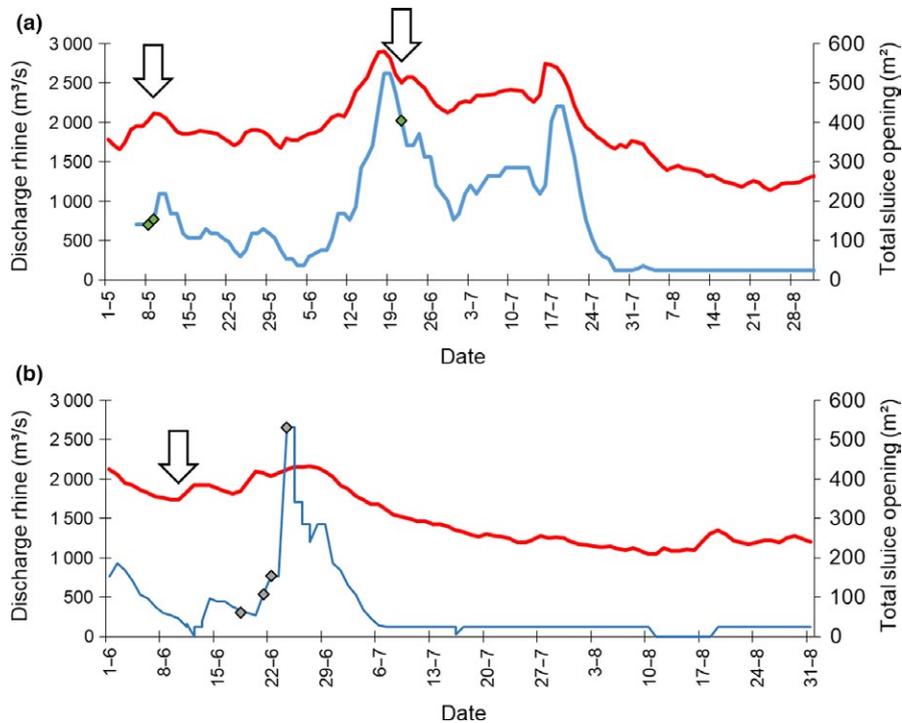
The downstream movement speed in m/s of individual sturgeon and the average speed for all sturgeons (net ground speed of the sturgeon

downstream + average river flow velocity) was calculated for the river stretch between the release site and the first station Waal\_Brakel, whereby the distance was measured in Google maps along the midst of the river and the time between the release moment and the first detection at this station. Detection rate of two Nedap stations (Waal\_Brakel and Beneden\_Merwede\_Sliedrecht, Table 1) was estimated by the number of sturgeon detected divided by the total number that should have been detected according to additional registrations downstream. Both calculations were not made for other river stretches nor other stations since there are many bifurcations further downstream thus possible detours.

## 5 | RESULTS

### 5.1 | Outmigration pathways

The outmigration pathways were mapped (Figure 1a and b) based upon detections derived from 63 (72%) of the sturgeon (Table 1);



**FIGURE 2** (a) 2012 and (b) 2015 Rhine River discharge (red line), total opening of the sluices of the Haringvlietdam (blue line), release moments (arrows), and sturgeon detections at the Haringvlietdam in 2015 (green squares). Source: RWS Operationele bedieningsstaat Haringvlietdam

**TABLE 1** Detections collected by the Nedap Trail system in 2012 and 2015

Release site and month =>	Kekerdom		Spijk	
	May/June 2012 (n = 43)		June 2015 (n = 44)	
Name NEDAP stations Water_Location	n <sup>a</sup> sturgeons	n (%) detections	n <sup>a</sup> sturgeons	n (%) detections
Waal_Brakel	20 (6)	20	25 (6)	47
Beneden Merwede_Sliedrecht	2	2	2 (18)	13
Dordtsche Kil_s'Gravendeel	8	8	5	6
Noord_Kinderdijk	1	1	4	5
Spui_Zuidland	—	—	1	2
Oude Maas_Spijkenisse	9	14	14	18
Hartelkanaal_Port of Rotterdam	3	5	—	—
Nieuwe Waterweg_Port of Rotterdam	16	5,412 (99%)	19	365 (78%)
Haringvliet_Haringvlietdam	—	—	3	9
Total detected	26	5,462	31	465

<sup>a</sup>misses detections as recalculated from detections downstream.

additional data was obtained from finds on river banks and recaptures in the North Sea (Table 2, Figure 3). No sturgeon was detected upstream of the release sites.

Considering the release site in 2015, the sturgeon reached the first bifurcation 9.5 km downstream (Figure 1b) between the Pannerdensch kanaal (channel) which carries approximately a third in river discharge and the Waal (river) carrying two third of the discharge. All sturgeons detected followed the maximum river discharge.

At the first station ("Waal\_Brakel", Figure 1a and b) 20 and 25 sturgeons were detected in 2012 and 2015, respectively. But by back-tracking of individuals detected at stations further downstream

and by additional recaptures from the North Sea that were previously undetected, it was deduced that more sturgeons must have passed station Brakel undetected i.e. 29 and 32, respectively; the same principle applies to station "Beneden Merwede Sliedrecht" (Table 2, Figure 1a and b).

At 102/117 km downstream from the release location there is a second bifurcation between the Nieuwe Merwede and the Oude Merwede (Figure 1a and b). From this bifurcation two main routes lead towards the North Sea, *via* the discharge sluices of the Haringvlietdam or *via* the Port of Rotterdam (Nedap stations "Nieuwe Waterweg" and "Hartelkanaal", Table 1). In 2012 the

**TABLE 2** number and percentage (n and %) of sturgeons detected at NEDAP stations, found on the river banks and recaptured by fishermen; (a) missed detections as recalculated from detections downstream; (b) undetected finds; (c) undetected recaptures

Year	Released	Confirmed passage first station Brakel (detected +a + b + c)	Stations near the North Sea			Found dead on river bank	Recaptured in the North Sea (c)	Confirmed dead at sea	Confirmed to have entered the North Sea (detected +c)	Data collected (detected + b + c)	No data
			Port of Rotterdam	Haringvliet-dam	Port of Rotterdam						
n	43	29 (20 + 6+0 + 3)	19	0	1	6 (3)	1	22 (19 + 3)	30 (26 + 1 + 3)	13	
2015	44	32 (25 + 6+1 + 0)	20	3	2	4 (0)	0	23 (23 + 0)	33 (31 + 2 + 0)	11	
Sum	87	61 (45 + 12+1 + 3)	39	3	3	10 (3)	1	45 (42 + 3)	63 (57 + 3 + 3)	24	
%	43	67%	44%	0%	2%	14%	2%	51%	70%	30%	
2015	44	73%	45%	7%	5%	9%	0%	52%	75%	25%	
Sum	87	70%	45%	3%	3%	11%	1%	52%	72%	28%	

sturgeons preferred the route **Nieuwe Merwede** → Hollandsch diep → Dordtsche Kil → Oude Maas → Nieuwe **Waterweg** (Figure 1a). In 2015 the sturgeons preferred the route **Beneden Merwede** → Oude Maas → Nieuwe **Waterweg** (Figure 1b).

Both years, most sturgeons migrated towards the station “Nieuwe Waterweg” which corresponds to the Port of Rotterdam (Table 2, Figure 1a and b). The number of detections collected at this station differed between both years: in 2012 the station collected 99% of all detections, in 2015 this proportion was 78% of all detections (Table 1) and for both years it corresponds to the most frequented area (169 and 95 days of detections).

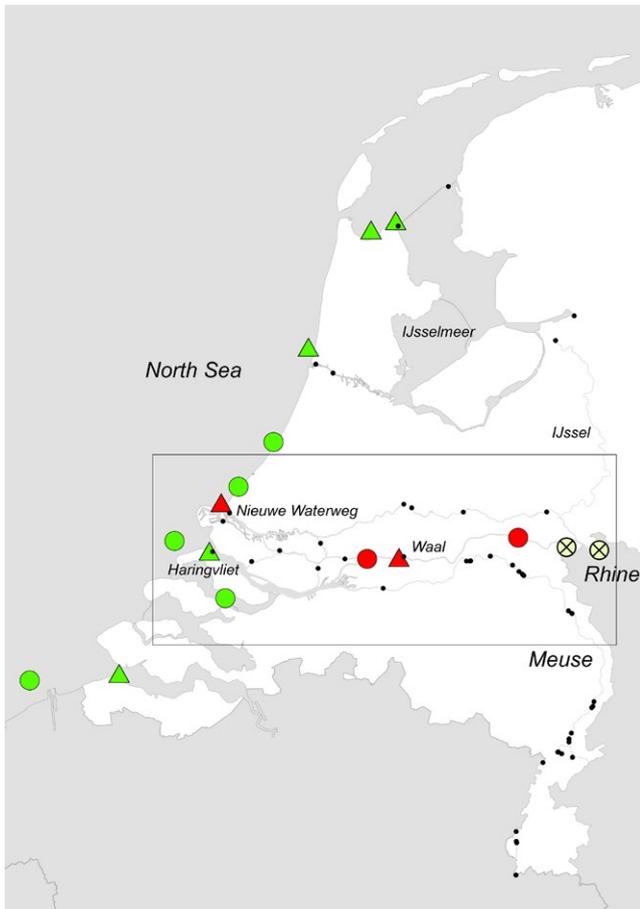
In 2012, the migration from the release site towards the Nieuwe Waterweg took between 2.5 and 48 days ( $n = 16$ ), with an average of seven days. Three sturgeon were detected in the Hartelkanaal (Port of Rotterdam), but no sturgeon was detected at the Haringvlietdam. In 2015, the migration to the Nieuwe Waterweg took between 3 and 52 days ( $n = 19$ ), with an average of 13 days. In 2015 sturgeon were also detected along the route towards the Haringvlietdam which took between 8 and 13 days ( $n = 3$ ), with an average of 11 days. Two sturgeons passed the Haringvlietdam immediately after their arrival, whereas a third sturgeon was delayed for 5 days. One sturgeon was detected in the channel Noord (Figure 1b) which most likely reached the North Sea through the Nieuwe Waterweg. Thus, in both years at least 50% of the sturgeons were confirmed to have reached the North Sea (Table 2).

In 2012 the average movement speed downstream was 1.2 m/s (106 km/day) and the fastest sturgeon moved 1.6 m/s (142 km/day). In 2015, 1.1 m/s (96 km/day) and 1.5 m/s (127 km/day), respectively.

### 5.2 | Interactions between sturgeons, ship propellers and fishermen from the north sea

In total three sturgeons were found dead on river banks by pedestrians (Table 1, Figure 3), all within seven days after their release. Based upon the decomposition of the bodies they were dead for several days. None of the dead sturgeon were detected. Two were found between the release site and station Brakel, nearly decapitated with sharp cuts perpendicular to the body. A third sturgeon was found at 102 km from the release site but the transponder was broken, the sturgeon had a broken tail, a broken dorsal spine, and a sharp but shallow cut at the beginning of the belly.

Ten sturgeons were reported in coastal waters, representing 11% of all sturgeons released ( $n = 87$ ) and 22% of the sturgeons that were confirmed to have reached the North Sea ( $n = 45$ ) (Table 2). Nine sturgeons were released alive and one died in 2012 due to a stone that was picked up by the net. In 2012, six sturgeons (three not detected) were recaptured by beam trawlers (Figure 3). Five were caught between July 19 and August 20, thus within 1 month after the release. During this period shrimpers were licensed to fish without sieve net (to omit abundant sea weed), a provision to reduce by catch (Polet, Coenjaerts, & Verschoore, 2004). In 2015, four sturgeons, all detected by the Nedap system, were recaptured between June 28 and December 31. Two were caught in a gill net, one by a beam trawler and one by an angler on December 19 in the



**FIGURE 3** Locations of release locations (two circles with crosses), sturgeons found on river banks (red) and of reported recaptures (green). Circles = 2012, triangles = 2015

Oosterschelde (Figure 3). Until present (April 2018) no further recaptures were reported of tagged sturgeon from this study.

In total the observed mortality (finds and recaptures) was 5% ( $n = 4$ ). Sturgeons with unknown fate represented in 2012 25% ( $n = 11$ ) of the released sturgeons and 36% ( $n = 16$ ) in 2015 (Table 2).

## 6 | DISCUSSION

### 6.1 | Function of the Nedap trail system

In total 65% ( $n = 57$ ) of the sturgeons were detected which resulted in 5,927 detections collected by nine stations (Table 1). In 2012 the stations in the Beneden Merwede and in the Haringvlietdam were malfunctioning, both were repaired in that year. The other stations were functional during the study period, but there were still non-detections and back-tracking was done to receive a better image of the outmigration pathways. In a similar study with Atlantic salmon smolts (*Salmo salar*) the overall percentage of non-detections was 13.6% (unpublished data). Possible reasons for non-detections are: (a) the signal is interrupted when a transponder is less than 10 cm to the hull of a vessel; (b) when the transponder is parallel to the antennae the chance of non-detection becomes higher (Ensing & Breukelaar, 2017).

### 6.2 | Outmigration pathways

Both years, most sturgeon reached the Port of Rotterdam within 2 weeks. The overall downstream movement speed was approximately 100 km/day which is about 20 km/day faster than the estimated speed of the river. A close look at the outmigration patterns shows that the sturgeons probably followed the routes with the highest river discharge. In 2015, at the first bifurcation all sturgeon took the route over the Rhine/Waal, which carries approximately 2/3 of river discharge. At the second bifurcation Beneden-/Nieuwe Merwede the same principle applies, although a bit less obvious, which can be explained as follows: the sluices of the Haringvlietdam are used to redirect river water in the Lower Rhine network to facilitate navigation and to prevent excessive salt water intrusions in the Port of Rotterdam. When the river discharge is below 1,100 m<sup>3</sup>/s the sluices are closed and most river water flows into the Port of Rotterdam and out into the North Sea. At higher river discharges the redundant river water is discharged during ebb tides under free fall into the North Sea via a measured opening of the sluices of the Haringvlietdam. This starts at a river discharge of between 1,100 and 1700 m<sup>3</sup>/s (RWS, 1984) and at higher discharges consequently more water is directed via the Nieuwe Merwede towards the Haringvlietdam.

In 2015, the sturgeon preferred the route through the Beneden Merwede. In the first week after their release the average river discharge was 1868 m<sup>3</sup>/s and the average sluice opening of the Haringvlietdam was 65 m<sup>2</sup>. Three sturgeons were detected at the Haringvlietdam. However, in 2012, the sturgeons preferred the route through the Nieuwe Merwede. In the first seven days after the release the average river discharge was somewhat higher than in 2015: 2,000 m<sup>3</sup>/s and 2,443 m<sup>3</sup>/s and the average sluice opening of the Haringvlietdam was 164 m<sup>2</sup> and 314 m<sup>2</sup>. No sturgeon was detected at the Haringvlietdam but this station was out of order in that year. In 2012 three sturgeons not previously detected were recaptured at sea, and this is an indication that probably more sturgeons entered the North Sea through the Haringvlietdam.

Nevertheless, most sturgeons were detected at station Nieuwe Waterweg, a location with a high influx of the sea, characterized by a dynamic salt-fresh water gradient (Dankers, Texel, & Steenbergen, 2006). Here the sturgeon stayed on average 14 and 22 days, and probably this is an expression of acclimatization behaviour to salt water. Notably, sturgeon that passed the Haringvlietdam did have no time to adapt to salt water, they went from Lake Haringvliet immediately into the North Sea and this could have been a problem for their wellbeing or even survival.

Given the high average movement speed and the uniformity with which the sturgeons migrated downstream it is not very likely that any sturgeon stayed in the river. In addition, no sturgeon was detected during the year after the last detection observed in 2015.

### 6.3 | Sturgeons found on river banks, recaptures from north sea and mortality rates

Three sturgeons were found dead along a 100 km shoreline. In this river stretch, the banks are not easily reached by foot, limiting the number of possible encounters. It is likely that not all sturgeons that

died washed ashore, nor were discovered but the exact number remains unknown due to the non-detections. Several studies describe the loss of Atlantic sturgeon (*Acipenser oxyrinchus*) due to collisions with ships and propellers in the Delaware and James rivers, USA (Balazik et al., 2012; Brown & Murphy, 2010). No direct evidence was collected, but the wounds described and shown in pictures resemble those of the finds in the Rhine.

Mortality was not only observed in the river but also at sea. The reported recapture rate was quite high from 14% to 9% according to years but the mortality declared by fishermen was low (10%). The Dutch coast is intensively fished by demersal fisheries such as gill-netting and beam trawling (e.g. Bergman & Hup, 1992) and this probably hampers future sturgeon rehabilitation when fishing gear is not fine-tuned to minimize the bycatch. Commercial fishers were willing to report their catch. In 2012, five out of six sturgeons were caught within one month when shrimpers were allowed to fish without sieve nets. A sieve net reduces bycatch in beam trawling, most round fish will then be released under water (e.g. Polet et al., 2004). In 2015, only one sturgeon was caught by a shrimper. By that time sieve nets were obligatory and it seems from the reduced number of bycatch that sieve nets may work for sturgeon. The other gear types mentioned are impossible to facilitate with comparable escape routes for round fish. Thus other measures would be necessary to reduce possible mortality and it is therefore recommended to aid commercial fishermen and anglers by delivering good id-cards and handling protocols.

The estimation of overall mortality lies between  $n = 4$  and 28 (4 confirmed dead, 24 unknown fate) i.e. 5%–32% (Table 2). It is difficult to interpret what happened with the undetected sturgeons. Considering the variability of the Nedap system detection efficiency, some could have reached the North Sea without being detected, and some could have died either due to ship propellers or due to difficulties to adapt to the natural environment. Notably, the sturgeons were raised in a protected environment for many years and released into a main European River that is intensely navigated and with high current velocity. Although the sturgeons were acclimatized to river water, most likely the sturgeons encountered difficulties in adapting their behaviour immediately after the release, and this could have caused extra mortality in comparison to wild sturgeons of the same age that would be more adapted to the River environment.

## 6.4 | Towards a Rhine sturgeon action plan

Considering the first key question as mentioned in the introduction section, it seems that the outmigration pathways in the Lower Rhine are available and the Port of Rotterdam corresponds to the main entrance at sea. However, when regarding the extremely slow growth of an European sturgeon population and the long generation time, any source of mortality amongst individual sturgeons caused by mankind (i.e. ship propellers and by-catch) may continue to hamper current and future efforts to restore the population, as is outlined for a close relative, the Atlantic sturgeon *Acipenser oxyrinchus* (Boreman, 1997; Gross, Repka, Robertson, Secor, & van Winkle, 2002). Considering the ship propellers injuries observed

in this study as well as the rate of by-catch, the overall estimated mortality being between 5% and 32%, the key questions 3 (interference with navigation) and 5 (cooperation with fishermen) are prior questions to be assessed in the project of a Rhine sturgeon action plan.

To complete the present study carried out on sturgeons >3 yo, studies on YOY sturgeon survival and behaviour (habitat selection, downstream migration) in freshwater and transitional waters would be relevant. Such a study should preferably be carried out during 2019–2020 (see key question no. 7) when a new management scheme of the discharge sluices of the Haringvlietdam will be implemented to improve fish migration between the natural estuary of Rhine and Meuse Rivers and the North Sea, and includes the recovery of a semi-permanent salt-fresh water transitional zone in this estuary (Paalvast, 2016). However, considering the actual availability of YOY in the French captive stock it may not happen before 2021. When the assessment of experimental release of YOY in the Rhine will be possible, a comparison with the behaviour described in the Gironde (Acolas, Le Pichon, & Rochard, 2017) and the habitat assessment in the Elbe (Gessner, Zahn, Jaric, & Wolter, 2014) or a joined study would make sense to help find data gaps, differences in survival, growth parameters and spatial and temporal distribution.

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## ORCID

Niels W. P. Brevé  <http://orcid.org/0000-0002-2152-3690>

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