Data report: Glass eel and yellow eel migration in the Rhine Meuse estuary

A data report of a mark recapture study spring 2022

Author(s): A.B. Griffioen[1], P. Philipsen[2], B. van Wijk[3], H.V. Winter[1]

1. Wageningen Marine Research
2. Nature At Work
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Wageningen University &
Research report C060/22

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Summary

English

Connectivity between sea and freshwater inland habitats is heavily obstructed by anthropogenic barriers leading to a high pressure on diadromous fish populations including European eel (*Anguilla anguilla*). Nevertheless each spring millons of juvenile eels (glass eel) arrive at European coasts to access freshwater habitats. Coastal glass eel migration behaviour highly depends on tidal currents including in estuaries. However, this behaviour is severly hampered in regulated water systems. Therefore a better understanding of glass migration behaviour in highly regulated water systems is needed to take proper mitigation actions. Therefore a mark-recapture experiment was conducted in spring 2022 by releasing 21.424 tagged glass eels along the coast (Haringvliet and Nieuwe Waterweg) and 4.870 glass eels at inshore locations of the Nieuwe Waterweg, Hollandsche Ijssel, Haringvliet and adjecent rivers. In addition 1.097 young yellow eel were tagged at multiple inland locations of the study area.

The results showed that (untagged) glass eels were caught throughout the study area up to at the very eastern side of the study area 70km inland. The number of tagged glass eels released along the coast were enough to answer the research questions (abundance and distribution). Multiple recaptures (n=121) were present at the westside of the study area: Rozenburg, Westland and Zaaijer, but also at the very east side of the study area at Krimpenerwaard. Therefore, using the data collected in 2022, an overall abundance estimate can be made and how this relates to inland local abundance estimates.

For the Haringvliet multiple recaptures (n=1980) were found at the coastal side of the Haringvlietdam, Zuiderdiep and the Goereese sluis (Stellendam) to estimate the coastal abundance at the Haringvliet. Additionally one tagged glass eel was found in the hinterland at the pumping station Putten.

In addition to the eastwards dispersal of glass eels, tagged glass eels showed also dispersal along the coast. Glass eels released at Haringvliet and Nieuwe Waterweg were recaptured at Katwijk (and vice versa). Tagged glass eels showed also dispersal between Nieuwe Waterweg and Haringvliet.

Multiple locations showed increased catches of young yellow eels (elvers) during the season. Similar to the local abundance estimates of glass eels using tagged an locally released glass eel, a young yellow eel (elver) local abundance estimate at relevant locations can be made.

This report gives an overview of the fieldwork procedures, catches and recaptures. This report is anticipating final results, which will be incorporated in a final report to be published in 2023. The research will be continued in 2023 when multiple fish passages will be studied on efficiency.

Nederlands

De connectiviteit tussen zee- en binnenland wordt belemmerd door diverse barrières. Dit veroorzaakt een hoge druk op diverse diadrome vispopulaties, waaronder Europese paling (*Anguilla anguilla*). Toch komen er elk jaar nog miljoenen glasalen aan bij de Nederlandse kust die naar het zoete water willen migreren. Glasalen zijn nabij de kust sterk afhankelijk van getijdenstromingen om te verplaatsen, ook in estuaria, dit wordt selectief getijde gedrag genoemd. Dit zogenaamde selectief getijden transport wordt helaas ernstig belemmerd door allerlei barrieres die ervoor zorgen dat er geen getijwerking meer is. Om die reden is het nodig beter inzicht te krijgen in het gedrag van glasaal in gebieden die sterk worden gecontroleerd op gebied van watermanagement. Juist om gericht mitigerende maatregelen te nemen ter bevordering van de migratie van glasaal. Om deze reden is in het voorjaar van 2022 een groot merk-terugvangst experiment uitgevoerd met 21.424 gemerkte glasalen die langs de kust (Haringvliet en Nieuwe Waterweg) zijn vrijgelaten en daarnaast 4.870 gemerkte glasalen die in het achterland zijn losgelaten op diverse locaties in de Nieuwe Waterweg, de Hollandsche IJssel, het Haringvliet en andere aangrenzende rivieren. Ook zijn er aanvullend 1.097 jonge rode alen gemerkt op meerdere kustlocaties van het studiegebied. Dit rapport geeft een overzicht van de veldwerkprocedures, vangsten en terugvangsten vooruitlopend om de eindrapportage. Volgend voorjaar wordt het onderzoek voortgezet bij diverse vispassages.

Uit de resultaten blijkt dat (ongemerkte) glasaal werd gevangen in het hele studiegebied tot aan de uiterste oostelijke locaties van het studiegebied circa 70 km landinwaarts. Het aantal gemerkte glasalen dat langs de kust werd uitgezet was voldoende om de onderzoeksvragen (aanbod en verspreiding) te beantwoorden. Aan de westzijde van het studiegebied zijn meerdere terugvangsten gevonden (n=121): Rozenburg, Westland en Zaaijer, maar ook bij Krimpenerwaard aan de oostzijde van het studiegebied (n=1). Met deze terugvangsten en de gegevens die in 2022 zijn verzameld kan een schatting worden gedaan van het aanbod en de verspreiding van glasaal in het gebied en hoe dat in verhouding staat tot de lokale aanbodschattingen verder landinwaarts.

Voor het Haringvliet zijn meerdere terugvangsten (n=1980) gevonden aan de kustzijde van de Haringvlietdam, Zuiderdiep en de Goereese sluis (Stellendam). Met deze terugvangsten wordt een schatting gemaakt hoeveel glasalen er bij de Haringvlietdam in 2022 zijn aangekomen en hoe dat in verhouding staat tot de lokale aanbodschattingen verder landinwaarts. Bij gemaal Putten is één gemerkte glasaal gevonden die oorspronkelijk bij de kust was losgelaten.

Naast de oostwaartse verspreiding van glasaal, vertoonden gemerkte glasaal ook verspreiding langs de kust. Gemerkte glasaal die is vrijgelaten bij Haringvliet en de Nieuwe Waterweg is teruggevangen bij Katwijk (en vice versa). Ook was er uitwisseling van gemerkte glasalen tussen Nieuwe Waterweg en Haringvliet.

Meerdere locaties vingen gedurende het seizoen jonge rode alen (elvers en pootalen). Ook hiervan is een deel gemerkt en vergelijkbaar met de lokale schattingen met behulp van gemerkte glasaal, kan een lokale aanbodschatting worden gemaakt van de hoeveelheid jonge gele aal (elvers en pootalen).

Dit rapport geeft een overzicht van de veldwerkprocedures, vangsten en hervangsten vooruitlopend op het eindrapport. In 2023 wordt het onderzoek voortgezet wanneer meerdere vispassages worden onderzocht op efficiëntie.

1 Introduction

The European eel (*Anguilla anguilla* L.) is an economical important species and is listed on the IUCN red list as critically endangered (Jacoby and Gollock 2014). Based on recent analyses of multiple time-series across Europe, current recruitment numbers in the North Sea consist of just 0.6% of those from 1960-1979 (ICES 2021a). Many factors may have contributed to this decline but most of these factors are anthropogenic such as overexploitation (Dekker 2000, 2003), barriers to fish migration resulting in habitat loss or fragmentation (Feunteun 2002, Tesch 2003, van Puijenbroek et al. 2019) and changes in oceanic conditions and atmosphere regime shift due to climate change (Knights 2003, Friedland et al. 2007, Bonhommeau et al. 2008a, Bonhommeau et al. 2008b, Miller et al. 2016, Drouineau et al. 2018, Westerberg et al. 2018, Borges et al. 2019). Nonetheless, each year silver eel migrate towards the Sargasso sea for spawning and each year millions of glass eels arrive at Europe's coastal areas (Figure 1-1) to reach their freshwater habitats between February and June (ICES 2021b).

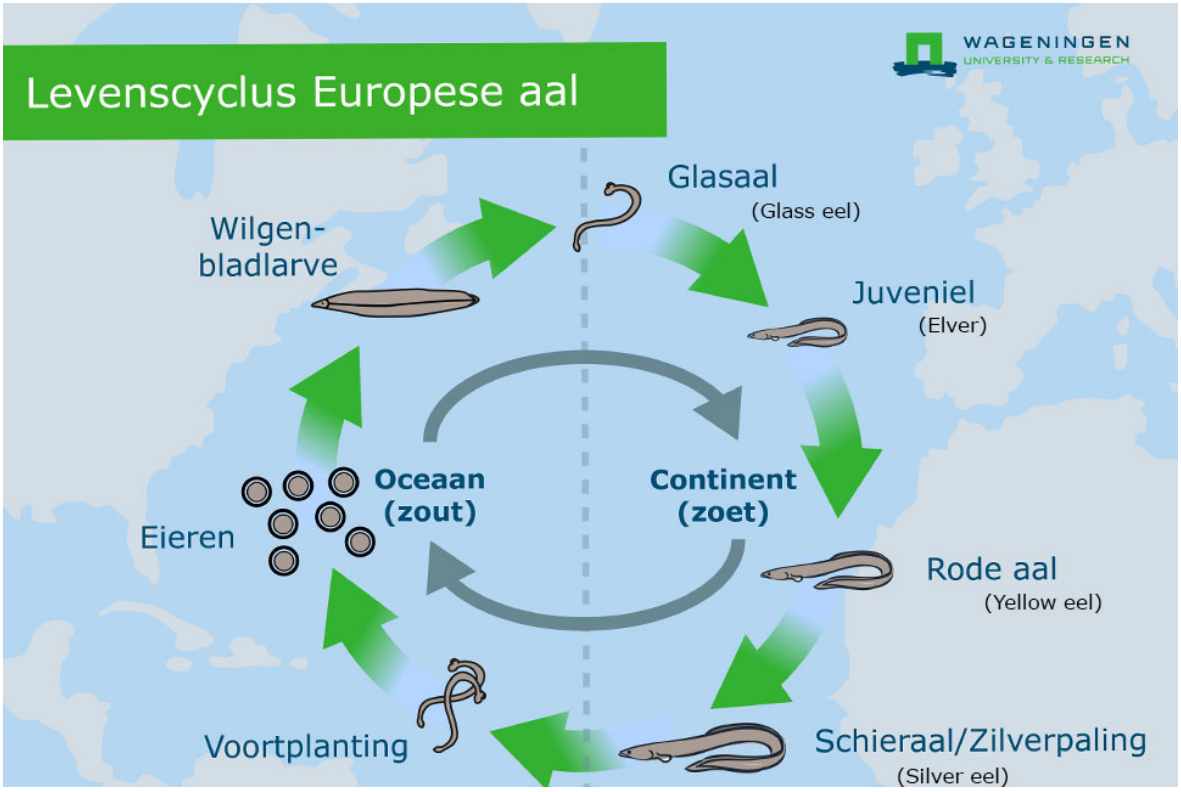


Figure 1-1 Life cycle of the European eel (Anguilla anguilla)

Glass eels use multiple cues (e.g. salinity gradient, organic substances) and migration strategies (e.g. passive drifting, selective tidal stream transport STST, active swimming) in order to reach freshwater habitats (Harrison et al. 2014, Cresci 2020). At the break point of tidal streams (tidal limit), glass eel switch from using tidal streams to counter-current swimming which may lead to temporal accumulations due to the loss of tidal advection (Edeline et al. 2007). In river systems, the majority of the glass eels settle below the tidal limit, including the more productive marine or estuarine habitats (Gross et al. 1988, Tsukamoto and Arai 2001, Bardonnet et al. 2005, Daverat et al. 2006, Edeline et al. 2006, Edeline et al. 2007, Cairns et al. 2009, Marohn et al. 2013). Subsequently a random dispersal in the yellow eel stage follows thereafter (Ibbotson et al. 2002).

Tidal currents and natural river water flow play a major role in glass eel migration. As the Netherlands are situated below sea level, a large part of the land and many waterbodies are closed off by dikes to protect the land from flooding. Therefore natural estuaries, including tidal currents and unidirectional river flow, are scarce. Moreover, many catchment areas are below sea level and must be managed by

waterboards in order to control safe water levels. In these areas waterflows originating from discharge sluices or pumping station might induce conflicting associated migration cues for glass eels. For example excess of freshwater is discharged into sea during low water, inducing high water velocities while in natural esturies low water periods are associated with no or limited water velocities. In general heavily modified (altered) or artificial water bodies are poorly studied in terms of migration for small diadromous fish like glass eel. Former estuaries like the Ijsselmeer (former Zuiderzee), which has been closed of by a large dam (Afsluitdijk), now lack tidal currents and a salinity gradient is no longer present (Figure 1-2). Other estuaries or entrances that have been closed off by large dams or sluice complexes are the Haringvliet and the man made North Sea Canal.

To tackle the knowledge gap about glass eel migration behaviour in strongly altered systems specific research was conducted in the North Sea canal (2018) and Lake IJsselmeer (2020). A mark-recapture experiment was executed along the 28km long North Sea Canal (Griffioen et al. 2019) and in 2020 in lake Ijsselmeer (Schiphouwer and Kooiman 2021). The research concluded that glass eel could successfully pass the sluice-complex using the ship locks and could continue their migration towards the very end of the canal. They migrated with an average speed of 0.6-0.8 km/day with peaks of 1.8 km/day. Migration to polder areas, situated further inland, was observed as well as redistribution after initial selected barriers along the canal. Contrary to the North Sea canal, the IJsselmeer is a freshwater habitat, and migration to polders further inland does not seem necessary for the majority of the glass eels. Schiphouwer and Kooiman (2021) recaptured three individuals at two entrances along the inland Ijsselmeer coast, out of 5400 marked glass eel released outside the sluice complex. Here an average swimming speed of 0.49 km/day was measured. In addition, they found that the majority of eel (~91%) that were caught at habitats further inland near fish passages consisted of young yellow eel instead of glass eel (~9%).

In addition to the North Sea Canal and the Afsluitdijk (lake Ijsselmeer), this present study is carried out in a third large highly managed partially man-made and modified area called the Rhine Meuse estuary (*Figure 1-2*). The Rhine Meuse estuary differs from the North Sea Canal (closed off, no tidal currents, brackish) and lake Ijsselmeer (closed off, no tidal currents, freshwater). The Rhine Meuse estuary has two main entrances for fish to reach further inland areas: 1) the Nieuwe Waterweg (openly accessible, tidal currents and salinity gradient) and 2) the Haringvliet (closed off, subdued tidal currents, fresh water). The Nieuwe Waterweg and the Haringvliet are connected with the rivers Oude Maas, Spui and Dordtsche Kill (Figure 1-3). Both areas, Nieuwe Waterweg and Haringvliet are heavily managed and modified to ensure safe commercial vessel trafficking and water safety. Also water levels in surrounding water systems (e.g. polders) are controlled by pumping stations and discharge sluices, sometimes causing an unnatural flow direction.

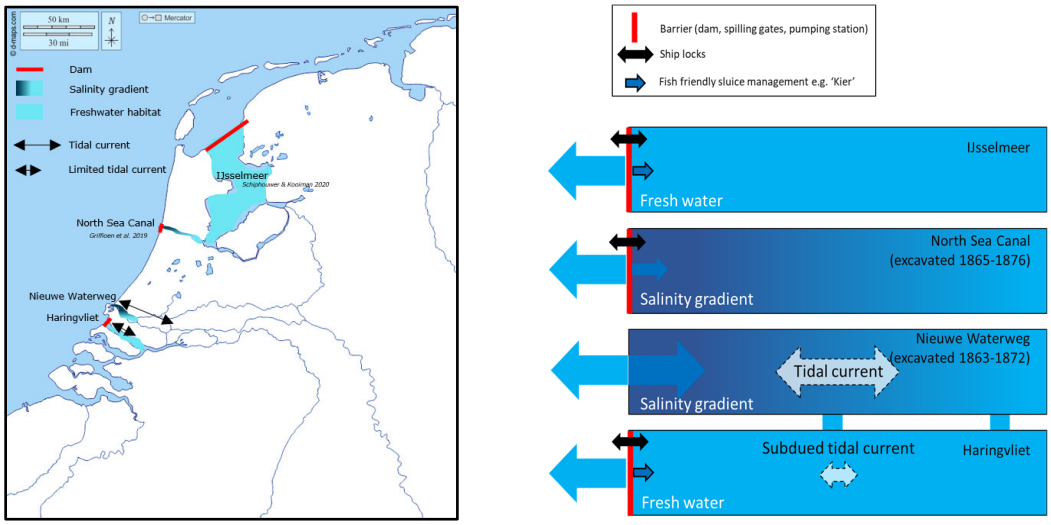


Figure 1-2 Large entrances for migratory fish along the Dutch coast

Priority area in the Rhine West Roadmap for Fish Migration
The regional water authorities in and around the studysite (Rijkswaterstaat, the waterboards and the Province of Zuid-Holland) have been working together to improve fish migration for many years. The Rhine Meuse estuary is a priority area for fish migration measures within the Rhine-West river basin cooperation, a regional water council that coordinates (fish migration) measures to improve water quality in line with the EU WaterFramework Directive (WFD) requirements.

The Rhine-West cooperation focusses on improving fish migration and connectivity between the North sea (salt water), the brackish water of the estuary and fresh water bodies in the hinterland. Because the study site is situated below sea level many dykes and dams (such as the Haringvlietdam) have been constructed to protect the reclaimed land behind the dykes (polders) form flooding. Hence why there is a clear distinction between the main river (Rijkswater) and the regional water behind the dyke (polders areas managed by waterboards where excess water is being pumped out; historically by windmills but nowadays by pumping stations). Important flagship species for restoring fish migration in the Rhine-Meuse estuary are the eel and three-spined stickleback.

As a result of the Rhine-West cooperation the conceptual framework of the Rhine West 'Roadmap for Fish Migration' or Fishroadmap' was developed in 2014. The studysite was identified as a priority area for fish migration: "*The Nieuwe Waterweg (and Haringvliet) is currently the main gateway to the Rhine river basin for migratory fish. The (Rhine West) water authorities and their local partners want to develop a joint approach to fish migration in the Rotterdam region. A success story like the joint approach of the Noordzeekanaal is being anticipated*".

The Fishroadmap-method identifies waterways as 'highways', 'regional waterways' (A roads) and 'local waterways' (B roads). Next, information on barriers, fish passes, and habitat quality is gathered in a web-based GIS (GeoWeb) tool and plotted on migratory routes to be established). Then connectivity maps are produced to indicate along which 'roads for fish migration' barriers need to be lifted first (prioritized). The Fishroadmap[1] is now being used nationally in the Netherlands (Kroes et al. 2018) and has also been used to prioritize fish migration measures within the Thames Estuary (Bodnar et al. 2021).

The Rhine-West Fishroadmap is based on extensive research and monitoring of the effectiveness of fish migration measures and migratory routes between the main river (Rijkswater) and the polders behind the dykes (Philipsen and Winter 2016). Important Fishroadmap-research in another priority area for fish migration, 'the Noordzeekanaal', was used to develop the research plan and techniques for the Rhine Meuse estuary (Winter et al. 2020, Griffioen et al. 2022).

This research (and consequent report) has been initiated by the Rhine-West regional water council. The resulting conclusions and recommendations will be implemented in the Rhine-West Fishroadmap to improve fish migration measures already planned for in the regional Rhine West river basin management plan for the WFD period 2021-2027.

1.1 Goal study

To further study glass eel migration in heavily modified and artificial water bodies and to compare with previous studies, an integral assessment was executed to study overall migration effectiveness from sea to inland at catchment level. Moreover, waterboards in the study area are willing to optimize migration opportunities but need more insight in the current migration opportunities in order to adjust or implement fish migration measures. The results of this research will be used to help prioritize fish migration measures in the Rhine West Fishroadmap and regional river basin management plan for 2021-2027 as well as fish migration plans by the individual water authorities. The research report specifically contributes to the knowledge-development needed to improve the Rhine-West Fishroadmap cooperation and effectiveness of fish migration measures in and around the Rhine-Meuse Estuary.

[1] https://www.clo.nl/indicatoren/nl1350-vispassages **and** https://storymaps.arcgis.com/stories/784f89c209bb4362b6453e6ad8f733be

Therefore, a large mark recapture study was executed in the Rhine Meuse estuary in order to study the current opportunities of glass eel migration in the study area. The results will give insight in the adaptability of the glass eel in relation to water flows and possible conflicting associated cues. To estimate abundance and to study passage efficiency and delay, multiple groups of tagged glass eels were released on the seaside and at multiple inland locations.

This study aim is:

1. to estimate abundance of glass eel at the seaside and at inland locations
2. to study distribution of glass eel alongside the river sections
3. to determine passage efficiency and delay along multiple inland locations
4. to give advice in possible actions needed to further enhance migration opportunities for fish

Accompanying research questions are:

1. What is the overall abundance of glass eels in the Nieuwe Waterweg and Haringvliet in spring 2022?
2. What is the abundance of glass eel near local barrier at inland locations?
3. What is the ratio between overall and local abundance of glass eel in the Rhine Meuse estuary?
4. Do glass eels experience delay at inland barriers and if so, what is the estimated average number of days that glass eels?
5. What is the passage efficiency for glass eel of realized fish migration measures in the study area? Insight in the impact on connectivity at the regional level (Rhine West WFD Region).
6. What management measures are needed in order to optimize fish migration and how should these measures be prioritized? These measures are in addition to or refine the measures already planned by the water authorities and visualised via the GIS based National Fishroadmap managed by Rijkswaterstaat.

To our knowledge this study gives an unique insight in the migration of glass eels starting from the sea towards inland river systems in heavily modified or artificial water bodies common to big harbours at coastal cities such as Rotterdam, Amsterdam, Antwerp and London.

This *data report* gives insight in the number of fish being caught, the number marked and recaptured fish and, in addition, an overview of the methodology, including tagging procedures. This data report is anticipating final results, which will be incorporated in a final report to be published in 2023.

The study will be continued in 2023

In spring 2023 the study will be continued. Due to summer drought and technical issues, four fish passages could not be studied in 2022. These locations will therefore be studied in 2023. In addition to the glass eel migration, thee spined stickleback (*Gasterosteus aculeatus* L. 1758*)* will also be studied at these locations if they are caught in the nets behind the different fish passages. When they are present and caught in sufficient numbers they will also be marked with a VIE tag in the tail similar to the previous study in the North Sea Canal (Griffioen et al. 2019).

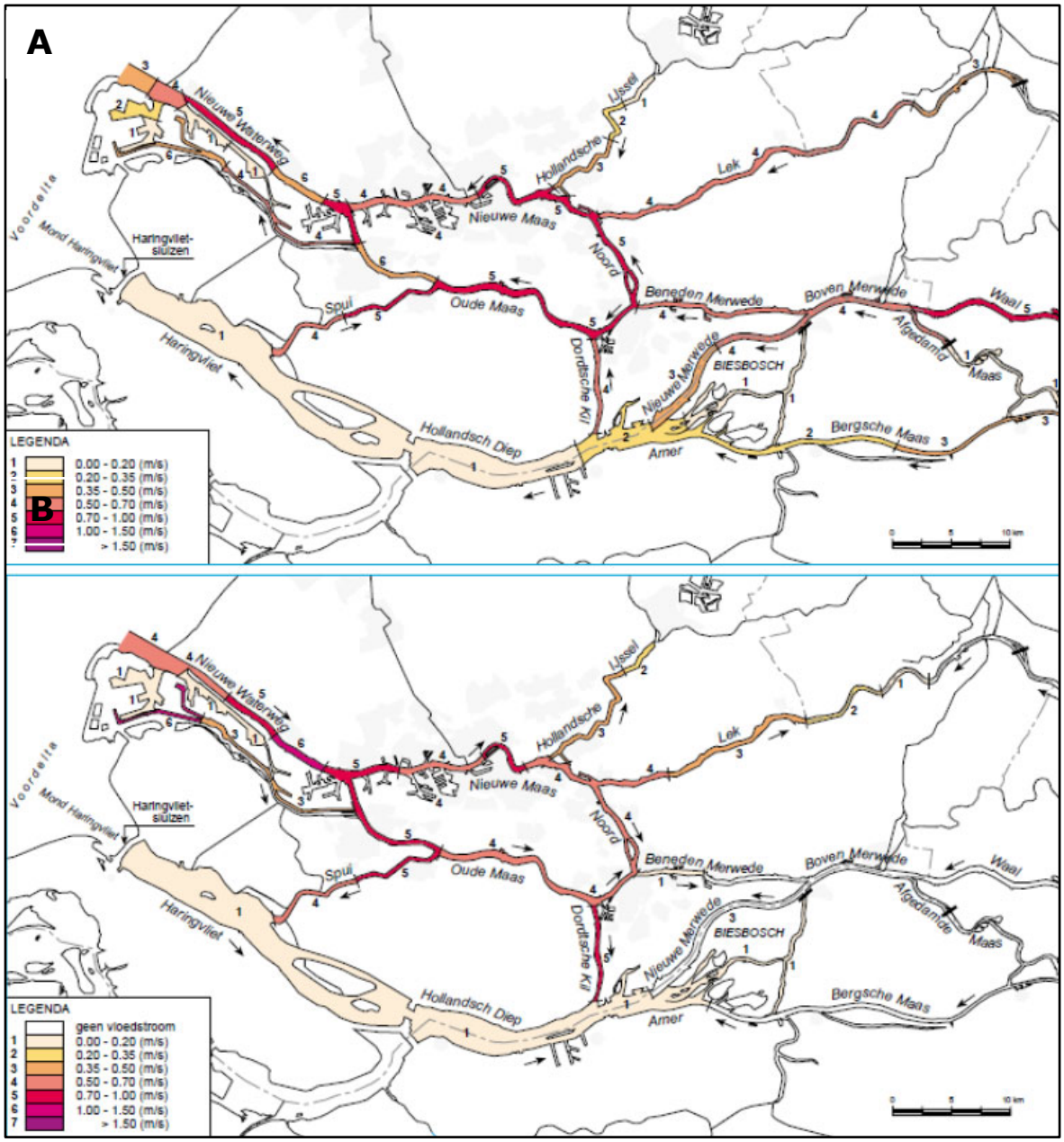


Figure 1-3 Waterflow direction and maximum velocities during low (A) and high (B) tide (Hees and Peters 1998).

2 Materials and Methods

2.1 Studysite

The study was executed in the Rhine-Meuse delta (Figure 2-1 and Figure 2-2). In general two regions can be identified as the Nieuwe Waterweg including the hinterland and the Hollandsche Ijssel (locations K-O). (section 1 and 2 in Figure 2-1) and the Haringvliet including the hinterland up to the Biesbosch at location U and V (section 3 and 4 in Figure 2-1). Contrary to the Haringvliet, the Nieuwe Waterweg is openly accessible for migratory fish. The Haringvliet has a 1km large discharge sluice complex containing 17 locks, each 56m wide. In an average year, the sluices discharge $30*10^9 m^3$ water, originating from the rivers Rhine and the Meuse. Adjacent to the Haringvlietsluizen, a shiplock, the Goereesesluis, is located, operating for ship traffic 24/7 (Figure 2-2 section 3 location B). Since 2018 Rijkswaterstaat adjusted the management protocol to facilitate fish migration, allowing salt water, including fish, into the Haringvliet via 'de Kier'. When safety protocols allows, lock #17 is opened when the water level on the North Sea-side is higher compared to that of the Haringvliet (inflow).

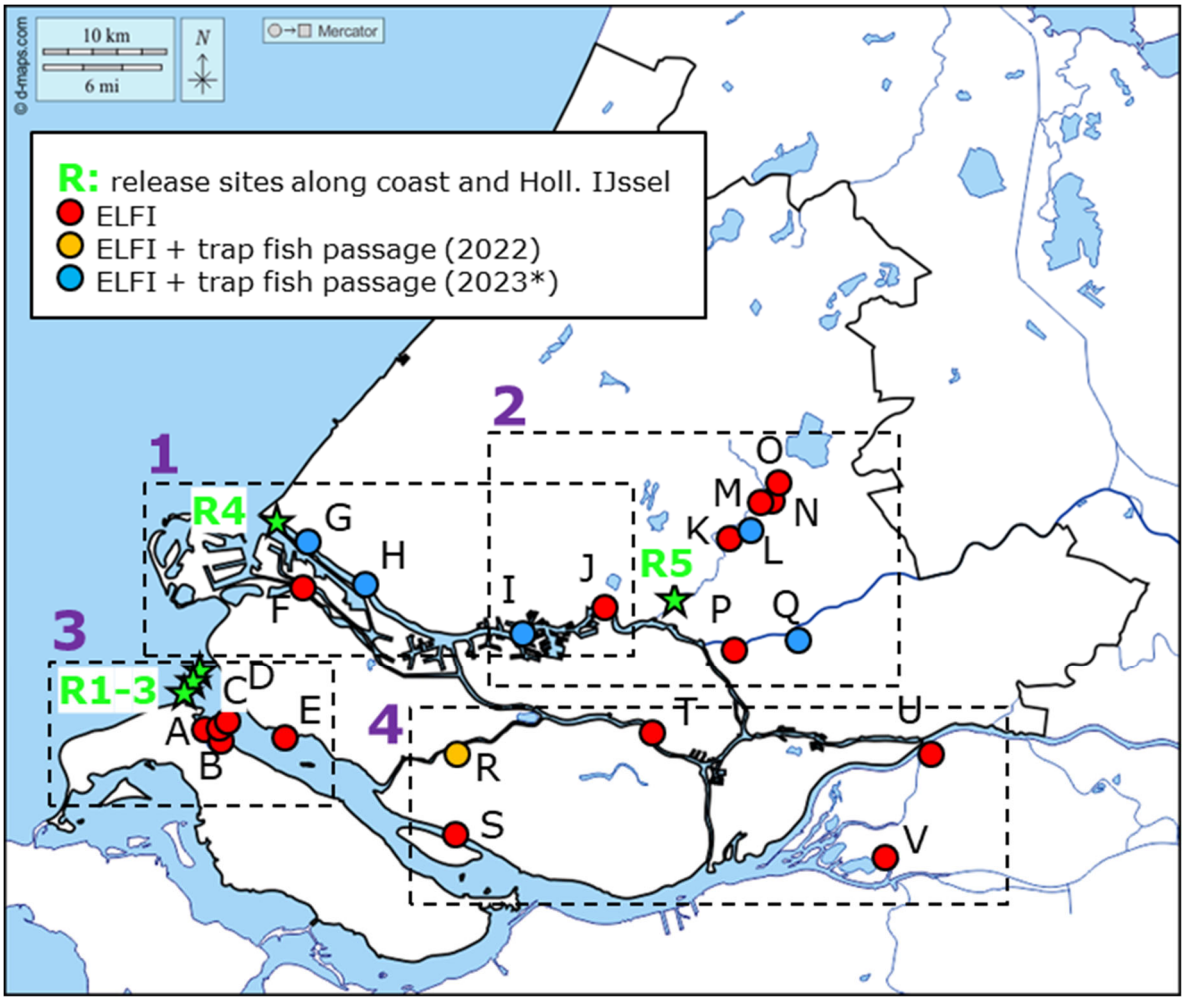


*Figure 2-1 The Rhine-Meuse delta with different monitoring locations A-V. At each location, when glass eel in sufficient numbers were caught, either local or translocated marked glass eels were released. * Locations G, H, I, L and Q are monitored in 2022 using an ELFI, but fish passage efficiency will be studied in 2023.*

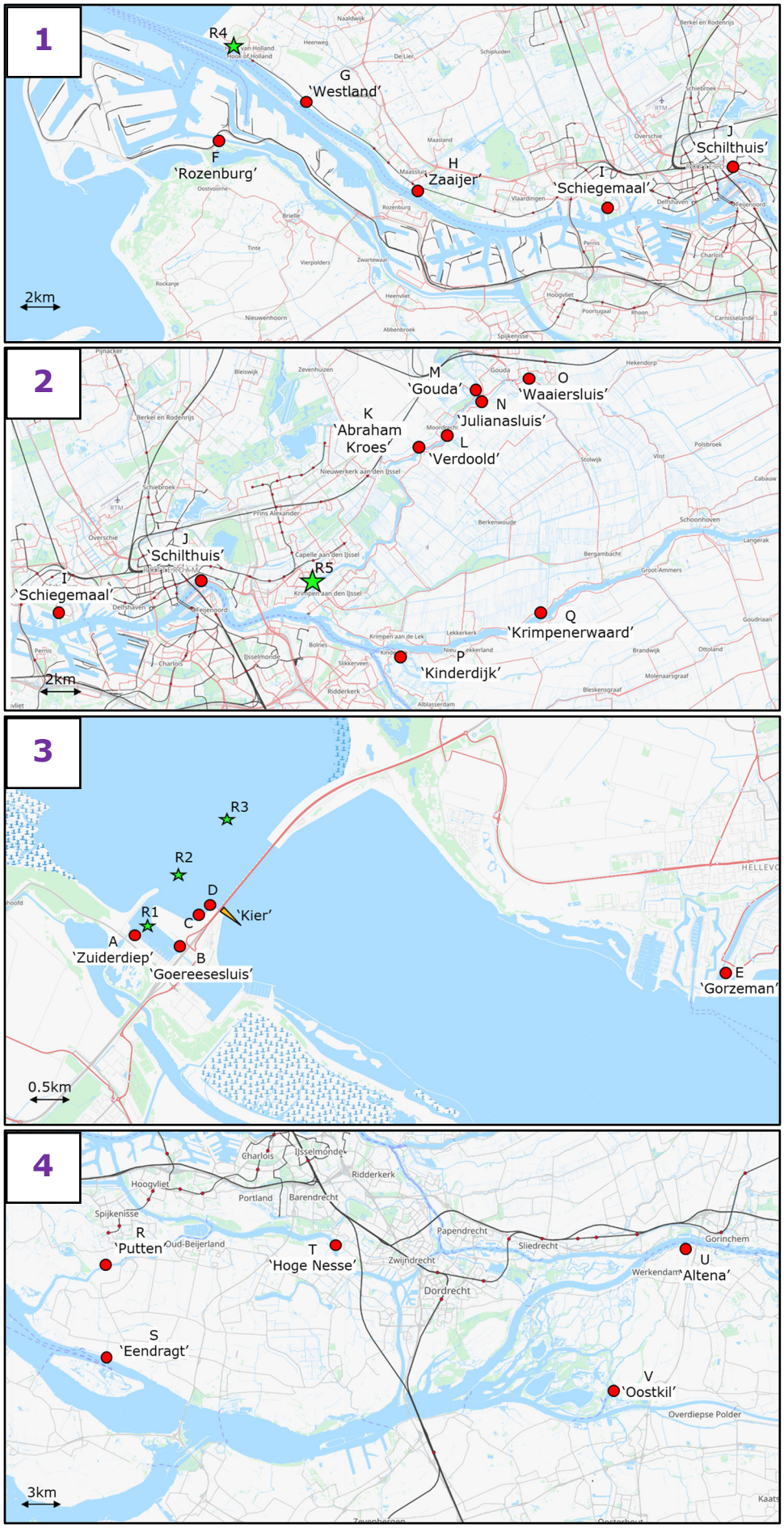


Figure 2-2 Detailed overview of the sections indicated in Figure 2-1

2.2 Monitoring

To catch eel along the coast and in the hinterland 22 ELFI's were installed (www.elverfinder.com) during spring 2022 (Figure 2-1). An ELFI is a 'mobile eel ladder' that catches glass eel and young yellow eel using an attraction flow, pumped from the hinterland. The ELFI's were emptied once or twice a week during the months March – June 2022. The catch was divided into glass eels and yellow eels and counted. When numbers were too high, the total catch was weighed in the field. During the study period, subsamples (each subsample contained three samples of 10-25gr each) were taken to measure the individual weight per eel in order to estimate the total catch. In addition to the ELFI monitoring, a lift monitoring program was carried out by volunteers coordinated by RAVON (Schiphouwer et al. 2019). All volunteers were instructed and provided with an UV flashlight and a reference cards to discriminate the VIE colour codes correctly. Near discharge lock #17 of the Haringvlietsluizen (the most southern lock) a monitoring program was carried out by ATKB to measure fish migration through the Kier (Figure 2-2 section 3). They used large liftnets (3x3m) and small traps in the locks[2]. During the study all catches were checked for recaptures. The mark recapture program followed a non-destructive approach (Skalski et al. 2009). In other words, all catch was released again.

2.3 Tagging procedures and test fish

Eels (glass eels and yellow eel[3]) were caught at several locations with ELFI's and liftnets during the study period. The eels were then divided into different groups based on their catch location, catch date, and method of catch. Subsequently the eels were tagged (each group with an unique colour code) with Visible Implant Elastomer Tag (VIE tag, Northwest Marine Technology) in spring 2022 and ultimately released again. Preferably tagged eels were released at the same location as they were initially caught. At some locations however translocation of tagged eels was necessary since catches were low.

A previous pilot study showed that a mark recapture study at the Haringvlietdam may be difficult to execute due to low catches (Bergsma et al. 2020). Therefore additional glass eels were caught along the Dutch coast (e.g. Den Oever, Katwijk and Harlingen) to complement the target of 20.000 that was released along the coast to ensure recaptures at the estuarine barriers and inland locations to estimate abundance. In addition to the 'coastal tagged glass eels', glass eels at inland locations were caught, tagged and released to estimate local abundance and to calculate average delay.

In total 26.286 glass eels were tagged (subsamples: avg. weight 0.31gr range 0.25-0.35), divided over 60 different groups (Table 1). In addition 1.097 yellow eel (avg. weight 4.28gr range 0.42-114.91gr, avg. length 14.5cm range 7.1-46.5cm) were tagged divided over 24 groups. The eels were anesthetized with 0.4ml/l 2-phenoxyethanol and equipped with one, two or three tags in unique combinations using fluorescent colours: blue, green, pink, orange, red and green. The groups were released again on different days during the migration season (see appendix A for details per group).

Glass eel housing procedures
The glass eels used for tagging at release sites R1-R5 were transported in aerated 50L tanks to the lab facilities in IJmuiden. Most glass eels originated from location A (Zuiderdiep), Den Oever and Harlingen (north of the Netherlands). The glass eels at inland location were collected and stored locally in the field in PVC tubes (40x16cm equipped with 0.5 mm^2 mesh netting at both endings) which were placed in the ELFI. When enough glass eel were collected within ten days (>30-100 individuals per location), the glass eels were tagged in the field with an unique colour code. The majority of the locations however, had not enough glass eels to tag sufficient numbers of eels per release groups. At these locations, glass eels from location A and Katwijk were collected, transported to lab facilities in Ijmuiden, tagged and released again at various locations.

In the lab, the glass eels were kept in multiple 45L aquaria (lwh: 50x30x30cm) which were connected on a filtered saltwater (22-24‰) system, aerated and temperature controlled at 8-11°C. In the aquaria

[2] https://www.rijkswaterstaat.nl/nieuws/archief/2021/08/onderzoeken-naar-de-optimale-kieropening-voor-trekvissen
[3] Elvers

cage enrichment was available, in the form of multiple PVC-pipes (3-4cm diameter) to prevent stress and no food was provided since the glass eels were kept for a maximum of ten days.

Table 1 Table of the number of marked glass and yellow eels per group for each location including release data, original catch device, original catch location, colour codes and number of eels per group. See appendix A for detailed description of each group.

								Marked groups		Marked fish	
			Distance from release (km)					Glass eel	Yellow eel	Glass eel	Yellow eel
Location	**Location name**	**Site description**	**R1**	**R2**	**R3**	**R4**	**R5**				
R1	Goereesesluis	Release site	-	-	-	-	-	3		1110	
R2	Haringvlietdam South (lock #17)	Release site	-	-	-	-	-	6		5202	
R3	Haringvlietdam North (lock #1)	Release site	-	-	-	-	-	6		5039	
R4	Hoek van Holland	Release site	-	-	-	-	-	8		10065	
R5	Hollandsche Ijssel	Release site	-	-	-	-	-	2		2074	
A	Zuiderdiep	Discharge sluice	0.2	1.0	1.8	32.0	-	R1/R2/R3		*	
B	Goereese sluis	Ship lock	0.5	1.2	2.2	32.0	-	3		*	
C	Haringvlietdam 1	Discharge sluice	1.0	0.7	1.2	31.0	-	R1/R2/R3		*	
D	Haringvlietdam 2	Discharge sluice	1.0	0.7	1.3	31.0	-				
E	Gorzeman	Pumping station	7.6	7.0	7.0	-	-	2	2	199	144
F	Rozenburg / Brielsemeer	Discharge sluice	-	-	-	8.0	-	3		317	
G	Westland	Pumping station	-	-	-	4.5	-	3		300	
H	Zaaijer	Pumping station	-	-	-	12.1	-	4		434	
I	Schiegemaal	Pumping station	-	-	-	23.5	-	3		319	
J	Schilthuis	Pumping station	-	-	-	31.0	-	3	2	263	162
K	Abraham Kroes	Pumping station	-	-	-	49.3	10.8		2		38
L	Verdoold	Pumping station	-	-	-	51.0	12.5	1	3	100	238
M	Gouda	Pumping station	-	-	-	53.5	15.0				
N	Julianasluis	Ship lock	-	-	-	53.5	15.0	1		102	
O	Waaiersluis	Ship lock	-	-	-	56.5	18.0	1	2	82	26
P	Kinderdijk	Pumping station	-	-	-	42.0	7.9	2	2	55	52
Q	Krimpenerwaard	Pumping station	-	-	-	50.2	16.1		2		38
R	Putten	Pumping station	-	-	-	37.3	-	4	2	262	119
S	Eendragt	Pumping station	22.0	22.0	22.0	-	-	1	3	99	109
T	Hoge Nesse	Pumping station	-	-	-	38.8	-	2	2	187	91
U	Altena	Pumping station	71.0	71.0	71.0	67.9	34.2	1	1	40	40
V	Oostkil	Pumping station	62.8	62.8	62.8	80.4	88.3	1	1	37	40
	Total							**60**	**24**	**26286**	**1097**

* Release groups R1-R3 used for these locations

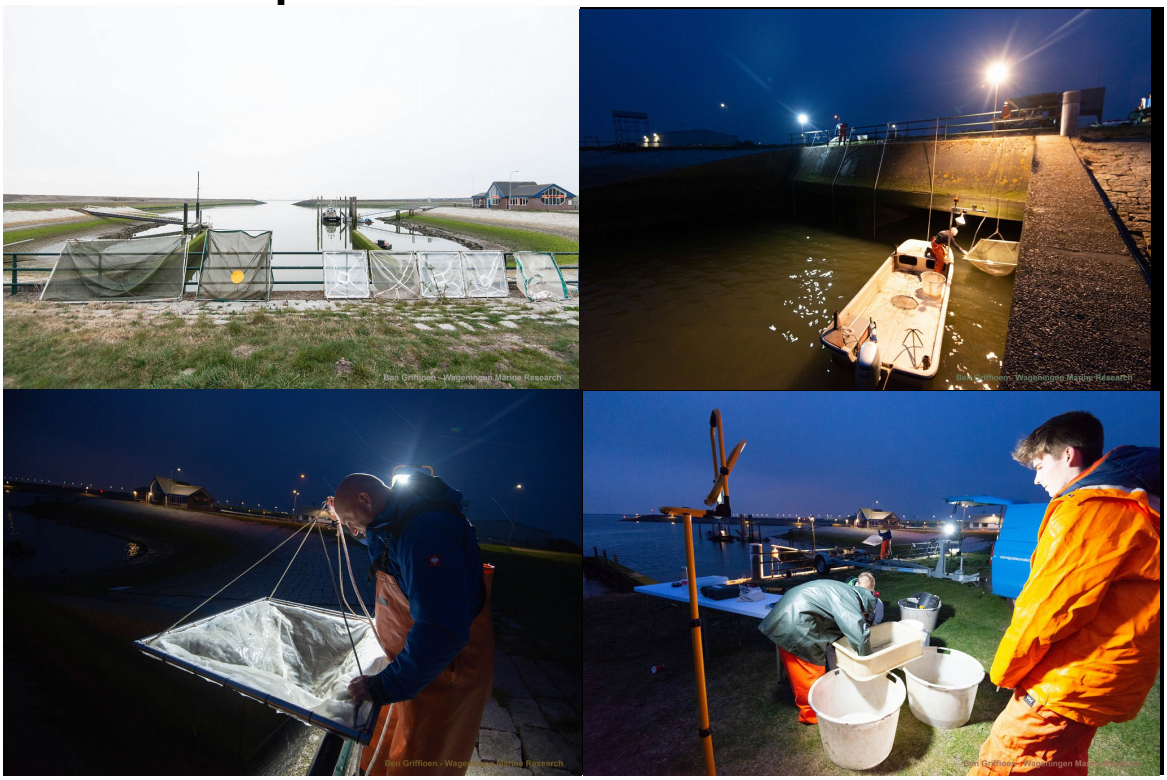
Elvers and (young) yellow eel[4]

The elvers and yellow eels were also tagged using VIE tags (*Figure 2-3*). Some individuals were short (approximately as long as a glass eel), but significantly heavier than an average glass eel. Recaptures in Katwijk revealed that some young yellow eels (elvers), that already reached the coast a year earlier, were also small. The smallest one was measured at 8.6cm and 0.54gr (Figure 2-3). All eels were caught using ELFI's and transported per location in aerated 50L tanks to lab facilities. In the lab, the eels were kept in multiple 50L tanks filled with local (fresh) water. The tanks were aerated and temperature controlled at 14.0-14.5°C. In the tanks cage enrichment was available, in the form of coconut fibers to prevent stress. No food was provided since they were kept for a maximum of seven days. Except for location U and V all eels were caught and released at the same location.

Figure 2-3 Left: Marked elvers (young yellow eel) with pink near the head and pink in the tail. The eel at the top is a glass eel for size reference. Right: An elver released with marking yellow-green in Katwijk on May 10th 2021 and recaptured on May 30th 2022 in Katwijk measuring 8.6cm and 0.54gr. Unpublished results Wageningen Marine Research.

[4] In this report elvers or young yellow eel are defined as eel in general larger but always heavier than glass eel.

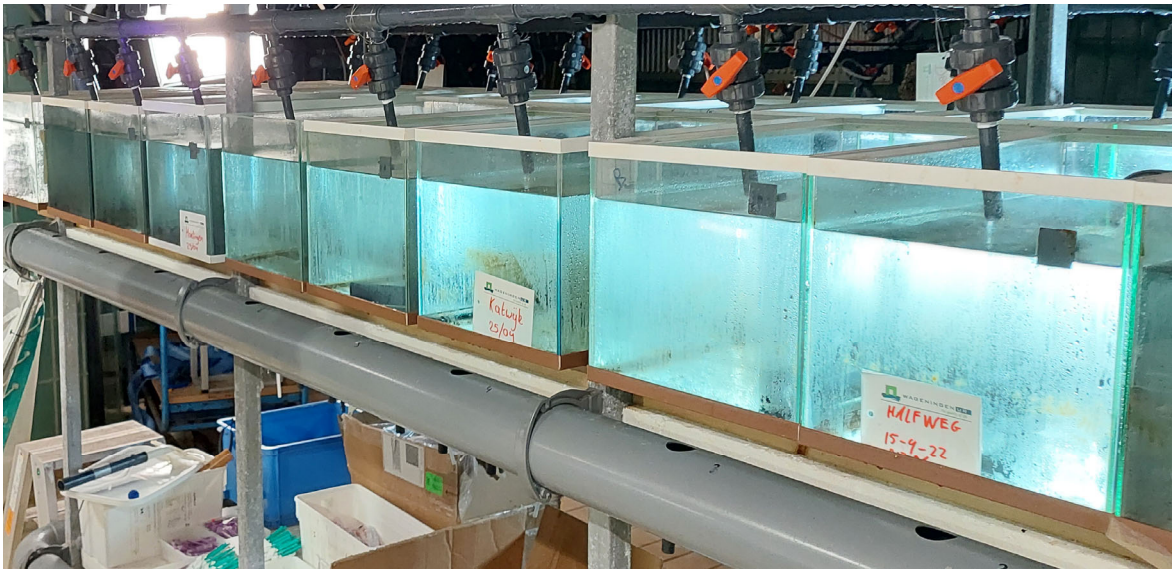
Fieldwork impressions



Catching glass eels using liftnets at location A (Zuiderdiep).

Catching glass eels using ELFI's at location C (Haringvliet) and location B (Stellendam).

Catching glass eels using ELFI's at location E (Gorzeman) and location F (Rozenburg).



Lab facilities in Ijmuiden

Tagging glass eels in Ijmuiden and 1504 green-green tagged glass eels to be released again

Examples of colour codes for glass eels.

Transportation of glass eels in aerated 50L tanks near the Haringvlietdam.

Release of tagged glass eels at location R (Putten) and T (Hoge Nesse)

Marked yellow eel (elver)

3 Results

3.1 Catches

A total of 37.965 glass eels were caught and checked for tags between the 1st of March 2022 and the 4th of July 2022 (Table 2 and Figure 0-1). Most glass eels were caught at location A (n=27.921 glass eels), B (n=3.424 glass eels) and H (n=4.249 glass eels) (see Figure 3-1 for locations). At location M (Gouda), N (Julianasluis) and V (Oostkil) no glass eels were caught.

In addition 2.586 young yellow eel were caught. Most of them were caught on location L (Verdoold, n=586 elvers) and E (Gorzeman, n=440 elvers). No yellow eel were caught at location F and M. The seasonal course of the eel catches differed per location (Figure 3-2). For example, at location E a clear pattern can be seen where: initially glass eels were caught during April, and subsequently yellow eel was caught during May and June. Near the coast, yellow eels were absent (loc. F, Rozenburg) or present in small numbers compared to glass eel (e.g. loc. A – D). On the east side of the study area, further land inwards, this is reversed (locations J, L, Q and S).

Table 2 Table of eel catches divided in glass eel and yellow eel at each locations including start and end date of the monitoring.

			Start date			Last date			Glass eel		Yellow eel	
Location	**Location name**	**Site description**	**D**	**M**	**Y**	**D**	**M**	**Y**	**Catch**	**CPUE**	**Catch**	**CPUE**
A	Zuiderdiep	Discharge sluice	1	3	2022	4	7	2022	27921	242.8	96	0.8
B	Goereese sluis	Ship lock	1	3	2022	4	7	2022	3424	31.7	21	0.2
C	Haringvlietdam South	Discharge sluice	8	3	2022	27	6	2022	196	1.6	3	0.0
D	Haringvlietdam North	Discharge sluice	8	3	2022	27	6	2022	168	1.9	7	0.1
E	Gorzeman	Pumping station	5	4	2022	4	7	2022	52	0.6	440	5.0
F	Rozenburg / Brielsemeer	Discharge sluice	5	4	2022	21	6	2022	405	5.4	0	0.0
G	Westland	Pumping station	18	3	2022	30	6	2022	297	3.7	32	0.4
H	Zaaijer	Pumping station	17	3	2022	30	6	2022	4249	48.8	33	0.3
I	Schiegemaal	Pumping station	18	3	2022	30	6	2022	282	3.2	44	0.5
J*	Schilthuis	Pumping station	31	3	2022	9	6	2022	185	2.9	260	4.1
K	Abraham Kroes	Pumping station	29	3	2022	28	6	2022	7	0.1	49	0.6
L	Verdoold	Pumping station	18	3	2022	28	6	2022	17	0.2	586	5.6
M	Gouda	Pumping station	28	3	2022	13	6	2022	0	0.0	0	0.0
N	Julianasluis	Ship lock	28	3	2022	13	6	2022	0	0.0	1	0.0
O	Waaiersluis	Ship lock	11	4	2022	28	6	2022	48	0.6	37	0.5
P	Kinderdijk	Pumping station	4	4	2022	27	6	2022	108	1.3	84	1.0
Q	Krimpenerwaard	Pumping station	4	4	2022	28	6	2022	21	0.3	62	0.8
R	Putten	Pumping station	5	4	2022	24	6	2022	214	2.9	312	4.3
S	Eendragt	Pumping station	24	3	2022	24	6	2022	91	1.0	288	3.3
T	Hoge Nesse	Pumping station	29	3	2022	5	7	2022	268	2.9	206	2.2
U	Altena	Pumping station	19	4	2022	20	6	2022	12	0.2	21	0.3
V	Oostkil	Pumping station	19	4	2022	20	6	2022	0	0.0	4	0.1
	Totaal								**37965**		**2586**	

*The closing of a safety door damaged the hose after 9th of June 2022. Because of the complex installation at this location the ELFI was disconnected and removed.

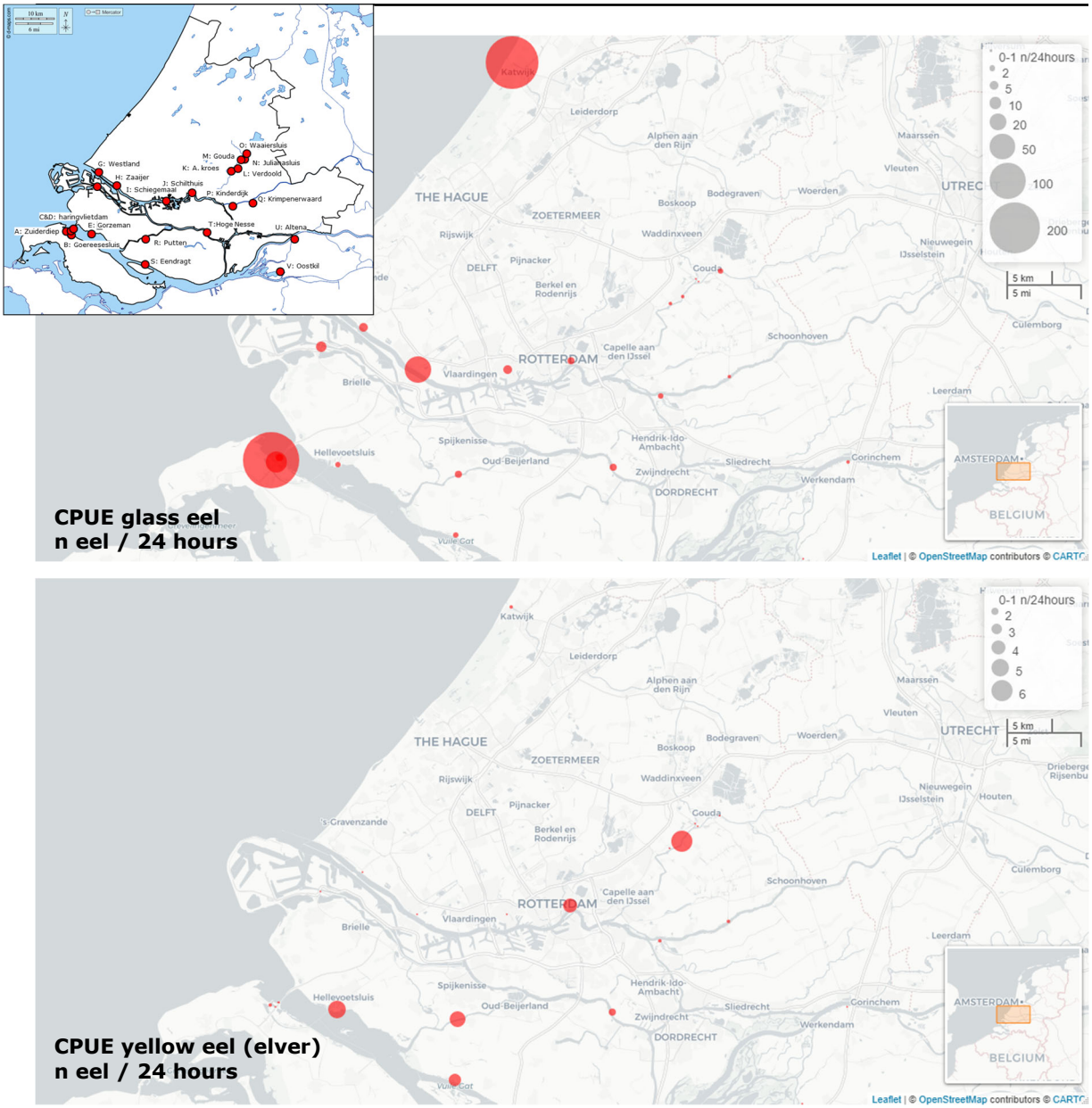


Figure 3-1 Catches of glass eel (top) and yellow eel / elvers (bottom) at each monitoring location in the study area. Numbers expressed as n eel / 24 hours.

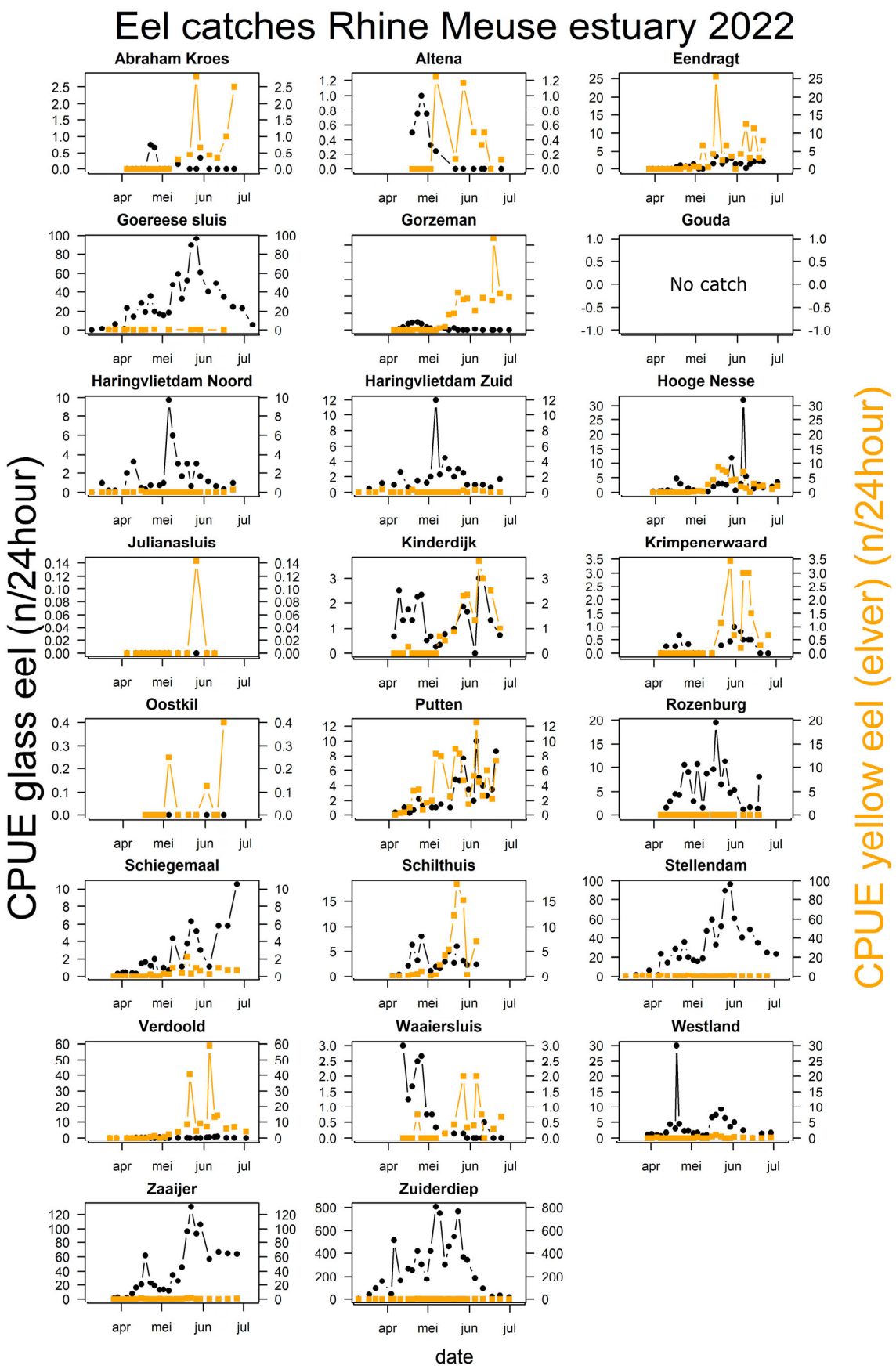


*Figure 3-2 Catches of glass and young yellow eel (elvers) during the study period at each monitoring location. CPUE = Catch Per Unit Effort expressed in n eel / 24 hours. In **black**: left Y-axis CPUE of glass eel. In **yellow**: right Y-axis CPUE of yellow eel.*

3.2 Recaptures

Glass eel - ELFI

In total 3.883 marked glass eel were recaptured with the ELFI (Table 3). One should bear in mind that this study followed a non-destructive method[5] with both tagged and untagged glass eels. Hence the recapture rate may be >100%. The results showed that, from within the groups that were released at Hoek van Holland (location R4), 121 recaptures were caught further inland at multiple locations (Figure 3-3). These recaptures originated from multiple marked groups (Table 3), which gives a good insight in the distribution along the course of the Nieuwe Waterweg. In addition, multiple glass eels, that were released at Hoek van Holland (Nieuwe Waterweg) were caught at Zuiderdiep (n=21) or the Goereesesluis (n=2). Tagged glass eels from Hoek van Holland were also found at Katwijk (n=3). Vice versa tagged glass eels released at Katwijk were recaptured a Zuiderdiep (n=3, Table 3).

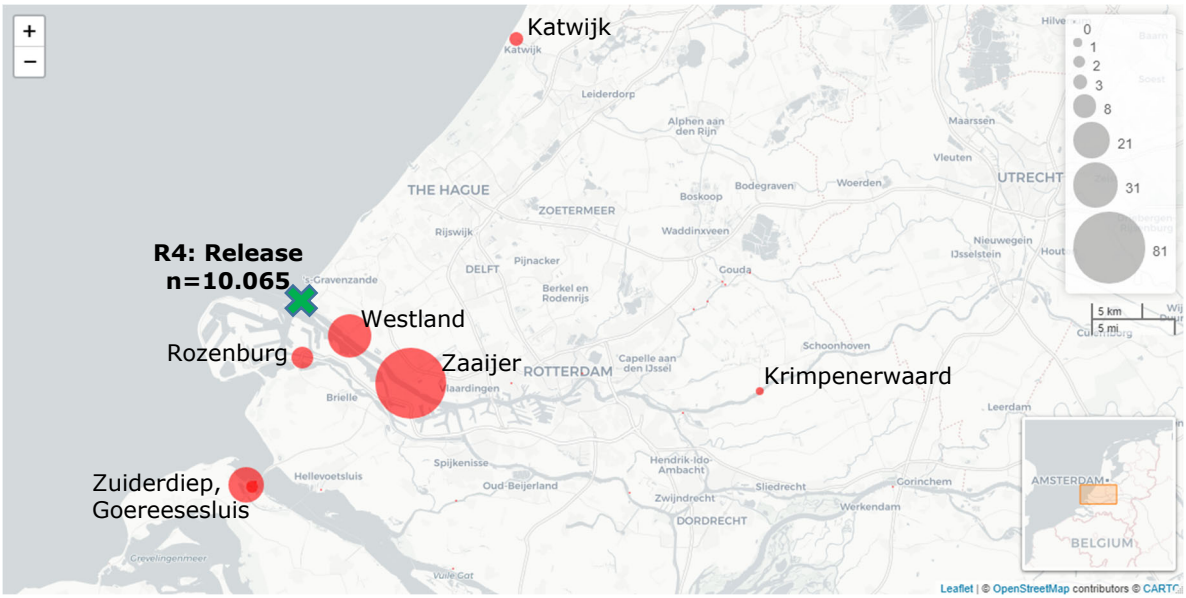


Figure 3-3 Number n of recaptured (tagged) glass eel which were originally released at Hoek van Holland (total released n=10.065). Numbers correspond with Table 3.

The glass eels released at the seaside of the Haringvlietdam were recaptured again at the seaside of the Haringvlietdam (Figure 3-4). One tagged glass eel (n=1) was found in the hinterland at pumping station Putten. Some tagged glass eels however showed dispersal along the coast. Tagged glass eels released at the Haringvliet showed dispersal from the Haringvliet toward the Nieuwe Waterweg (n=1, Westland and n=4, Zaaijer). In general 14.8% (range 0-262.8%) was recaptured when all tagged glass eels are pooled together.

[5] A non-destructive means that individuals, both tagged as untagged, are released again at the catch side of the barrier as described by Skalski et al. (2009). Therefore it could be that glass eels are recaptured multiple times. This is important to quantify both delay and to measure an abundance estimate throughout the study period. A similar approach is done with mark recapture studies along the coast and during the study in the North Sea Canal (Griffioen et al. 2019). A recapture rate >100% gives an clear indication of a migratory delay at the barrier.

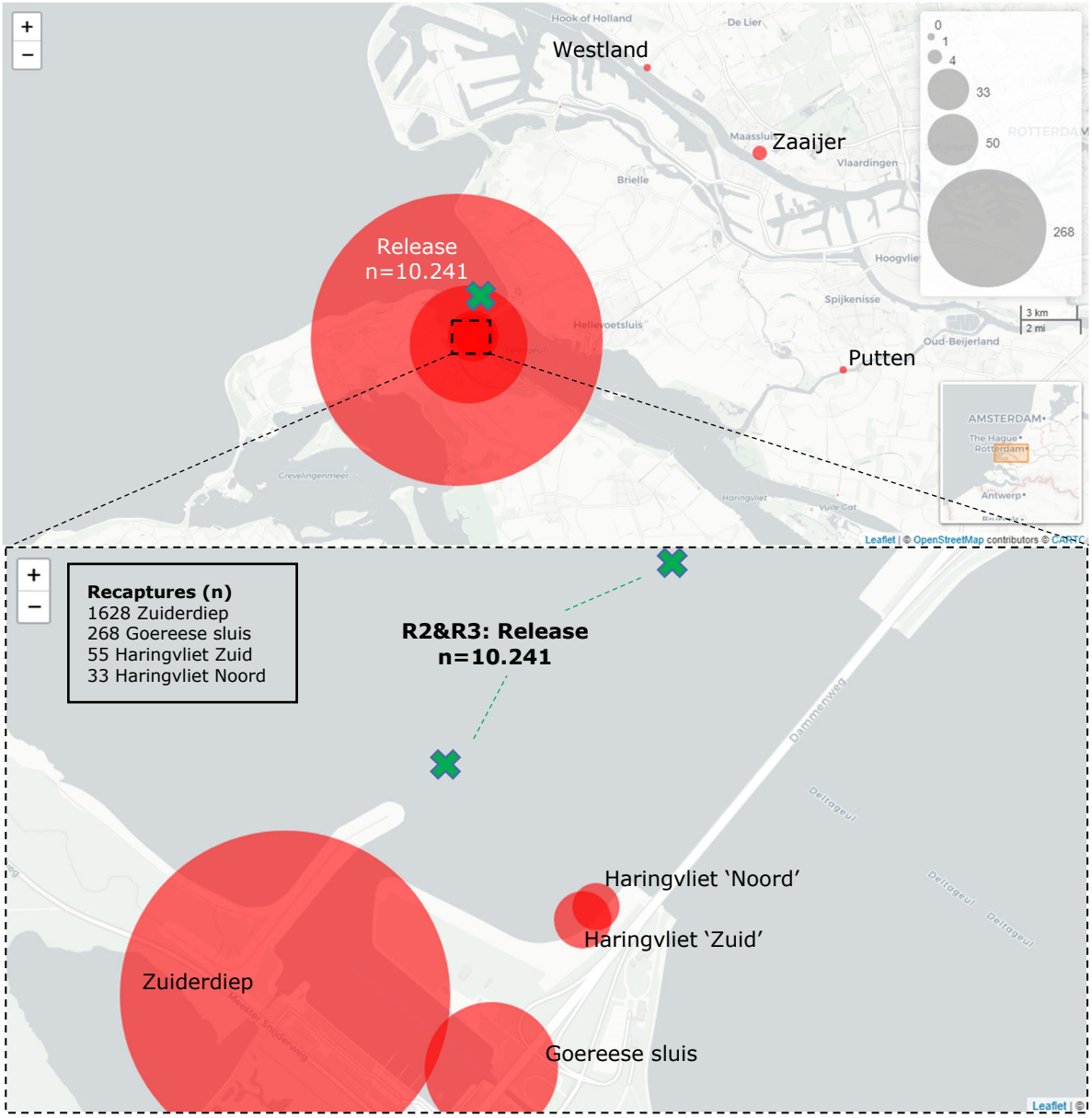


Figure 3-4 Number n of recaptured (tagged) glass eel which were originally released at seaside of the Haringvlietdam (total released n=10.241). Numbers correspond with Table 3.

Table 3 Table of recaptured glass eels in the ELFI's per group and per location. re=red, ye=yellow, pi=pink, bl-blue, gr=green, or=orange, ZD=Zuiderdiep, DO=Den Oever, HL=Harlingen, KW=Katwijk, EL=ELFI, LN=Liftnet. See detailed description of groups in Appendix A.

Colour	Release location	Release date	Catch device	Catch location	Number	Abraham Kroes	Altena	Eendragt	Goereese sluis	Gorzeman	Gouda	Haringvlietdam Noord	Haringvlietdam Zuid	Hooge Nesse	Julianasluis	Katwijk	Kinderdijk	Krimpenerwaard	Oostkil	Putten	Rozenburg	Schiegemaal	Schilthuis	Verdoold	Waaiersluis	Westland	Zaaijer	Zuiderdiep	Percentage recapture
-	Abraham Kroes	limited catches																											-
re-re-re	Altena	6/15	EL	ZD	40																								-
bl-pi-bl	Eendragt	5/17	EL	ZD	99			14																					14.1%
ye-pi	Goereese sluis	4/28	EL	HL	441				15				1															47	14.3%
ye-bl-ye	Goereese sluis	5/19	EL	ZD	352				41			1																201	69.0%
gr-pi-gr	Goereese sluis	5/23	EL	ZD	317				32				1															151	58.0%
-	Gouda	no catches																											-
pi-or	Gorzeman	5/12	EL	ZD	100					1																			1.0%
or-or-bl	Gorzeman	5/25	EL	ZD	99																								-
gr-ye	Haringvlietdam	4/5	EL	ZD	423				17																			65	19.4%
or-gr	Haringvlietdam	4/5	EL	ZD	417				13																			80	22.3%
bl-bl	Haringvlietdam	4/5	LN	ZD	862				12			1														1		175	21.9%
pi-pi	Haringvlietdam	4/5	LN	ZD	860				6																			94	11.6%
or-bl-or	Haringvlietdam	4/21	EL	ZD	211				9																			91	47.4%
or-ye-or	Haringvlietdam	4/21	EL	ZD	222				9				1															83	41.9%
or-pi-or	Haringvlietdam	4/21	LN	ZD	235				3																			50	22.6%
or-re-or	Haringvlietdam	4/21	LN	ZD	239				4																			48	21.8%
re-re	Haringvlietdam	4/28	EL	DO	1554				40			3	11							1								197	16.2%
gr	Haringvlietdam	4/28	EL	HL	1525				18																		1	187	13.5%
re-ye	Haringvlietdam	5/5	EL	DO	1904				76			13	17															286	20.6%
ye-ye	Haringvlietdam	5/5	EL	DO	1789				61			16	21														3	272	20.8%
gr-re	Hoek van Holland	4/12	EL	ZD	994																2					2	9		1.3%
re	Hoek van Holland	4/12	LN	ZD	569											2					2						2	1	1.2%
ye	Hoek van Holland	4/20	EL	ZD	1244																1					5	19	4	2.3%
gr-or	Hoek van Holland	4/20	LN	ZD	702																						14		2.0%
pi	Hoek van Holland	4/28	EL	HL	2028																1					8			0.4%
or-bl	Hoek van Holland	4/28	EL	ZD	771																					4	7	3	1.8%
gr-gr	Hoek van Holland	5/6	EL	DO	1508				1									1			1					4	12	7	1.7%
or	Hoek van Holland	5/6	EL	ZD	2249				1							1					1					8	18	6	1.6%
gr-pi	Hollandsche Ijssel	5/11	EL	ZD	1000												5	1											0.6%
re-pi	Hollandsche Ijssel	5/19	EL	ZD	1074																								-
or-or-or	Hooge Nesse	5/25	EL	ZD	121									4															3.3%
re-ye-ye	Hooge Nesse	6/14	EL	ZD	66																								-
or-or-ye	Julianasluis	5/16	EL	KW	102																								-
bl-ye	Katwijk	5/13	EL		346				2																			1	0.9%
gr-gr-gr	Kinderdijk	5/2	EL		40												16												40.0%
ye-ye-ye	Kinderdijk	6/8	EL		15												9												60.0%
-	Krimpenerwaard	limited catches																											-
pi-pi-pi	Oostkil	6/15	EL	ZD	37																								-
gr-gr-re	Putten	5/13	EL	ZD	100															1									1.0%
re-or	Putten	5/25	EL	ZD	105															4									3.8%
ye-re-re	Putten	5/31	EL		25															18									72.0%
re-pi-pi	Putten	6/14	EL		32																								-
gr-ye-gr	Rozenburg	5/9	EL		116																46								39.7%
or-bl-bl	Rozenburg	5/12	EL	ZD	99																19								19.2%
re-gr	Rozenburg	5/19	EL	KW	102																30								29.4%
pi-pi-gr	Schiegemaal	5/12	EL	ZD	89																	6							6.7%
pi-pi-re	Schiegemaal	5/16	EL	ZD	78																	4							5.1%
pi-pi-ye	Schiegemaal	5/19	EL	ZD	152																	19							12.5%
re-re-ye	Schilthuis	5/9	EL		32																		9						28.1%
re-re-pi	Schilthuis	5/12	EL	ZD	81																		2						2.5%
or-gr-or	Schilthuis	5/19	EL	ZD	150																		15						10.0%
bl-ye-ye	Verdoold	5/16	EL	KW	100																			7					7.0%
pi-gr-gr	Waaiersluis	5/16	EL	ZD	82																								-
bl-gr-gr	Westland	5/12	EL		45																					57			126.7%
ye-bl-pi	Westland	5/16	EL	KW	103																					16			15.5%
re-bl-bl	Westland	5/19	EL	ZD	152																					15	4		12.5%
gr-gr-ye	Zaaijer	4/21	EL		154																						303		196.8%
gr-gr-pi	Zaaijer	5/9	EL		94																						247		262.8%
gr-gr-or	Zaaijer	5/12	EL	ZD	80																						141		176.3%
ye-ye-or	Zaaijer	5/19	EL		106																						244		230.2%
TOTAL					**26286**	**0**	**0**	**14**	**360**	**1**	**0**	**34**	**52**	**4**	**0**	**3**	**30**	**2**	**0**	**24**	**103**	**29**	**26**	**7**	**0**	**120**	**1024**	**2049**	**14.8%**

Glass eel – Liftnet program

In addition to the ELFI's multiple recaptures were found using lift nets and traps (Table 4). During the fieldwork on April 12th, 33 marked glass eels were caught, out of in total 1643 glass eels. During the lift net program near the Haringvlietsluizen (lock #17), two marked glass eel were found among a catch of 142 glass eels. Volunteers of RAVON caught nine marked glass eels at the locations Rozenbrug, Westland, Zaaijer and Zuiderdiep.

Table 4 Table of (re)captured glass eels using liftnets and traps

Date	Time	Location	Catch device	Number	Colour code	Program
12 April 2022	21:00-01:30	Zuiderdiep	Lift net 1x1m & 1.6x2.4m	9	pink-pink	WMR / VSN
12 April 2022	21:00-01:30	Zuiderdiep	Lift net 1x1m & 1.6x2.4m	17	blue-blue	WMR / VSN
12 April 2022	21:00-01:30	Zuiderdiep	Lift net 1x1m & 1.6x2.4m	7	green-yellow	WMR / VSN
12 April 2022	21:00-01:30	Zuiderdiep	Lift net 1x1m & 1.6x2.4m	1610	untagged	WMR / VSN
26 April 2022		Haringvlietdam lock #17	Lift net 3x3m	40	untagged	ATKB
09 May 2022		Haringvlietdam lock #17	Lift net 3x3m	50	untagged	ATKB
09 May 2022		Haringvlietdam lock #17	Lift net 3x3m	1	red-yellow	ATKB
23 May 2022		Haringvlietdam lock #17	Lift net 3x3m	46	untagged	ATKB
23 May 2022		Haringvlietdam lock #17	Lift net 3x3m	1	yellow-blue-yellow	ATKB
07 June 2022		Haringvlietdam lock #17	Lift net 3x3m	2	untagged	ATKB
21 June 2022		Haringvlietdam lock #17	Lift net 3x3m	1	untagged	ATKB
10 May 2022		Haringvlietdam lock #17	Trap in discharge lock	1	red-yellow	ATKB
28 April 2022	21:45	Zuiderdiep	Liftnet 1x1m	1	pink-pink	RAVON
09 May 2022	22:20	Rozenburg	Liftnet 1x1m	1	green-yellow-green	RAVON
12 May 2022	22:15	Zuiderdiep	Liftnet 1x1m	1	red-yellow	RAVON
16 May 2022	22:10	Westland	Liftnet 1x1m	1	yellow-blue-pink	RAVON
19 May 2022	22:35	Westland	Liftnet 1x1m	1	red-blue-blue	RAVON
23 May 2022	22:20	Westland	Liftnet 1x1m	1	red-blue-blue	RAVON
23 May 2022	23:50	Zaayer	Liftnet 1x1m	1	green-green-orange	RAVON
30 May 2022	23:55	Zaayer	Liftnet 1x1m	1	green-green-green	RAVON
02 June 2022	23:20	Zaayer	Liftnet 1x1m	1	green-green-pink	RAVON

Recaptures elvers and young yellow eel

In total 191 marked yellow eel were recaptured using the ELFI. It should be taken into account that this study followed a non-destructive approach[6] meaning that individuals, both tagged as untagged, could be recaptured multiple times. In general 17.1% (range 0-61.8%) was recaptured when all tagged elvers are pooled together.

Table 5 Table of recaptured yellow eel per group and per location.

colour	Release location	Release date	Catch device	Catch location	Number	Abraham Kroes	Altena	Eendragt	Gorzeman	Hoge Nesse	Kinderdijk	Krimpenerwaard	Oostkil	Putten	Schilthuis	Verdoold	Waaiersluis	
green-yellow-green	Abraham Kroes	9.6.22	ELFI	Abraham Kroes	16													-
orange-orange	Abraham Kroes	14.6.22	ELFI	Schilthuis	22													-
red	Altena	15.6.22	ELFI	Verdoold	40													-
pink-yellow-yellow	Eendragt	31.5.22	ELFI	Eendragt	47													-
green	Eendragt	14.6.22	ELFI	Eendragt	55			4										7.3%
green-red	Eendragt	14.6.22	ELFI	Eendragt	7													-
pink-pink	Gorzeman	15.6.22	ELFI	Gorzeman	92				10									10.9%
green-orange-orange	Gorzeman	22.6.22	ELFI	Gorzeman	52				1									1.9%
red-pink-pink	Hooge Nesse	31.5.22	ELFI	Hooge Nesse	62					7								11.3%
green-orange-orange	Hooge Nesse	22.6.22	ELFI	Gorzeman	29													-
green-red-red	Kinderdijk	8.6.22	ELFI	Kinderdijk	24						3							12.5%
green-orange	Kinderdijk	14.6.22	ELFI	Kinderdijk	28						5							17.9%
green-green	Krimpenerwaard	9.6.22	ELFI	Krimpenerwaard	25							7						28.0%
green-yellow	Krimpenerwaard	15.6.22	ELFI	Krimpenerwaard	13													-
orange	Oostkil	15.6.22	ELFI	Verdoold	40								2					5.0%
yellow-red-red	Putten	31.5.22	ELFI	Putten	73									13				17.8%
pink-pink-yellow	Putten	14.6.22	ELFI	Putten	46									1				2.2%
yellow-red	Schilthuis	30.5.22	ELFI	Schilthuis	86										15			17.4%
red-green-green	Schilthuis	2.6.22	ELFI	Schilthuis	76										8			10.5%
yellow-yellow	Verdoold	25.5.22	ELFI	Verdoold	144											89		61.8%
red-red	Verdoold	9.6.22	ELFI	Verdoold	54											19		35.2%
pink	Verdoold	15.6.22	ELFI	Verdoold	40											4		10.0%
green-green-green	Waaiersluis	9.6.22	ELFI	Waaijersluis	20												1	-
orange-orange-green	Waaiersluis	15.6.22	ELFI	Waaijersluis	6												2	-
TOTAL					**1097**	**0**	**0**	**4**	**11**	**7**	**8**	**7**	**2**	**14**	**23**	**112**	**3**	**17.1%**

[6] See footnote #4

3.3 Length weight elvers and yellow eel

In the ELFI's also young yellow eels (elvers) were caught. Of the individuals that were marked, two individuals were larger than 40cm (Figure 3-5). The majority of the catch however was <20cm (elvers). The length variety differed among locations (Figure 3-5)[7]. The largest variety in length was found at Verdoold (avg. 14.5cm; range: 8.1-46.5cm), Hoge Nesse (avg. 16.2cm; range: 7.2-37.2cm) and Eendragt (avg. 18.7cm; range: 8.1-41.8cm). The smallest young yellow eel were found at Schilthuis (avg. 12.3cm; range: 9.2-19.0cm) and the Waaiersluis (avg. 12.2cm; range: 7.8-18.9cm).

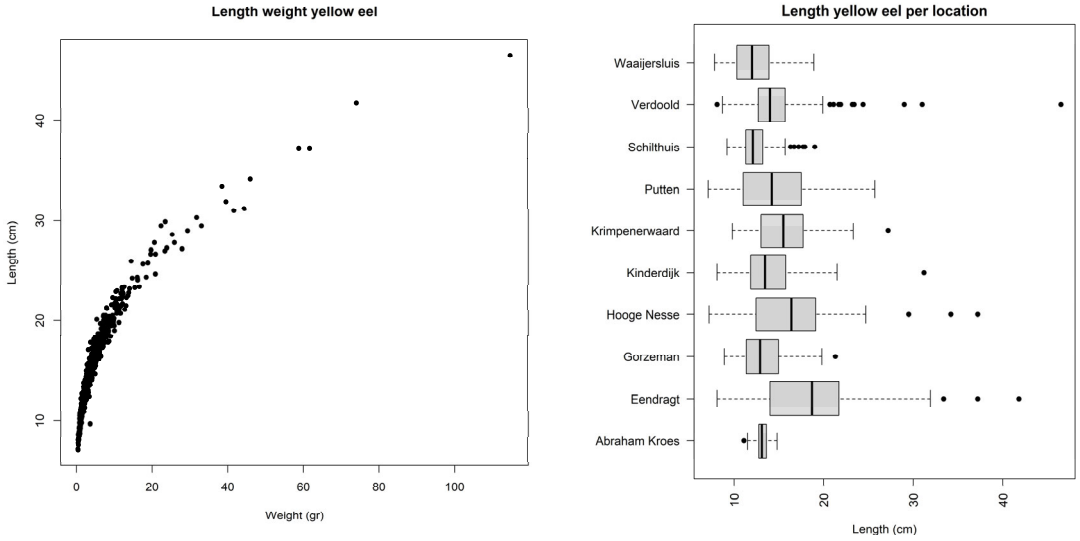


Figure 3-5 Length and weight of yellow eel during the study period.

[7] Two groups of elvers/ young yellow eel were transported from Verdoold and Schilthuis to location Abraham Kroes, Oostkil and Altena (**Error! Reference source not found.**).

3.4 Passage efficiency

At location R (Putten) the efficiency of a fish passage was measured. The trap was placed on April 20th, to catch glass eels and yellow eel. In total 262 tagged glass eels (four different groups) and 119 yellow eel (two different groups) were released near the fish passage. None of the tagged glass eels were recaptured in the trap. Among the catch was round goby, tubenose goby, roach, rudd, common bleak and bream (Table 6). No eel (n=0) was caught in the trap during the study period. Also juvenile Chinese mitten crab (*Eriocheir sinensis*) was caught, as well as large amounts of fish larvae, on June 7th and June 21st (undetermined species). The passage efficiency was measured at 0%.

Furthermore, at five other locations, passage efficiency assessments had been planned, using a net behind the fish passages. However, at Location H and I, strong currents (inflow) and trash in the water column, caused major damage to the traps, the frame and the grooves at the sides of the wall. Additionally, at all locations, a lack of rain resulted in waterboards deciding to allow large volumes of water into the polders and other water systems. This made taking samples, using traps impossible. Therefore it was decided to postpone the passage efficiency assessment at locations (G), H, I, L and Q to 2023. A sixth location (G: Westland) had already been postponed until next year.

The postponed fieldwork did not affect the estimation of abundance at the seaside and at inland locations and the distributional assessment alongside the river sections. A mark-recapture experiment to measure abundance and to measure distribution can independently be measured.

Table 6 Table of the catch in the trap at location R (Putten) behind the fish passage

Common name	**Latin name**	**N**	**CPUE**
Round goby	*Neogobius melanostomus*	32	0.52
Western tubenose goby	*Proterorhinus semilunaris*	10	0.16
Roach	*Rutilus rutilus*	3	0.05
Rudd	*Scardinius erythrophthalmus*	1	0.02
common bleak	*Alburnus alburnus*	2	0.03
Bream	*Abramis brama*	1	0.02
Fish larvae		>>1000	

4 Conclusions and recommendations

4.1 General remarks on the study

This data report gives an overview of the planned and work that has been carried out in the spring of 2022. During the study 37.965 glass eels and 2.586 yellow eels were caught. In total 26.294 glass eels and 1.097 yellow eels were tagged divided over multiple groups. In general 17.1% (range 0-61.8%) was recaptured when all tagged elvers are pooled together. In general 14.8% (range 0-262.8%) was recaptured when all tagged glass eels are pooled together.

Prior to the fieldwork and experimental design, four major research aims and six accompanying research questions were defined.

1. **What is the overall abundance of glass eels in the Nieuwe Waterweg and Haringvliet in spring 2022?**
   This can be estimated using the data collected in spring 2022.
2. **What is the abundance of glass eel near local barrier at inland locations?**
   This can be estimated using the data collected in spring 2022.
3. **What is the ratio between overall and local abundance of glass eel in the Rhine Meuse estuary?**
   This can be estimated using the data collected in spring 2022.
4. **Do glass eels experience delay at inland barriers and if so, what is the estimated average number of days that glass eels?**
   This can be estimated using the data collected in spring 2022.
5. **What is the passage efficiency for glass eel of realized fish migration measures in the study area?**
   This can be measured for one location and will be measured in spring 2023 for the other relevant locations.
6. **What management measures are needed in order to optimize fish migration and how should these measures be prioritized?**
   With all the information collected in spring 2022 and 2023 this question can be answered in the final report.

The data collection to answer the fifth research question has been partially postponed, due to technical issues, as previously described in the results. The postponed fieldwork *does not* affect the other research questions.

In the final report[7] we will further present and the insights that have been found in spring 2022. It will present a detailed analysis including a comparison to discharge data retrieved from the different waterboards. The final report will also include the pass efficiency research that will be executed in the spring of 2023.

4.2 Abundance estimate using a mark recapture approach

To estimate the abundance, enough marked glass eels should be released, to ensure recaptures along the course of the water body or at the coastal side of the barrier. At the start of the study, the initial plan was to tag 20.000 glass eel, along the coast, divided into 8 groups (over two locations) and subsequently follow them along the course of the Nieuwe Waterweg and the Haringvliet. A previous pilot study showed that a mark recapture study at the Haringvlietdam may be difficult to execute due to low catches (hundreds of glass eels) (Bergsma et al. 2020). Therefore additional glass eel along the Dutch coast were caught to complement the target of 20.000. Contrary to the pilot study however we managed

to catch large amounts of locally caught glass eels at the Zuiderdiep (47% of the total n=9.998) using liftnets and the ELFI. The other part (53%), was complemented with catches of other locations along the coast also to limit the number of different colour codes within the study. In conclusion, we succeeded to tag and release 21.242 glass eels, divided over 21 groups along the coast. In the hinterland we managed to release 4.874 tagged glass eel in order to measure local and regional abundance.

Overall abundance
Results showed that the number of tagged glass eels was enough to answer the research question related to abundance. Multiple recaptures were present at the westside of the study area: Rozenburg, Westland and Zaaijer, but also at the very west side of the study area at Krimpenerwaard. Therefore an abundance estimate can be made using the data collected in 2022.

At the coastal side of the Haringvlietdam multiple recaptures (n=1980[8]) were found at the Haringvlietdam, Zuiderdiep and the Goereese sluis (Stellendam). In the hinterland however recaptures were limited to the one at Putten. Similar to the study executed by Schiphouwer and Kooiman (2021) glass eels may settle in the fresh water area before migrating further inland as young yellow eel. The Haringvliet itself may already be an optimal habitat to settle for glass eel.

Local and regional abundance in the hinterland
The results showed that (untagged) glass eels were caught throughout the study area up to at the very eastern side of the study area at location O (Waaiersluis) and U (Altena). Therefore, the overall abundance within the overall study area, can be related to the multiple local abundances at most monitoring locations. Multiple groups of tagged glass eels were released at most of the locations, either by using locally caught glass eel, or by transporting them from elsewhere. In addition to this, we additionally released 2.074 tagged glass eel at the Hollandsche Ijssel to estimate the regional abundance of glass eel. We recaptured them back at Kinderdijk (n=5) and Krimpenerwaard (n=1) showing that part of them drifted downstream.

Yellow eel abundance
Multiple locations showed increased catches of young yellow eels during the season. Therefore those eel were collected and tagged and released to estimate abundance of young yellow eel at those sites. Local abundance estimates can be made using tagged glass eels released at multiple sites.

4.3 Distribution along the coast and alongside the river sections

To study distribution along the river course, the tagged glass eels are monitored at inland locations. Similar to question 1, one should release enough marked glass eels to ensure recaptures along the course of the water body. The results showed that multiple recaptures were present at multiple locations and of multiple marked groups (total n=121). This gives insight in the distribution along the course of the Nieuwe Waterweg. In the Haringvliet one tagged glass eel (n=1) was found at Putten. In addition to the westwards dispersal tagged glass eels showed also dispersal along the coast gives additional information about glass eels dispersal along the coast in relation to environmental factors such as waterflow and wind direction (Suijkerbuijk 2022).

4.4 Passage efficiency and recommendations

The experiences of the current monitoring programme (2022), and the technical issues that accompany measuring passage efficiency continuously using a trap behind the fishpassage (damage to the traps and construction due to excessive waste in the water), showed that this method was unsuited for future use. It is therefore recommended to measure passage efficiency over a few consecutive days (evenings), instead of a measurement throughout the whole monitoring period, to prevent damage to the traps

[8] In the final report data may show more recaptures since the ELFI is still in operation.

(Griffioen et al. 2018). Measuring consecutive evenings will allow the emptying of the trap more frequently and the removal of waste from the trap before it can damage the construction. Since this is more labour intensive, the monitoring period will be shorter. This approach will lead to a measurement of minimal passage efficiency[9] similarly measured at pumping station Schoute (Griffioen et al. 2018). Previous research has shown that an estimation can be made calculating overall passage efficiency (Griffioen and Berg 2022). It is recommended to release multiple tagged groups in different periods. After each release a monitoring of consecutive days must be executed. In addition to the passage efficiency measurements, a mark recapture program using an ELFI must be carried out in front of the fish passage in order to measure 'delay[10]' and total abundance throughout the migration period to get insight in the efficiency of the migrating glass eels near a barrier.

To compare abundance estimations and dispersal between years it is recommended to release multiple groups of tagged glass eels at the entrance of the Nieuwe Waterweg again similarly to the study carried out in 2022. Those eels can potentially be caught using ELFI's elsewhere and using a larger liftnet at location A (Zuiderdiep).

It should be noted that the missing information about passage efficiency at local fish passages in 2022 does not affect the results of the integral mark-recapture program estimating overall abundance of glass eel in the study area in 2022 and the study of distribution of glass eel throughout the study area.

[9] Some tagged glass eels potentially will pass the trap unnoticed after the monitoring.
[10] Delay as defined as the average number of days that the tagged glass eels are caught in front of the fish passage.

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6 Quality Assurance

Wageningen Marine Research utilises an ISO 9001:2015 certified quality management system. The organisation has been certified since 27 February 2001. The certification was issued by DNV.

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Appendix A

Table A Table of marked glass eels for each location including release data, original catch device, original catch location, colour codes and number of eels per group.

Group	Location ID	Location name	Release date	Catch device	Catch location	Translocation	Mark 1	Mark 2	Mark 3	Number
A	R2	Haringvlietdam	5/apr/22	ELFI	Zuiderdiep	No	green	yellow		423
A	R2	Haringvlietdam	5/apr/22	Lift net	Zuiderdiep	No	pink	pink		860
A	R3	Haringvlietdam	5/apr/22	Lift net	Zuiderdiep	No	blue	blue		862
A	R3	Haringvlietdam	5/apr/22	ELFI	Zuiderdiep	No	orange	green		417
A	R2	Haringvlietdam	21/apr/22	ELFI	Zuiderdiep	No	orange	yellow	orange	222
A	R2	Haringvlietdam	21/apr/22	Lift net	Zuiderdiep	No	orange	red	orange	239
A	R3	Haringvlietdam	21/apr/22	ELFI	Zuiderdiep	No	orange	blue	orange	211
A	R3	Haringvlietdam	21/apr/22	Lift net	Zuiderdiep	No	orange	pink	orange	235
A	R2	Haringvlietdam	28/apr/22	ELFI	Den Oever	Yes	red	red		1554
A	R3	Haringvlietdam	28/apr/22	ELFI	Harlingen	Yes	green			1525
A	R2	Haringvlietdam	5/mei/22	ELFI	Den Oever	Yes	red	yellow		1904
A	R3	Haringvlietdam	5/mei/22	ELFI	Den Oever	Yes	yellow	yellow		1789
A	R4	Hoek van Holland	12/apr/22	ELFI	Zuiderdiep	Yes	green	red		994
A	R4	Hoek van Holland	12/apr/22	Lift net	Zuiderdiep	Yes	red			569
A	R4	Hoek van Holland	20/apr/22	ELFI	Zuiderdiep	Yes	yellow			1244
A	R4	Hoek van Holland	20/apr/22	Lift net	Zuiderdiep	Yes	green	orange		702
A	R4	Hoek van Holland	28/apr/22	ELFI	Zuiderdiep	Yes	orange	blue		771
A	R4	Hoek van Holland	28/apr/22	ELFI	Harlingen	Yes	pink			2028
A	R4	Hoek van Holland	6/mei/22	ELFI	Zuiderdiep	Yes	orange			2249
A	R4	Hoek van Holland	6/mei/22	ELFI	Den Oever	Yes	green	green		1508
A	R1	Stellendam	28/apr/22	ELFI	Harlingen	Yes	yellow	pink		441
A	R1	Stellendam	19/mei/22	ELFI	Zuiderdiep	No	yellow	blue	yellow	352
A	R1	Stellendam	23/mei/22	ELFI	Zuiderdiep	No	green	pink	green	317
B	R5	Hollandsche Ijssel	11/mei/22	ELFI	Zuiderdiep	Yes	green	pink		1000
B	R5	Hollandsche Ijssel	19/mei/22	ELFI	Zuiderdiep	Yes	red	pink		1074
C	U	Altena	15/jun/22	ELFI	Zuiderdiep	Yes	red	red	red	40
C	S	Eendragt	17/mei/22	ELFI	Zuiderdiep	Yes	blue	pink	blue	99
C	E	Gorzeman	12/mei/22	ELFI	Zuiderdiep	Yes	pink	orange		100
C	E	Gorzeman	25/mei/22	ELFI	Zuiderdiep	Yes	orange	orange	blue	99
C	T	Hooge Nesse	25/mei/22	ELFI	Zuiderdiep	Yes	orange	orange	orange	121
C	T	Hooge Nesse	14/jun/22	ELFI	Hooge Nesse	No	red	yellow	yellow	66
C	N	Julianasluis	16/mei/22	ELFI	Katwijk	Yes	orange	orange	yellow	102
C	P	Kinderdijk	2/mei/22	ELFI	Kinderdijk	No	green	green	green	40
C	P	Kinderdijk	8/jun/22	ELFI	Kinderdijk	No	yellow	yellow	yellow	15
C	V	Oostkil	15/jun/22	ELFI	Zuiderdiep	Yes	pink	pink	pink	37
C	R	Putten	13/mei/22	ELFI	Zuiderdiep	Yes	green	green	red	100
C	R	Putten	25/mei/22	ELFI	Zuiderdiep	Yes	red	orange		105
C	R	Putten	31/mei/22	ELFI	Putten	No	yellow	red	red	25
C	R	Putten	14/jun/22	ELFI	Putten	No	red	pink	pink	32
C	F	Rozenburg	9/mei/22	ELFI	Rozenburg	No	green	yellow	green	116
C	F	Rozenburg	12/mei/22	ELFI	Zuiderdiep	Yes	orange	blue	blue	99
C	F	Rozenburg	19/mei/22	ELFI	Katwijk	Yes	red	green		102
C	I	Schiegemaal	12/mei/22	ELFI	Zuiderdiep	Yes	pink	pink	green	89
C	I	Schiegemaal	16/mei/22	ELFI	Zuiderdiep	Yes	pink	pink	red	78
C	I	Schiegemaal	19/mei/22	ELFI	Zuiderdiep	Yes	pink	pink	yellow	152
C	J	Schilthuis	9/mei/22	ELFI	Schilthuis	No	red	red	yellow	32
C	J	Schilthuis	12/mei/22	ELFI	Zuiderdiep	Yes	red	red	pink	81
C	J	Schilthuis	19/mei/22	ELFI	Zuiderdiep	Yes	orange	green	orange	150
C	L	Verdoold	16/mei/22	ELFI	Katwijk	Yes	blue	yellow	yellow	100
C	O	Waaijersluis	16/mei/22	ELFI	Zuiderdiep	Yes	pink	green	green	82
C	G	Westland	12/mei/22	ELFI	Westland	No	blue	green	green	45
C	G	Westland	16/mei/22	ELFI	Katwijk	Yes	yellow	blue	pink	103
C	G	Westland	19/mei/22	ELFI	Zuiderdiep	Yes	red	blue	blue	152
C	H	Zaaijer	21/apr/22	ELFI	Zaayer	No	green	green	yellow	154
C	H	Zaaijer	9/mei/22	ELFI	Zaayer	No	green	green	pink	94
C	H	Zaaijer	12/mei/22	ELFI	Zuiderdiep	Yes	green	green	orange	80
C	H	Zaaijer	19/mei/22	ELFI	Zaayer	No	yellow	yellow	orange	106
Total										**26286**

Table B Table of marked elvers and yellow eel for each location including release data, original catch device, original catch location, colour codes and number of eels per group.

Class	Location ID	Location name	Release date	Catch device	Catch location	Translocation	Mark 1	Mark 2	Mark 3	Number
Yellow eel	K	Abraham Kroes	9/jun/22	ELFI	Abraham Kroes	No	green	yellow	yellow	16
Yellow eel	K	Abraham Kroes	14/jun/22	ELFI	Schilthuis	No	orange	orange		22
Yellow eel	U	Altena	15/jun/22	ELFI	Verdoold	Yes	red			40
Yellow eel	S	Eendragt	31/mei/22	ELFI	Eendragt	No	pink	yellow	yellow	47
Yellow eel	S	Eendragt	14/jun/22	ELFI	Eendragt	No	green	red		7
Yellow eel	S	Eendragt	14/jun/22	ELFI	Eendragt	No	green			55
Yellow eel	E	Gorzeman	15/jun/22	ELFI	Gorzeman	No	pink	pink		92
Yellow eel	E	Gorzeman	22/jun/22	ELFI	Gorzeman	No	green	orange	orange	52
Yellow eel	T	Hooge Nesse	31/mei/22	ELFI	Hooge Nesse	No	red	pink	pink	62
Yellow eel	T	Hooge Nesse	14/jun/22	ELFI	Hooge Nesse	No	red	green	yellow	29
Yellow eel	P	Kinderdijk	8/jun/22	ELFI	Kinderdijk	No	green	red	red	24
Yellow eel	P	Kinderdijk	14/jun/22	ELFI	Kinderdijk	No	green	orange		28
Yellow eel	V	Oostkil	15/jun/22	ELFI	Verdoold	Yes	orange			40
Yellow eel	R	Putten	31/mei/22	ELFI	Putten	No	yellow	red	red	73
Yellow eel	R	Putten	14/jun/22	ELFI	Putten	No	pink	pink	yellow	46
Yellow eel	J	Schilthuis	30/mei/22	ELFI	Schilthuis	No	yellow	red		86
Yellow eel	J	Schilthuis	2/jun/22	ELFI	Schilthuis	No	red	green	green	76
Yellow eel	L	Verdoold	25/mei/22	ELFI	Verdoold	No	yellow	yellow		144
Yellow eel	L	Verdoold	9/jun/22	ELFI	Verdoold	No	red	red		54
Yellow eel	L	Verdoold	15/jun/22	ELFI	Verdoold	No	pink			40
Yellow eel	O	Waaiersluis	9/jun/22	ELFI	Waaijersluis	No	green	green	green	20
Yellow eel	O	Waaiersluis	15/jun/22	ELFI	Waaijersluis	No	orange	orange	green	6
Yellow eel	Q	Krimpenerwaard	9/jun/22	ELFI	Krimpenerwaard	No	green	green		25
Yellow eel	Q	Krimpenerwaard	15/jun/22	ELFI	Krimpenerwaard	No	green	yellow		13
Total										**1097**

Appendix B

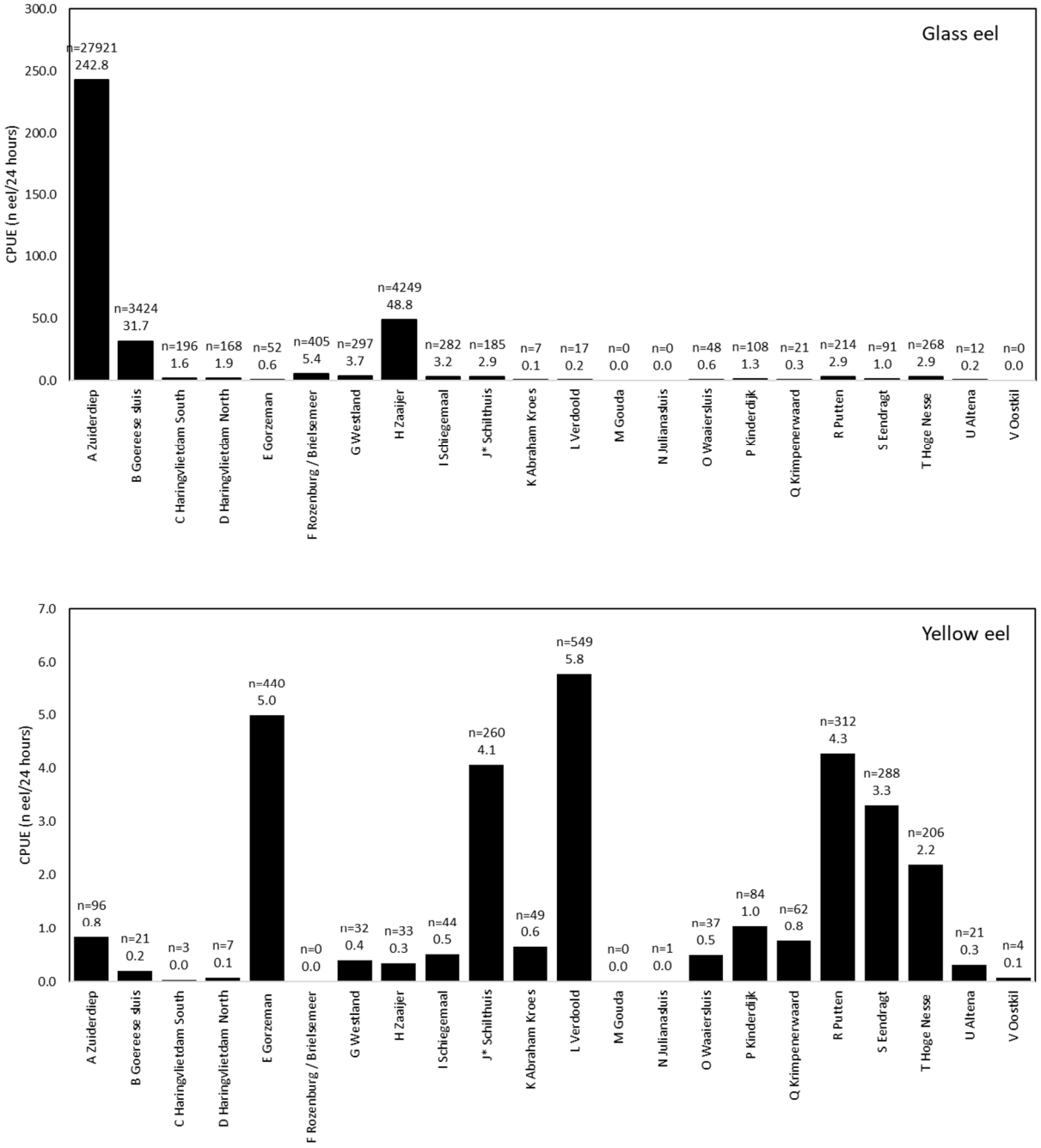

Figure 0-1 Catches of glass eel (top) and yellow eel / elvers (bottom) at each monitoring location in the study area.

Justification

Report C060/22
Project Number: 4316100279

The scientific quality of this report has been peer reviewed by a colleague scientist and a member of the Management Team of Wageningen Marine Research

Approved:	A.L. Hamer Researcher
Signature:	
Date:	06/10/2022

Approved:	Drs. Jakob Asjes MT member Integration
Signature:	
Date:	06/10/2022

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