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F.P.L. Collas, R. van Aalderen,
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F.P.L. Collas[1],
R. van Aalderen[2],
A.P. Scharbert[3]
&
R.S.E.W. Leuven[1]

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[1]Radboud University, Nijmegen
[2]Sportvisserij Nederland
[3]The Rheinischer Fischereiverband von 1880 e.V

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Authors:	F.P.L. Collas, R. van Aalderen, A.P. Scharbert & R.S.E.W. Leuven
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Foreword

This report describes and analyses the fish caught using stow net fishing (in Dutch: Ankerkuil visserij / in German: Hamenfischerei) in the river Rhine and the river Waal (a free flowing distributary of the river Rhine in the Netherlands). The fish monitoring was performed during the period November 2018 up to April 2021. Fishing was performed by professional fisherman in collaboration with the Dutch Angling Association (in Dutch: Sportvisserij Nederland; SNL) and the Rhenish Fishing Association from 1880 (in German: Rheinischer Fischereiverband von 1880 e.V.; RhFV). The project was part of a German-Dutch cooperation, named: Green Blue Rhine Alliance (GBRA). This conjoint project was funded by an European INTERREG VA subsidy, the Dutch Angling Association (SNL), the Directorate-General for Public Works and Water Management (in Dutch: Rijkswaterstaat; RWS), and by the District Government Dusseldorf (in German: Bezirksregierung Düsseldorf). The available data were analysed by Radboud University.

Content

Summary

In the period 2018 – 2021 stow net fishing was performed in the rivers Waal and Rhine. Stow net fishing is a historical commercial fishing technique used at the end of the 19th century up to the beginning of 2nd world war. This technique is based on an anchored ship with nets that passively collects downstream moving fish in the entire water column. Due to reduced catches by the deteriorating water quality, the fishing technique was abandoned. With the specific interest in restoring diadromous fish populations there is increasing need to monitor the effect of several management measures that have been taken to achieve healthy diadromous fish populations. Here the stow net might serve as an important approach for monitoring the downstream migration of diadromous fish species in the highly navigated main channel of the river Rhine and its distributaries. Additionally, it was unknown whether the diadromous fish species have preferences to migrate along a specific shore of the river or at a specific time of day and use shore channels along longitudinal training dams in the river Waal. .

All migratory fish species that were expected to be present were caught using the stow net, underpinning that the stow net is an important monitoring approach for the downstream migration of diadromous fish. Despite the relative small volume off sampled water, this also shows that diadromous fish still use the river Rhine to migrate downstream. No difference in diadromous fish catches was found between the left and right bank of the river nor between specific times of day. Caught diadromous fish species were: Atlantic salmon, Seatrout, River lamprey, Sea lamprey, Houting, Allis shad, Flounder, Three-spined stickleback and Eel. Higher diadromous fish concentrations were found in recently constructed shore channels behind longitudinal training dams in the river Waal. When comparing the fish length of Atlantic salmon with historical length frequency distributions the recent individuals were found to be larger.

Interesting differences between abundance and length of more common fish species were found for sampling locations in the German part of the Lower Rhine and the river Waal in the Netherlands. Although these locations were relatively close to each other, the relative abundance of fish differed distinctly. The fish assemblage in the river Waal was dominated by Roach, Bleak and Bream, whereas that of Lower Rhine in Germany was dominated by Bream, Roach and Nase. In general, the length of the common fish species were larger in Germany than in the Netherlands, though not for all species (e.g. Ide). In addition, common fish species were more abundantly caught during the night than during the day and fish diversity was higher in a recently constructed shore channel along a longitudinal training dam than in the main channel.

However, large aspects of downstream migration of diadromous fish still remain unknown. To fully understand when species start to migrate from upstream to downstream parts of the river a more extensive monitoring effort is required allowing for a direct linkage to river discharge. Despite the lack of an effect of riverside, it is still unclear whether diadromous fish also move right through the middle of the main channel which could not be monitored due to intense navigation (safety reasons). Several additional questions also arose due to the large number of mainly juvenile Roach, Bream and Nase caught in October. This could be an indication of local migration to winter habitat which was not documented before but could be important information for optimizing river management in favour of these fish species.

1. Introduction

1.1 Historical use of stow net fishing

Stow net fishing originated at the end of the 19th century (1870 – 1890) in the Rhine – Meuse river delta (Van Doorn 1971). The use of this fishing technique gradually moved upstream on the rivers with the first operating stow net fishery at Heerewaarden in 1901 (Van Doorn 1971). From there, its use further spread upstream up to the German border resulting in 130 to 152 stow net fishers in the Waal-Rhine river reaches from Heerewaarden to the German border in the period 1912 – 1914 (Van Doorn 1971). In Germany stow-net fisheries was concentrated in the lower Rhine section (Bürger 1926, Böcking 1981) but reached up to the upper Rhine in Baden. Yet at the end of the 19th century stow net fisheries were already used to address scientific questions (Hoek 1899). After the 2nd world war the stow net fishing quickly fell into disuse partially due to the decline of fish populations resulting from deterioration of water quality. The stow net fisheries presented in this report were performed near the municipality of Heerewaarden (The Netherlands) and Kalkar-Grieth (Germany) and reinstated this technique at a historically important stow net fishing locations in the German Lower Rhine and the Dutch river Rhine branches.

Figure 1.1: Photo of the boat that has been used for stow net fishing in the river Waal in the Netherlands during 2018 – 2021 (Photo: F. Collas).

1.2 Monitoring programme

River Waal (Netherlands)

Stow net fishing was performed in the main channel of the river Waal near the municipality of Tiel (The Netherlands) during a period of four years (2018-2021; Figure 1.1) by a professional fisherman in collaboration with SNL and RWS. The goal was to monitor downstream migrating fish species. The first stow net fishing was performed in November 2018. In 2019 fishing was performed in May, September and October. In 2020 fishing was limited to September and October. The month of April was intensively monitored in 2021. This report presents preliminary analyses of the fish caught during the stow net sampling. Moreover, the available fish data were compared with stow net fishing in an upstream part of the river Rhine near the municipality of Kalkar (Germany)

River Rhine (Germany)

Since 2019 a German project is using stow net fishing for monitoring target species of the *Natura 2000* sites in the river Rhine according to the European habitat directive. This project is initiated by the RhFV with subsidy of the European Maritime and Fisheries Fund. Fishing is performed by a professional fisherman on the river Rhine near Grieth and Rees (Figure 1.2). In 2020, a connection was made between the Dutch and German projects and extra funds from the GBRA project made it possible to perform additional monitoring in Germany allowing for overlap between the Dutch and German sampling. Stow net fishing in Germany was performed in October 2019; May, October and November 2020 and April and May 2021.

Figure 1.2: Photo of one of the two boats that were used for stow net fishing in the Lower Rhine in Germany during 2019 – 2021 (Photo: A. Scharbert).

1.3 Goal

This report aims to quantitatively analyse the fish data collected using the stow net fishing during 2018 – 2021 (Figure 1.3). The more detailed goals are:

- Analysing the richness and abundance of fish species in order to determine whether stow net fishing is a valuable sampling technique for downstream migrating fish.
- Comparing the recently collected stow net data to historically collected data on stow net fishing (1945 to now).
- Determining at which moments and locations stow net fishing is most effective (find the best monitoring strategy).

The present report answers the following questions:

- What was the effect of sampling effort under various conditions (e.g. time of day) on total species richness?
- Which species had the highest relative abundance and did its abundance differ between locations, time of day and sampling month?
- What is the effect of sampling location, time of day and sampling month on fish diversity caught using the stow net?
- What is the effect of sampling location, time of day and sampling month on fish density caught using the stow net?
- At what time of day do Atlantic salmon and Eel migrate?
- What is the expected number of downstream migrating Atlantic salmon in April 2021?
- What are the fish lengths of regularly caught fish (in particular of diadromous fish) using the stow net?
- Are the recently caught diadromous fish species in accordance to historical stow net catches?

1.4 Reader’s guide

This report contains preliminary analyses of the fish collected during stow net fishing on the river Waal and the German part of the Lower Rhine during the period 2018 – 2021. In chapter two the monitoring approach and subsequent analyses are described. Chapter three describes the results of the monitoring programme and chapter four concerns conclusions and recommendations based on the found results.

Figure 1.3: A sea trout collected during the stow net fishing in the river Waal.

2. Material and methods

2.1 General

During the sampling in the Netherlands, the stow net was used at several locations in the river Waal near the municipality of Tiel (Figure 2.1, Table 2.1). Depending on the specific sampling period either only the location between the shore channel or both locations were sampled (viz. the main channel and shore channel). If the water level of the river was too low stow net fishing in the Dreumel shore channel was performed at the end of the shore channel instead of the entrance of the shore channel. In the early stages of the monitoring fishing was mainly performed during the day. Starting from 2019 fishing was also performed during the night. The German stow net sampling started in October 2019 and continued until April 2021. Stow net fishing in April 2021 deviated from the locations used in the period 2018 and 2020. Additional locations were added to allow for comparing different shore channels (shore channel Dreumel compared to shore channel Ophemert) and between the left and right side of the river. While the monitoring in the river Waal was taking place, monitoring was also performed during the night in the German part German part of the Lower Rhine near the municipality of Kalkar (Figure 2.1).

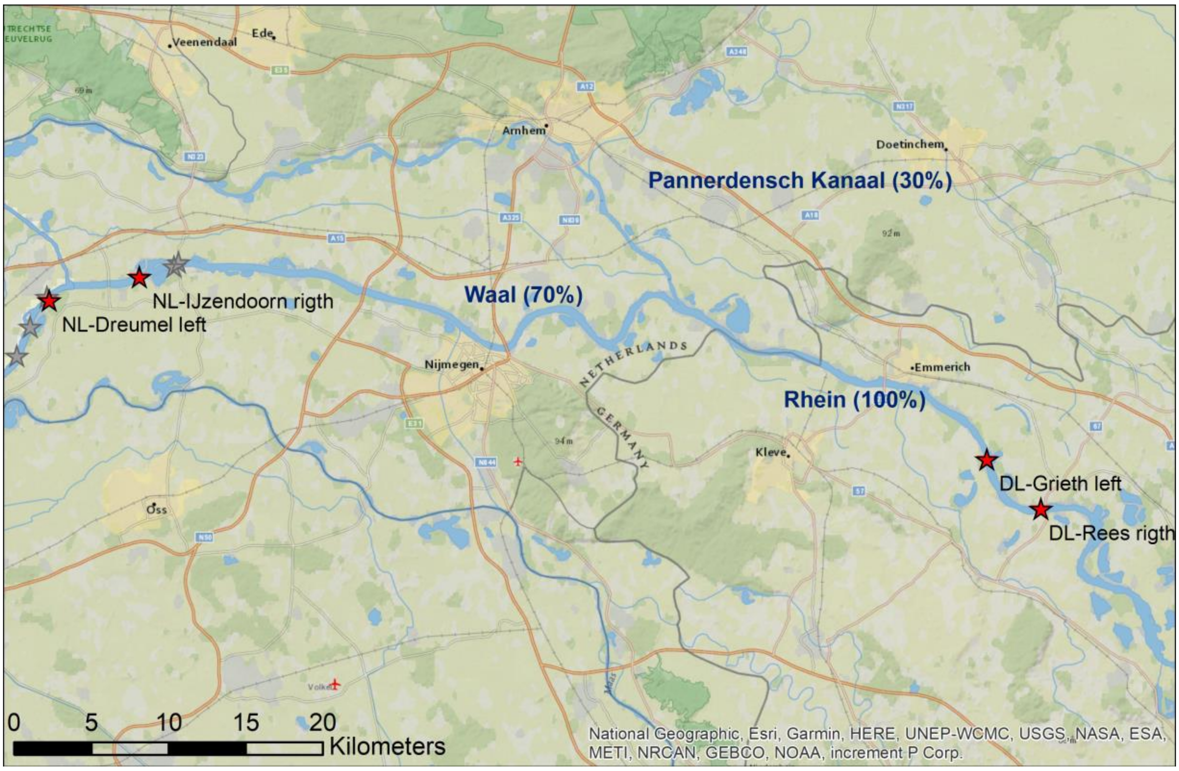

Figure 2.1: Monitoring locations in the rivers Rhine and Waal using the stow net in the period 2018 - 2021. Red stars indicate locations that were sampled throughout the project, the grey stars are locations that were sampled less frequently. The % indicates the percentage of discharge of each distributary of the total discharge of the river Rhine. For detailed maps per sampling location see Appendix 1.

Table 2.1: Overview of the sampled locations, the period and the number of hauls included in this report.

Country		Stow net sampling			
		Day		Night	
	Period	Main channel	Shore channel	Main channel	Shore channel
Netherlands	Nov. 2018	19	n.s.	n.s.	n.s.
	May 2019	8	12	1	5
	Sept. 2019	10	9	n.s.	7
	Oct. 2019	6	5	4	12
	Sept. 2020	4	8	2	13
	Oct. 2020	1	n.s.	5	10
	April 2021*	9	13	15	13
Germany	Oct. 2019	n.s.	n.s.	16	n.s.
	May 2020	n.s.	n.s.	5	n.s.
	Oct. 2020	n.s.	n.s.	5	n.s.
	Nov. 2020	n.s.	n.s.	9	n.s.
	April 2021	n.s.	n.s.	16	n.s.
	May 2021	n.s.	n.s.	5	n.s.

** An additional shore channel and several additional locations in the main channel were sampled*

2.2 Stow net fishing

The stow net fishing in the Netherlands was performed by the professional fishermen Bout-Van Dijke (see cover photo) with the ship ‘ De Harder’. In Germany the professional fisherman Rudi Hell was hired, with the ships Anita II and Heinz. The general fishing technique is the same (Figure 2.2):

- Anchoring the ship into the flow;
- Lowering beams connected to a net into the water;
- The lower beam is lowered to the river floor and the upper beam remains at the surface near the waterline;
- The flow opens the net between the beams.

The beam length of the net used in the Netherlands was 8 m with a smallest mesh size of 20 mm. In Germany, the beam length was 10 m and the smallest mesh size was 12 mm. The mesh size for both nets decreased towards the end of the net.

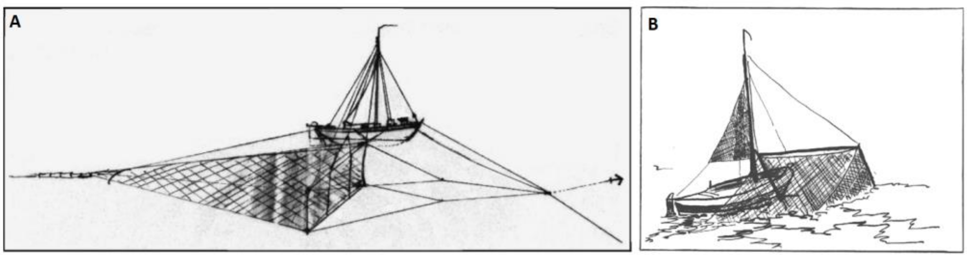

Figure 2.2: Drawing of stow net fishing from the side (A) and from behind (B) (Source: Nienhuis, 2008; Ganita Mare, 2017).

In the Netherlands, stow net sampling was performed in November 2018. Additional samples were collected in May, September and October 2019, September and October 2020 and April 2021 (Table 2.1). In general, per sampling period, two days were used to sample the main channel at the IJzendoorn location (Appendix 1, C) and two days in the Dreumel shore channel (Appendix 1, D). Sometimes sampling was limited to just one of the two locations based on the local water depth. On average the stow net was taken out of the water every 2 hours and 15 minutes, after which fish were collected and the net was lowered again. In the shore channel, sampling was simultaneously performed on both the port and starboard of the boat with two nets. In the main channel sampling was limited to the port side due to the presence of commercial navigation on the starboard side. In 2020 and 2021, occasional sampling at the starboard side was performed at the IJzendoorn location.

In Germany, sampling was performed from October 2019 until April 2021. The sampling was performed at two locations being Grieth and Rees (Figure 2.1). Fishing was limited to one net per location. The nets were lowered into the water around 18:00 after which the catch was retrieved at 08:00 the following day. On average sampling duration was 10 hours.

During each stow net fishing in the Netherlands, the flow velocity was measured at a depth of 30 cm below the water surface. Additionally, using a model the depth averaged flow velocity was calculated for each sampling day by RWS (memo RWS). Flow velocity data was unavailable for the April 2021 sampling due to the short time span.

2.3 Fish processing

After the stow net was retrieved all fish in the net were collected and put in a container with river water. They were quickly identified, measured and released back into the water (Figure 2.3). The largest fish were measured first. If the number of collected fish was high a sub set was taken and identified and measured after which the total catch was extrapolated.

Figure 2.3: Identification and measurement of sampled fish species in Germany (Photo: A. Scharbert).

2.4 Data analyses

2.4.1 Sampling effort

The species richness in the Netherlands and Germany was assessed per individual sample and per sampling period as a whole. With data on the species richness per sample a species accumulation curve (SAC) was fitted using the ‘Vegan’ package (Oksanen et al. 2019) in R (R core team 2020) and the ‘random’ approach. SACs were constructed for comparison of different subsets of fish data being: 1) day and night sampling; 2) sampling month; 3) year and 4) sampling in Germany and the Netherlands.

2.4.2 Relative abundance

The relative abundance of fish species was calculated for several contrasts being: 1) day and night; 2) sampling month; 3) year and 4) October 2020 and April 2021 sampling in Germany and the Netherlands.

2.4.3 Fish diversity

The caught fish species per stow net haul in the Netherlands were analysed using a non-parametric Kruskal-Wallis test since the data was not normally distributed nor gamma or poisson distributed. Transformation did not result in normally distributed data either. The Kruskal-Wallis test was performed for all fish species caught per stow net haul and for the diadromous fish species. Potential explanatory variables were analysed separately and were ‘Day or Night’, ‘Month’ and ‘Location’. Posthoc tests in case of significant effects between locations were performed using a pairwise Wilcoxon test using a Bonferroni correction. The fish diversity analysis was performed using R statistics (R Core Team 2020).

2.4.4 Fish density

For the fish data from the Netherlands the sampled volume (sampled width x sampled height x flow velocity) was used to derive the fish density per 1000 m^3 for each individual fish stow net haul combination. This resulted in a density for each haul of diadromous fish and all fish together.

Due to missing data at specific time frames various subsets with consistent data were analysed. The most valuable subset was the September and October 2019 and 2020 dataset since it allowed to assess the effect of day or night fishing, month, year and site. Fish densities were analysed using a Generalized Linear Model (GLM) with a gamma distribution and a log link. The gamma distribution was used since the data was not normally distributed and fitted a gamma distribution well. Due to the presence of zero’s a + 0.001 transformation was performed for the diadromous fish dataset. Potential explanatory variables used during model construction were ‘Time of day’, ‘Month’, ‘Year’ and ‘Location’, all having two levels.

To compare the various fishing months, an analysis was performed using only day time stow net samples for the months May, September, October and November. All fish density was normally distributed after a log10 (+0.001) transformation and subsequently analysed using a Linear Model (LM) with ‘Month’, ‘Year’ and ‘Location’ as potential explanatory variables. The diadromous fish density was gamma distributed after a + 0.00001 transformation.

The data from April 2021 for the Netherlands and Germany was analysed by deriving the catch per unit effort (individuals / sampling hour) of all fish and diadromous fish. The data distribution was characterized by a gamma distribution, with a +0.001 transformation for the diadromous fish assuming a similar discharge at each location. Potential explanatory variables for the data from the Netherlands were ‘Time of day’, ‘Location’ and ‘Riverside’. For the German data Riverside was the potential explanatory variable.

In general, multiple models were fitted with increasing complexity, including interactions between explanatory variables. Model selection was based on multiple indicators being: 1) the lowest AIC value, 2) the lowest BIC value, and 3) significant model improvement (tested using the ANOVA function). If there was a significant interaction or a main effect, a Tukey post-hoc analyses was performed using the function ´lsmeans´ from the package ´lsmeans´ (Lenth 2016).

2.4.5 Time of day of migration of Atlantic salmon and Eel

Based on the time of day of the Dutch stow net samples, an assessment was made of the time of day at which migration of Atlantic salmon and Eel mainly occurs. A comparison was made with the time of day during downstream migration of individuals of the same species outfitted with a NEDAP transponder (a fish tracking system; Breukelaar unpublished). This NEDAP data encompassed the period 2010 – 2020 allowing to determine the percentage of individuals that crossed a NEDAP cable per hour of day during this period. A distinction was made between three locations with NEDAP cables: Xanten (Lower Rhine, Germany), Brakel (river Waal, The Netherlands) and the Ophemert and Dreumel shore channel (river Waal, The Netherlands).

2.4.6 Migrating number of Atlantic salmon April 2021

The number of Atlantic salmon individuals migrating during the fishing in April 2021 in the Netherlands and Germany was calculated based on the assumption that the individuals of each species were homogenously distributed over the entire river width. This is supported by the result that the CPUE of diadromous fish did not differ between the left and right bank of the river both in the Netherlands and in Germany (see paragraph 3.4).

Before the number of individuals could be extrapolated using a bootstrapping approach, the sampled discharge of the river needed to be calculated. For the Netherlands, this was done using the 2018, 2019 and 2020 fishing data by multiplying the width of the net (8 meter) with the local sampling depth, yielding the sampled surface area. This was subsequently multiplied with the depth average flow velocity resulting in a sampled discharge (m^3/s). The discharge of the river on each sampling day was retrieved from gauging station Tiel via www.waterinfo.rws. Based on the stow net data from 2018, 2019 and 2020 the sampled river discharge ranged between 1.1 and 4.1% of the total river discharge and was on average 2.7%. For the data from

Germany extrapolation was more difficult due to the absence of flow velocity measurements. Fortunately, flow velocity measurements were collected in the middle of the water column in October 2020 during plastic monitoring. The river discharge at Lobith during the sampling days in October 2020 was 1355 $m^3.s^{-1}$, which is comparable to the measured discharge at Lobith during the sampling period in Germany (daily average: 1189 – 1350 $m^3.s^{-1}$). Therefore, the assumption was made that the flow velocity in the middle of the water column measured in October 2020 was representative for April 2021 yielding a sampled discharge of 3.7%.

The mean sampled river discharge was subsequently used to derive a correction factor of 37 and 27 for the Netherlands and Germany, respectively. The CPUE of Atlantic salmon in both countries in April 2021 were subsequently multiplied with the correction factor to yield the total amount of Atlantic salmon passing per hour along the entire river width. Subsequently, a gamma distribution was fitted to both datasets. The distributions were then used to draw an expected number of Atlantic salmon per hour along the entire river width for each hour during the sampling periods (336 and 528 hours for the Netherlands and for Germany). By taking the sum of the expected number of Atlantic salmon per hour for each period an estimate was made of the total number of individuals. The calculation of the expected number of Atlantic salmon per hour was repeated 1000 times to assess the 95% confidence interval in downstream migrating individuals.

2.4.7 Fish lengths

Based on the lengths of frequently caught fish during October 2020 and April 2021 a length distribution was fitted and compared to the length of fish caught during the same month in Germany. A length frequency distribution was also fitted for the lengths of diadromous fish caught during the recent fishing period in both the Netherlands and Germany (2018 – 2021). For Atlantic salmon and Seatrout historical length data of fish caught using stow net fishing was available for the year 1951 and also visualised as a length frequency distribution (Anonymous 1951).

2.4.8 Historical overview stow net fishing

A literature review was performed to acquire as many as possible literature sources that used stow net fishing to sample fish in the Dutch upper Rhine (Boven-Rijn) and the river Waal distributary. Subsequently, a semi-quantitative reconstruction of diadromous fishes caught in these rivers since the end of the 2nd world war was made. Moreover, if available fish lengths were included and compared to present day fish lengths of diadromous fish caught.

2.4.9 Anecdotal information

Relevant records that were noticed during the stow net fishing, but could not be analysed due to insufficient data, were written down.

3. Results

3.1 Species richness

In total, 41 fish species were caught during the stow net fishing in the river Rhine (31 species) and Waal (37 species) over the period 2018 - 2021. One of these 'species' concerned an unknown hybrid. The highest species richness was 23 species during night fishing in October 2020 and April 2021 (excluding the hybrid, Table 3.1). Overall fish diversity was higher at night than during the day (Table 3.1).

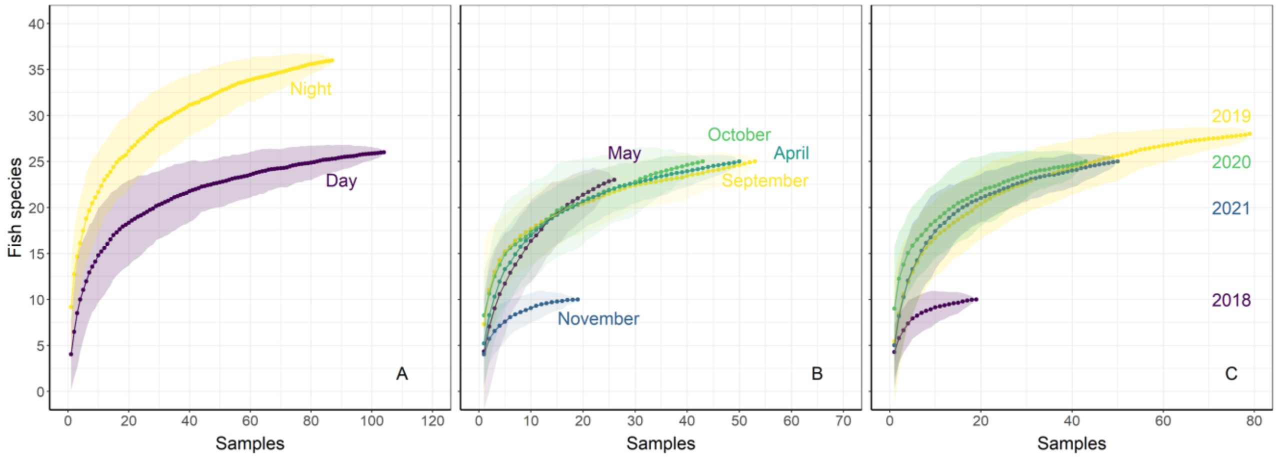

Figure 3.1. Species accumulation curves based on stow net fishing in the river Waal with a comparison between day and night (A), sampling months (B) and years (C).

Based on the species accumulation curves, most fish species were caught during the night (Figure 3.1A). The cumulative number of species only slightly differed between various months. Only in November, species richness was relatively lower (Figure 3.1B). The accumulation curves does not differ between years. Only the curve for 2018 is lower than the other curves, but this is likely due to the fact that in this year only day fishing was performed (Figure 3.1C).

Table 3.1: Overview of the caught fish species using stow net fishery in the river Waal during the period November 2018 – April 2021.

				2018		2019						2020				2021	
				November		May		September		October		September		October		April	
				Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night	Day	Night
Species	Latin species name	Guild	Diadromous	n = 19	n.s.	n = 20	n = 6	n = 19	n = 7	n = 11	n = 16	n = 12	n = 15	n = 1	n = 15	n = 22	n = 28
Bleak	*Alburnus alburnus*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	x	x	x	x
Perch	*Perca fluviatilis*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	x	x	x	x
Barbel	*Barbus barbus*	Reophilic	No	-	n.s.	-	x	-	x	x	x	x	x	x	x	-	x
Bitterling	*Rhodeus amarus*	Limnophilic	No	-	n.s.	-	-	-	x	-	-	-	-	-	-	-	x
Roach	*Rutilus rutilus*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	x	x	x	x
Vimba	*Vimba vimba*	Reophilic	No	-	n.s.	-	x	x	-	-	-	-	-	-	x	x	x
Flounder	*Platichthys flesus*	Reophilic	Yes	-	n.s.	-	x	-	x	-	-	-	x	-	-	-	x
Bream	*Abramis brama*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	x	x	x	x
Danube bream	*Ballerus sapa*	Reophilic	No	-	n.s.	-	-	-	-	-	-	-	x	-	x	-	x
Three-spined stickleback	*Gasterosteus aculeatus*	Eurytopic	Yes	-	n.s.	x	-	x	x	x	x	x	x	-	x	x	x
Elft	*Alosa alosa*	Reophilic	Yes	-	n.s.	-	-	x	x	-	-	-	-	-	-	-	-
Houting	*Coregonus oxyrinchus*	Reophilic	Yes	-	n.s.	x	x	x	-	-	-	-	-	-	-	-	-
Gibel carp	*Carassius gibelio*	Eurytopic	No	-	n.s.	-	-	-	-	-	-	-	-	-	x	-	-
Carp	*Cyprinus carpio*	Eurytopic	No	-	n.s.	-	-	-	-	-	x	-	x	-	x	-	x
Caucasian dwarf goby	*Knipowitschia caucasica*	Eurytopic*	No	-	n.s.	-	-	-	-	-	-	-	-	-	-	-	x
Bighead goby	*Ponticola kessleri*	Eurytopic	No	-	n.s.	-	x	-	-	-	-	-	-	-	-	-	-
White bream	*Blicca bjoerkna*	Eurytopic	No	-	n.s.	-	-	-	-	-	-	x	x	-	x	-	-
Chub	*Squalius cephalus*	Reophilic	No	-	n.s.	-	-	-	-	-	-	-	-	-	x	-	-
Eel	*Anguilla anguilla*	Eurytopic	Yes	x	n.s.	x	x	x	x	-	x	-	x	-	x	x	x
Tubenose goby	*Proterorhinus semilunaris*	Eurytopic	No	-	n.s.	-	x	-	-	-	-	-	-	-	-	-	-
Wels catfish	*Silurus glanis*	Eurytopic	No	-	n.s.	-	-	-	-	-	-	-	x	-	x	-	-
Monkey goby	*Neogobius fluviatilis*	Eurytopic	No	-	n.s.	x	-	-	-	-	x	x	-	-	x	-	-
Ruffe	*Gymnocephalus cernua*	Eurytopic	No	-	n.s.	-	-	-	-	x	-	-	-	-	-	-	x
Gudgeon	*Gobio gobio*	Reophilic	No	-	n.s.	-	-	-	-	-	-	-	-	-	-	x	x
River lamprey	*Lampetra fluviatilis*	Reophilic	Yes	-	n.s.	x	-	x	-	-	x	x	x	-	x	x	x
Asp	*Leuciscus aspius*	Eurytopic	No	x	n.s.	-	x	-	x	x	x	x	x	-	x	-	x
Dace	*Leuciscus leuciscus*	Reophilic	No	-	n.s.	-	-	-	-	-	-	-	-	-	x	-	-
Nase	*Chondrostoma nasus*	Reophilic	No	x	n.s.	-	-	x	x	x	x	x	x	x	x	-	x
Pike	*Esox lucius*	Eurytopic	No	-	n.s.	x	-	-	-	-	-	-	-	-	-	-	-
Pikeperch	*Sander lucioperca*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	-	x	x	x
Smelt	*Osmerus eperlanus*	Reophilic	Yes	-	n.s.	-	-	-	-	-	-	x	-	-	-	-	-
Ide	*Leuciscus idus*	Reophilic	No	x	n.s.	-	x	x	x	x	x	x	x	x	x	x	x
Whitefin gudgeon	*Romanogobio belingi*	Reophilic	No	-	n.s.	x	x	x	x	-	x	x	x	x	x	-	-
Salmon	*Salmo salar*	Reophilic	Yes	-	n.s.	x	-	-	-	-	-	-	-	-	-	x	x
Sea trout	*Salmo trutta*	Reophilic	Yes	-	n.s.	x	-	-	-	-	-	-	-	-	-	x	x
Sea lamprey	*Petromyzon marinus*	Reophilic	Yes	-	n.s.	x	x	-	-	-	x	-	-	-	-	x	x
Round goby	*Neogobius melanostomus*	Eurytopic	No	x	n.s.	x	x	x	x	x	x	x	x	-	x	x	x
Hybrid	-	-	-	-	n.s.	-	-	-	-	-	-	-	-	-	-	-	x
			Reophilic species:	2	n.s.	6	7	7	7	3	6	6	7	4	9	7	11
			Eurytopic species:	8	n.s.	10	10	8	8	9	11	10	12	4	14	8	12
			Limnophilic species:	0	n.s.	0	0	0	1	0	0	0	0	0	0	0	1
			Diadromous species:	1	n.s.	7	4	5	4	1	4	3	4	0	3	5	6
			Total species:	10	n.s.	16	17	15	16	12	17	16	19	8	23	15	24
			Total:	38													

* Van Treeck et al. (2020) assigned the species to limnophilic but in the Netherlands it was caught under fast flowing and standing water conditions. Therefore, the species was considered a eurytopic species

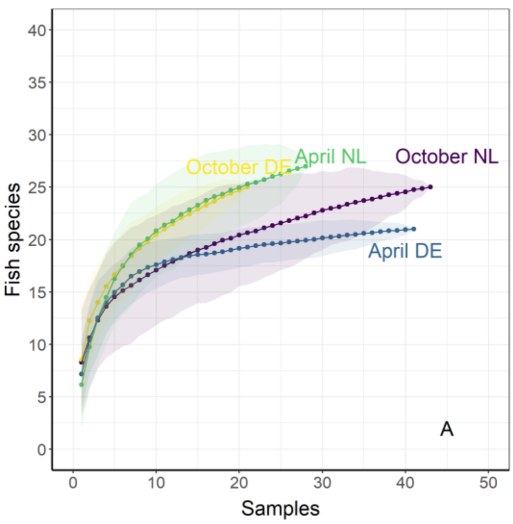

Figure 3.2. Species accumulation curves based on stow net fishing in the river Waal in the Netherlands and in the Lower Rhine in Germany using data of the night sampling is in similar months.

When comparing the SAC for night fishing in Germany with that for the Netherlands during October 2020, the collected number of fish species per sample was higher in Germany than in the Netherlands (Figure 3.2A). This was likely an effect of haul duration per sample as in the Netherlands hauls were on average 2 hours and 15 minutes, whereas the hauls in Germany were overnight, often longer than 8 hours. However, in April 2021 the SAC of the Netherlands nightly samples was higher compared to the data from April 2021 (including some sampling in May 2021) of Germany (Figure 3.2A).

Table 3.2. Overview of collected fish species during comparable stow net fishing in the Netherlands and in Germany.

				2019		2020				2021	
				October		May	October		November	April	
				NL	DE	DE	NL	DE	DE	NL	DE**
Species	Latin species name	Guild	Diadromous	n = 16	n = 16	n = 5	n = 15	n = 5	n = 9	n = 28	n = 21
Bleak	*Alburnus alburnus*	Eurytopic	No	x	x	x	x	x	x	x	x
Perch	*Perca fluviatilis*	Eurytopic	No	x	x	x	x	x	x	x	x
Barbel	*Barbus barbus*	Reophilic	No	x	x	x	x	x	x	x	x
Bitterling	*Rhodeus amarus*	Limnophilic	No	-	-	-	-	-	-	x	-
Roach	*Rutilus rutilus*	Eurytopic	No	x	x	x	x	x	x	x	x
Vimba	*Vimba vimba*	Reophilic	No	-	x	-	x	-	-	x	x
Flounder	*Platichthys flesus*	Reophilic	Yes	-	x	x	-	x	-	x	-
Bream	*Abramis brama*	Eurytopic	No	x	x	x	x	x	x	x	x
Danube bream	*Ballerus sapa*	Reophilic	No	-	-	-	x	-	-	x	-
stickleback	*Gasterosteus aculeatus*	Eurytopic	Yes	x	x	x	x	x	x	x	-
Allis shad	*Alosa alosa*	Reophilic	Yes	-	-	-	-	x	x	-	x
Gibel carp	*Carassius gibelio*	Eurytopic	No	-	x	-	x	-	-	-	-
Carp	*Cyprinus carpio*	Eurytopic	No	x	x	-	x	x	x	x	-
goby	*Knipowitschia caucasica*	Eurytopic*	No	-	-	-	-	-	-	x	-
Bighead goby	*Ponticola kessleri*	Eurytopic	No	-	-	x	-	-	-	-	x
Coregonus spec.	*Coregonus spec.*	?	Yes	-	-	x	-	-	-	-	-
White bream	*Blicca bjoerkna*	Eurytopic	No	-	x	-	x	-	x	-	x
Chub	*Squalius cephalus*	Reophilic	No	-	x	-	x	x	x	-	x
Eel	*Anguilla anguilla*	Eurytopic	Yes	x	x	-	x	x	x	x	x
Wels catfish	*Silurus glanis*	Eurytopic	No	-	x	-	x	-	x	-	-
Monkey goby	*Neogobius fluviatilis*	Eurytopic	No	x	x	-	x	-	-	-	-
Ruffe	*Gymnocephalus cernua*	Eurytopic	No	-	-	-	-	-	-	x	-
Gudgeon	*Gobio gobio*	Reophilic	No	-	x	x	-	x	x	x	spec.
River lamprey	*Lampetra fluviatilis*	Reophilic	Yes	x	-	spec.	x	-	-	x	x
Asp	*Leuciscus aspius*	Eurytopic	No	x	x	x	x	x	x	x	x
Dace	*Leuciscus leuciscus*	Reophilic	No	-	x	-	x	-	-	-	-
Nase	*Chondrostoma nasus*	Reophilic	No	x	x	-	x	x	x	x	x
Pike	*Esox lucius*	Eurytopic	No	-	-	x	-	-	x	-	-
Pikeperch	*Sander lucioperca*	Eurytopic	No	x	x	x	x	x	x	x	x
Sunbleak	*Leucaspius delineatus*	Limnophilic	No	-	-	-	-	x	-	-	-
Ide	*Leuciscus idus*	Reophilic	No	x	x	x	x	-	x	x	x
Whitefin gudgeon	*Romanogobio belingi*	Reophilic	No	x	-	-	x	-	-	-	spec.
Salmon	*Salmo salar*	Reophilic	Yes	-	-	x	-	-	-	x	x
Sea trout	*Salmo trutta*	Reophilic	Yes	-	-	x	-	-	-	x	x
Sea lamprey	*Petromyzon marinus*	Reophilic	Yes	x	-	spec.	-	-	-	x	x
Round goby	*Neogobius melanostomu:*	Eurytopic	No	x	x	x	x	-	-	x	x
Hybrid	-	-	-	-	-	-	-	-	-	x	-
			Reophilic species	6	8	8	9	6	6	11	10
			Eurytopic species	11	14	9	14	9	12	12	10
			Limnophilic species	0	0	0	0	1	0	1	0
			Diadromous species	4	3	7	3	4	3	6	6
			Total species	17	22	17	23	16	18	24	20
			Total:	37							

* Van Treeck et al. (2020) assigned the species to limnophilic but in the Netherlands it was caught under fast flowing and standing water conditions. Therefore, the species was considered a eurytopic species

** This includes a limited number of samples collected at the beginning of May 2021

Fish diversity in October 2019 was lower in the Netherlands than in Germany (Table 3.2). However, in October 2020 and April 2021 the fish diversity was higher in the Netherlands than in Germany.

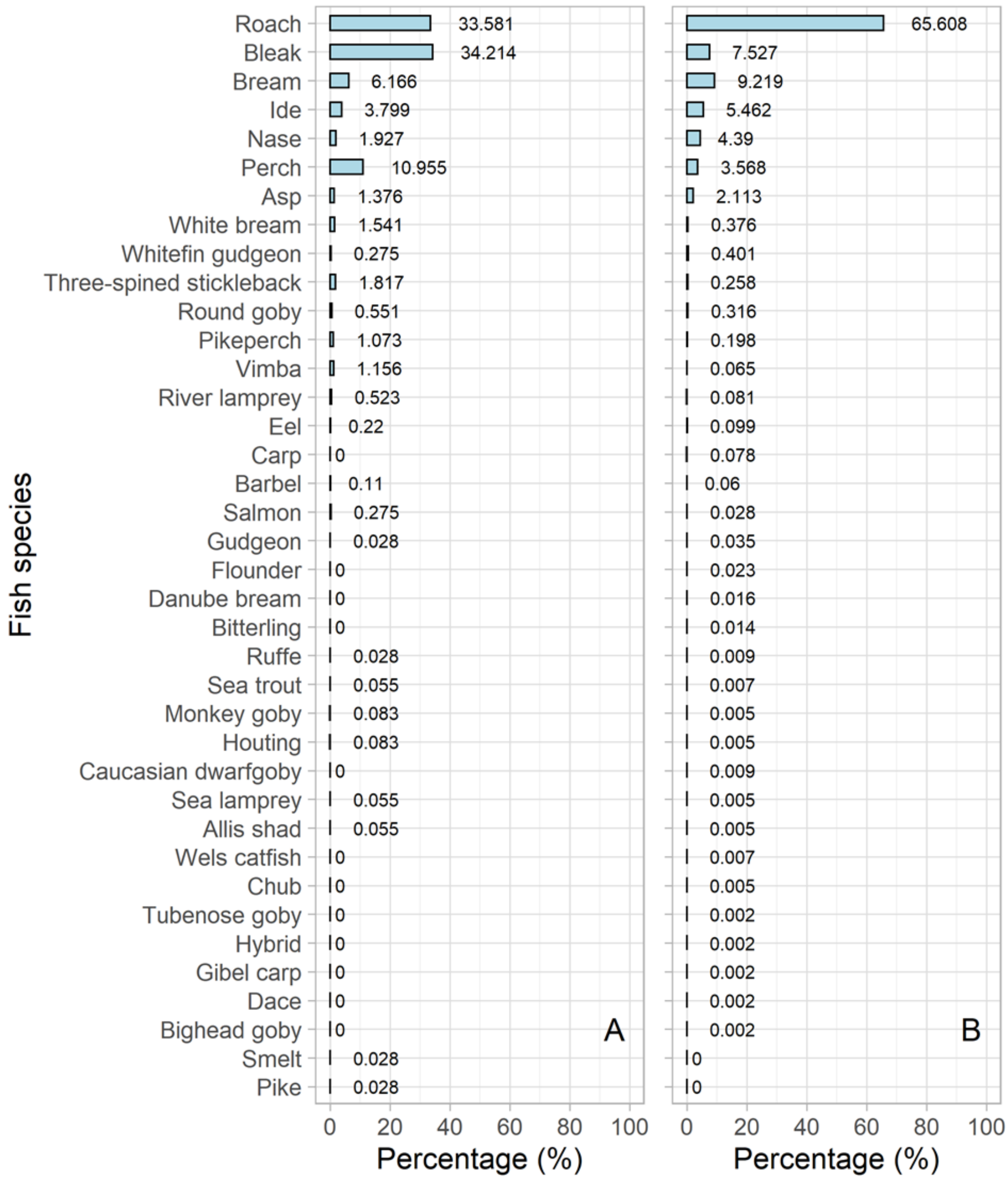

Figure 3.3. Relative abundance of fish species collected with stow net fishing during day (A) and night (B) in the river Waal.

3.2 Relative abundance

The composition of caught fish differed between day and night. During the day the relative abundance of Bleak and Perch was higher than during the night (Figure 3.3A and B). At night, Roach was the most abundant fish species (Figure 3.3A and B).

When comparing the relative abundance of fish species between several months more differences are found. In general, Roach, Bleak and Bream are the most abundant fish species in this part of the river Waal throughout the year (Figure 3.4). In April the relative abundance of Vimba, Round goby and River lamprey was higher compared to all other months (Figure 3.4A). In May, the relative abundance is more evenly distributed between several species and Roach was not the most abundant fish species (Figure 3.4B). In September, the relative composition has changed and has become less even, being mainly dominated by Roach, Bream, Nase and Perch (Figure 3.4C). In October, the community was completely dominated by Roach (Figure 3.4D) which subsequently decreased again in November (Figure 3.4D). In November, Bleak was the most abundant fish species (Figure 3.4E).

The relative abundance of fish species in samples of the river Waal in the Netherlands and Lower Rhine in Germany differed. If we look at all collected fish during all sampling events the most abundant fish in the Netherlands was Roach (Figure 3.5 left) whereas in Germany the most abundant fish was Bream (Figure 3.5 right). In the Netherlands Bleak, Ide and Asp constituted to a high relative abundance but in Germany these species had a very low relative abundance. In Germany, Carp and Chub was caught more frequently than in the Netherlands.

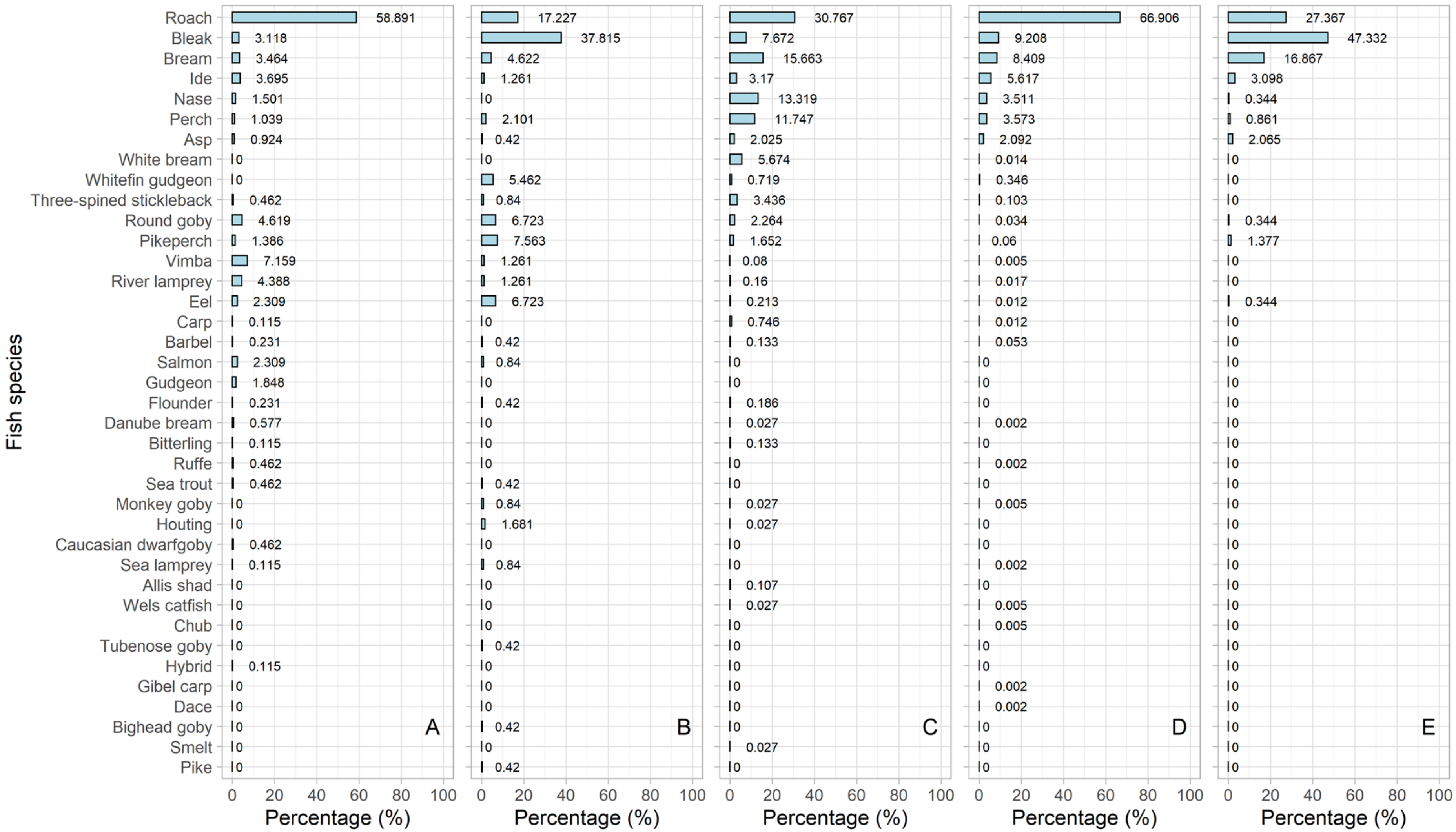

Figure 3.4. Relative abundance of fish species in April (A), May (B), September (C), October (D) and November (E) in the river Waal.

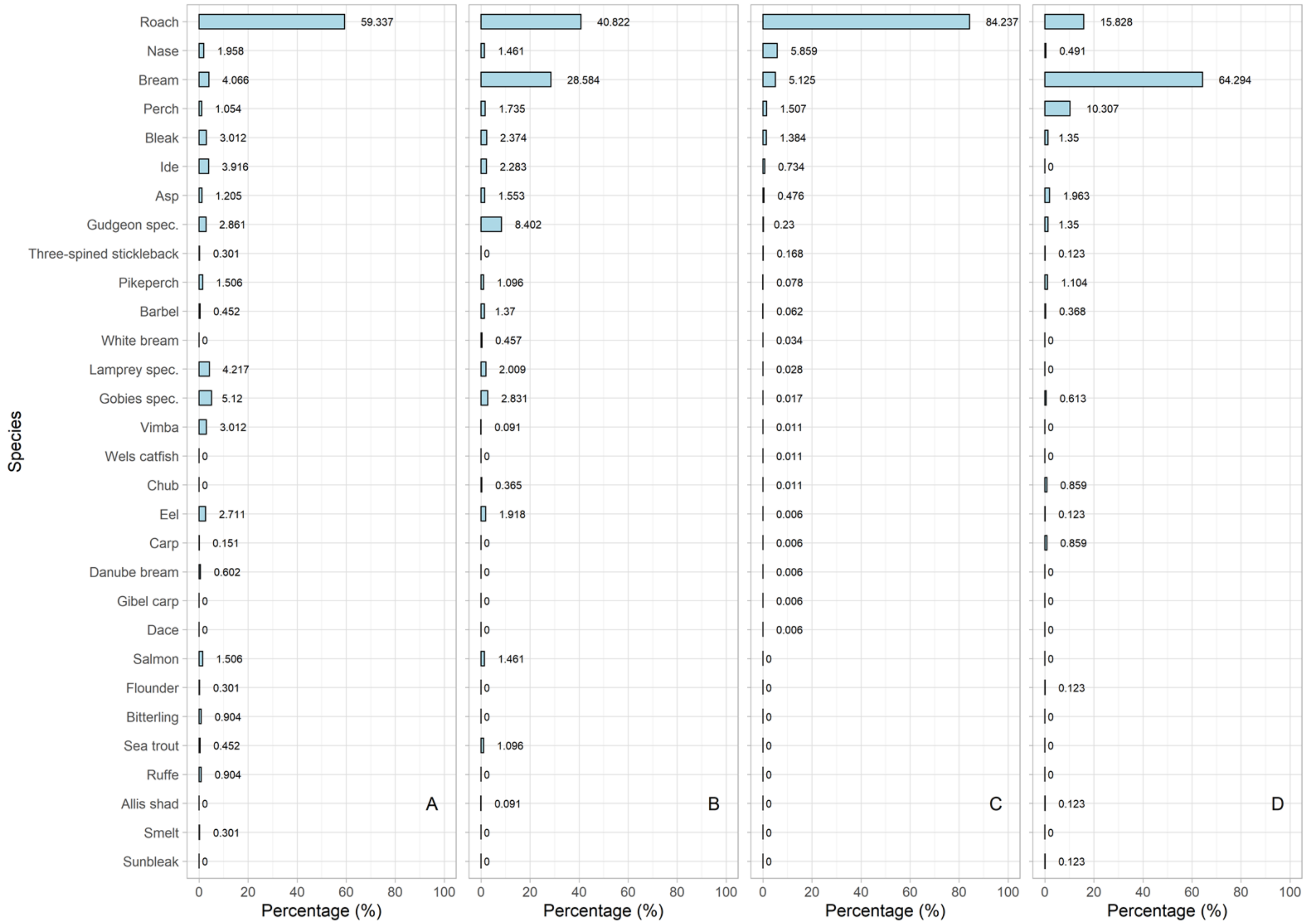

Figure 3.5. Relative abundance of fish species collected in April in the Netherlands (A) and Germany (B) and in October in the Netherlands (C) and Germany (D).

3.3 Fish diversity

Total fish diversity per stow net sample was significantly higher during the night than during the day (χ_2 = 90.909, DF = 1, P-value < 0.001; Figure 3.6A) and was higher in the shore channel than in the main channel (χ_2 = 16.304, DF = 1, P-value < 0,001; Figure 3.6B). The fish diversity per stow net haul differed significantly between months (χ_2 = 4.341, DF = 1, P-value < 0.001; Figure 3.6C). The highest diversity was observed in the month of October and the lowest diversity was observed in November (Figure 3.6C).

Diadromous fish diversity was also higher during the night than during the day (χ_2 = 20.229, DF = 1, P-value < 0,001; Figure 3.7A) and in the shore channel compared to the main channel (χ_2 = 9.4072, DF = 1, P-value < 0.01; Figure 3.7B). Sampling period significantly affected diadromous fish species richness per stow net haul (χ_2 = 33.896, DF = 1, P-value < 0.001), with the highest species richness in the months April, May and September (Figure 3.7C).

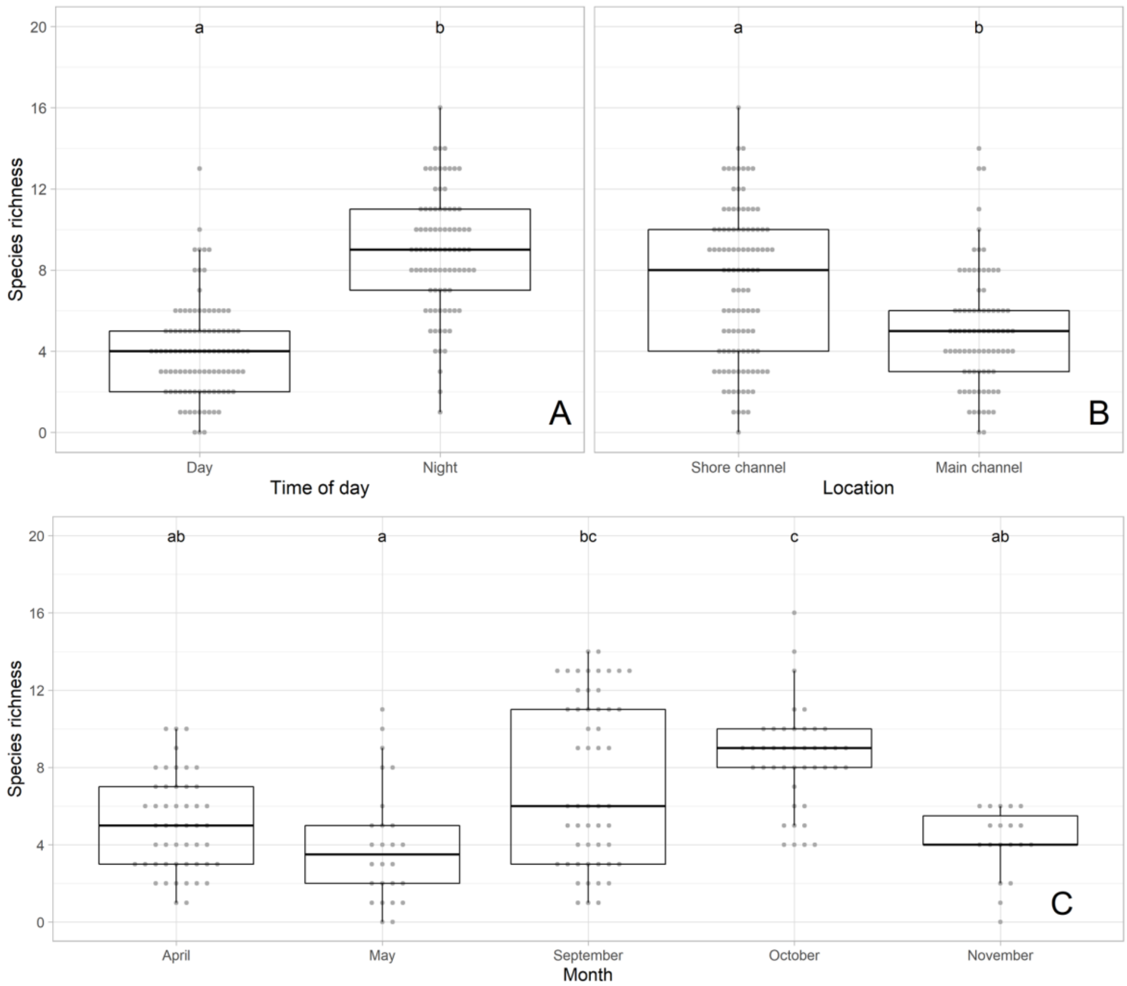

Figure 3.6. Species richness per stow net haul based on the time of day (A), the location (B) and the sampling month (C) for the river Waal. The letters indicate significant differences.

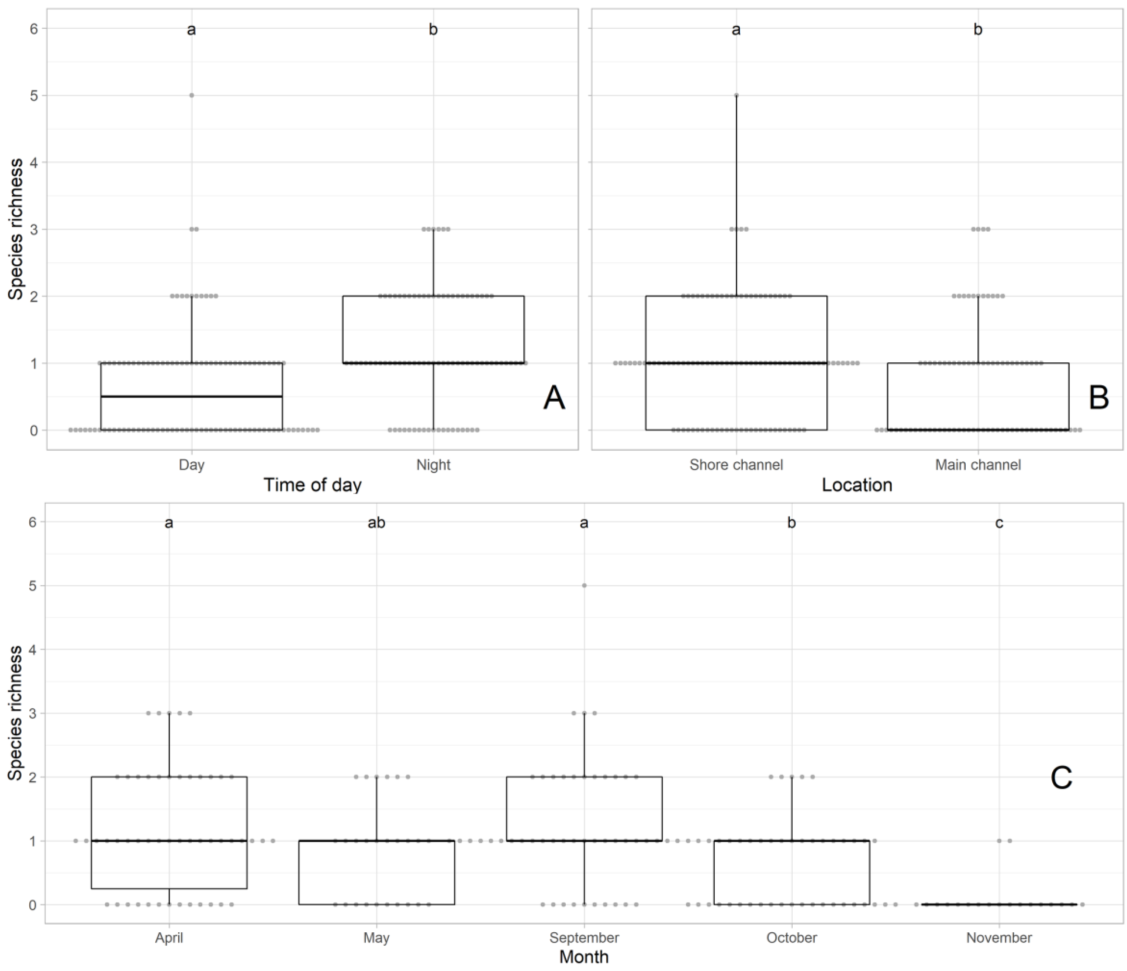

Figure 3.7. Diadromous fish species richness per stow net haul based on the time of day (A), the location (B) and the sampling month (C) for the river Waal. The letters indicate significant differences.

3.4 Fish density

<u>Effect of time of day, month and year</u>

The density of fish per 1000 m^3 differed significantly between day and night ($\chi_2 = 108.04$, DF = 1, P-value < 0.001; Figure 3.8A) and between months ($\chi_2 = 61.344$, DF = 1, P-value < 0.001; Figure 3.8B). The density between locations only differed significantly during the day based on a significant interaction between location and sampling time ($\chi_2 = 25.891$, DF = 1, P-value < 0.001; Figure 3.8A). Post-hoc analysis showed that the density at night was significantly higher at both locations in the river Waal compared to the same locations during the day (P-value < 0.001 and < 0.001, respectively). During the day, fish density was significantly higher in the shore channel than in the main channel (P-value < 0.001). There was no difference in density between locations during the night. Fish densities were significantly higher in October than in September.

Diadromous fish densities per 1000 m^3 were low during September and October. There was no significant difference between sampling time ($\chi_2 = 2.923$, DF = 1, P-value = 0.06). Diadromous fish density per 1000 m^3 was significantly higher in September than in October ($\chi_2 = 42.496$, DF = 1, P-value < 0,001; Figure 3.9) and was significantly higher in 2020 than in 2019 (χ_2 = 15.603, DF = 1, P-value < 0,001). The best model did not include the effect of location indicating that densities do not differ between the two sampling locations.

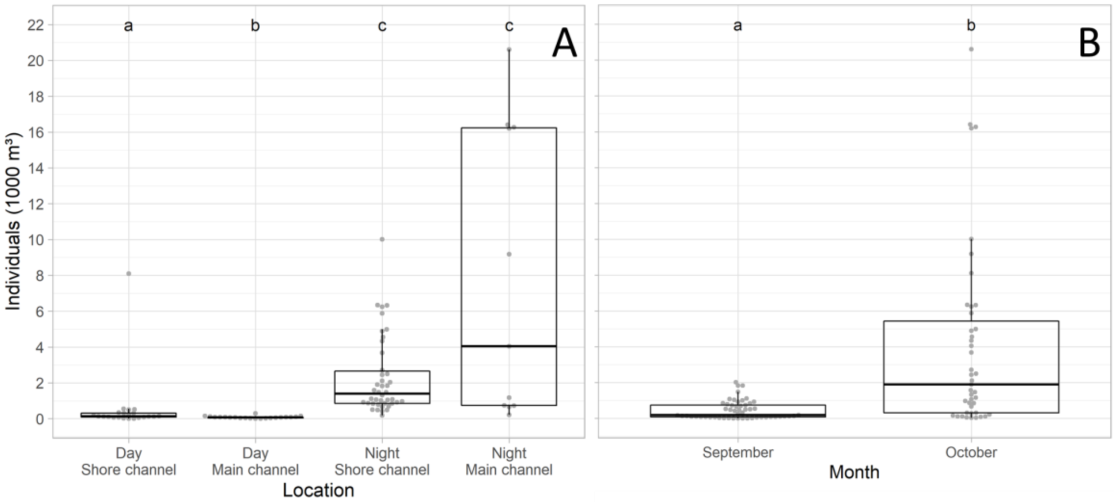

Figure 3.8. Density of all fish caught using the stow net sampling based on the difference between sampling time (day and night) and location (A) and month (B). The letters indicate significant differences.

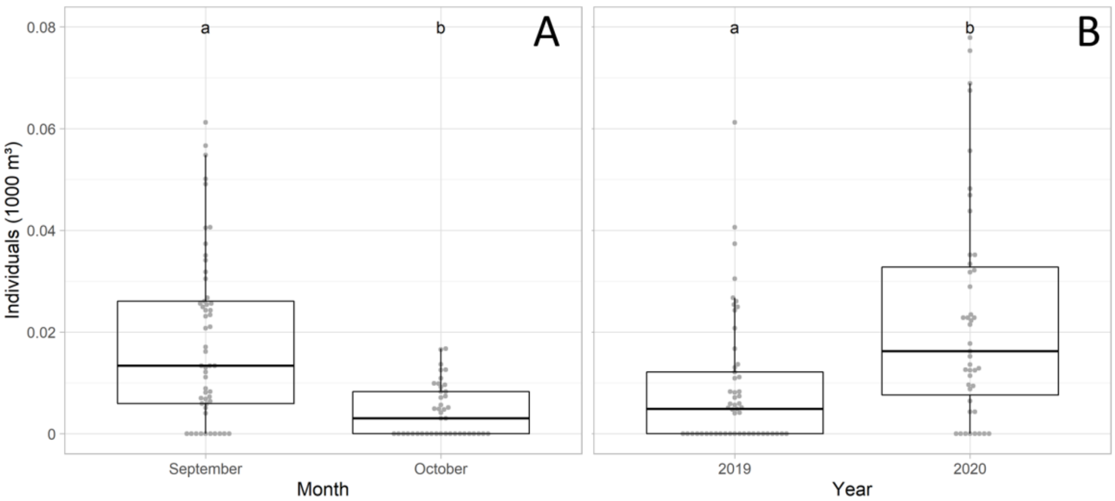

Figure 3.9. Density of all diadromous fish caught using the stow net sampling based on the difference between sampling months (A) and year (B). The letters indicate significant differences.

<u>Effect of month on catches during the day</u>

Fish density during the day was found to differ significantly between sampling months (F-value = 14.2515, DF = 3, P-value = < 0.001; Figure 3.10A). No significant effect was found of sampling location (F-value = 0.0742, DF = 1, P-value = 0.64; Figure 3.10B). Post-hoc analysis showed that the fish density during the day was lowest in the month May compared to all other months (P-value < 0.001 for all comparisons). No significant difference was found between the fish density in September, October and November.

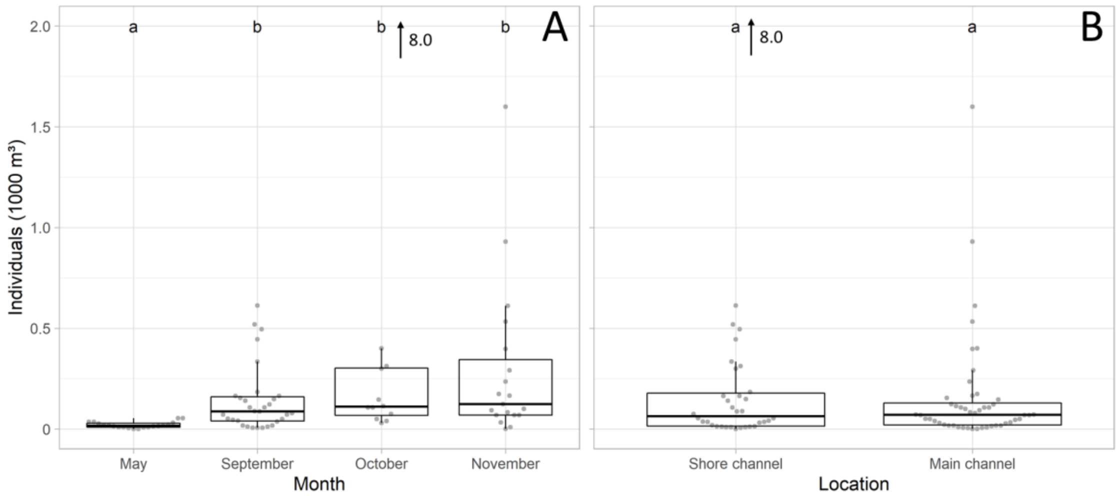

Figure 3.10. Density of all fish caught using the stow net sampling based on the difference between sampling months (A) and location (B). The letters indicate significant differences.

Diadromous fish density was found to be significantly higher during the day in the shore channel compared to the main channel (χ_2 = 20.290, DF = 1, P-value = < 0.01; Figure 3.11A). Additionally, diadromous fish density significantly differed between months (χ_2 = 89.975, DF = 3, P-value = < 0.001; Figure 3.11B). Diadromous fish density was significantly higher in the month September compared to the months May, October and November (P-value < 0.001 for all comparisons). No significant difference was found between the fish density in May, October and November.

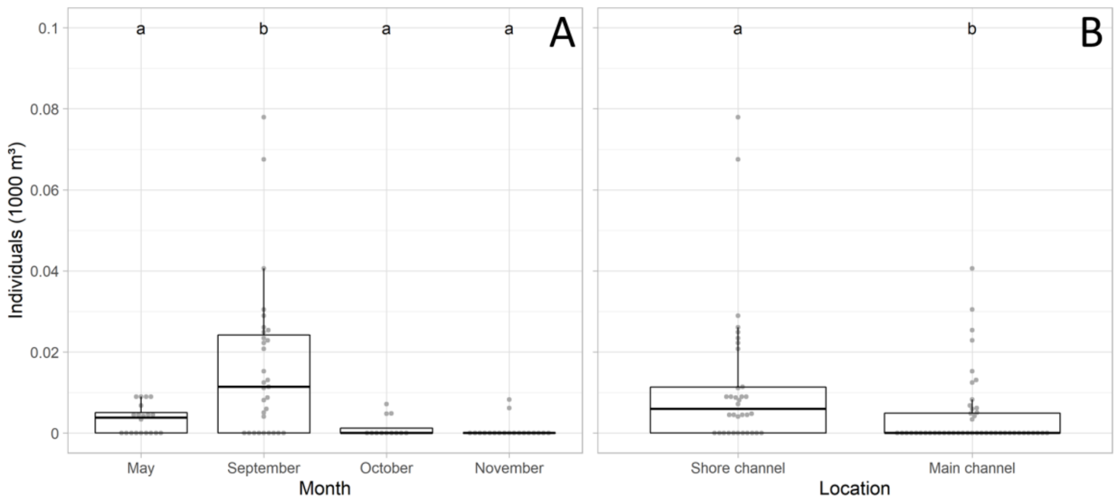

Figure 3.11. Density of diadromous fish caught using the stow net sampling based on the difference between sampling months (A) and location (B). The letters indicate significant differences.

<u>CPUE April sampling</u>

Fish catch per unit of effort (CPUE) in April 2021 in the river Waal was significantly lower during the day than during the night (χ_2 = 5.3044, DF = 1, P-value = < 0.001; Figure 3.12A). Fish density did not significantly differ between riverside (χ_2 = 1.1245, DF = 1, P-value = 0.08; Figure 3.12B), though the effect is close to a significant difference. The CPUE of diadromous fish did not significantly differ between time of day (χ_2 = 2.1289, DF = 1, P-value = 0.16; Figure 3.12A). In addition, the R^2 value of the model is very low indicating that the majority of variation is unexplained (Supporting information, Table S2).

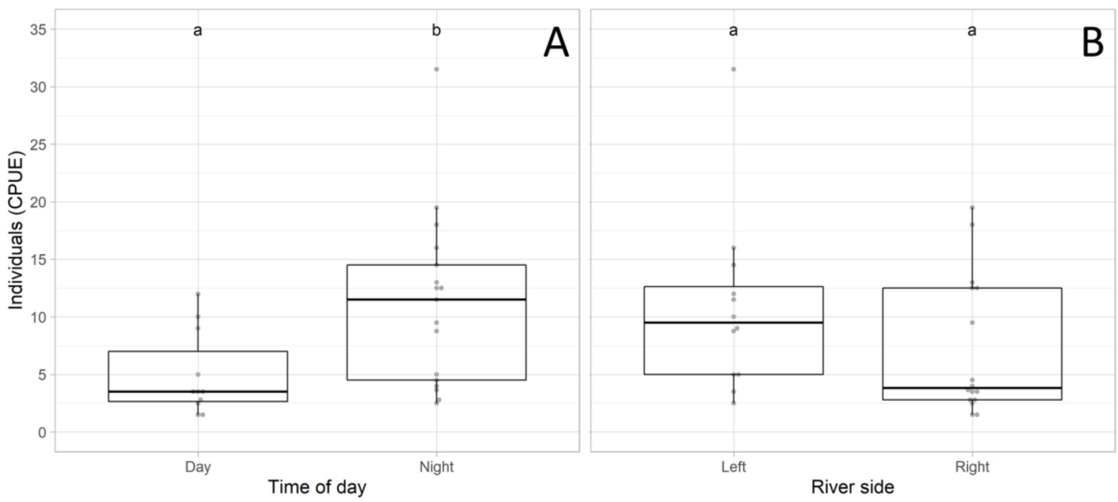

Figure 3.12. CPUE of all fish caught using the stow net sampling in April 2021 in the river Waal based on the difference between time of day (A) and riverside (B). The letters indicate significant differences.

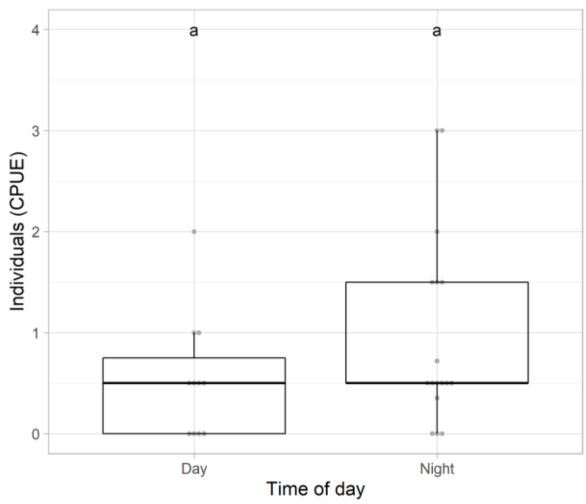

Figure 3.13. CPUE of diadromous fish caught using the stow net sampling in April 2021 in the river Waal based on the difference between time of day. The letters indicate significant differences.

In the German Lower Rhine fish catch per unit of effort (CPUE) in April - May 2021 significantly differed between riverside (χ_2 = 73.81, DF = 1, P-value = < 0.001, R^2 = 0.63; Figure 3.14A). The CPUE of diadromous fish did not significantly differ between riverside (χ_2 = 0.013557, DF = 1, P-value = 0.90; Figure 3.3.14B).

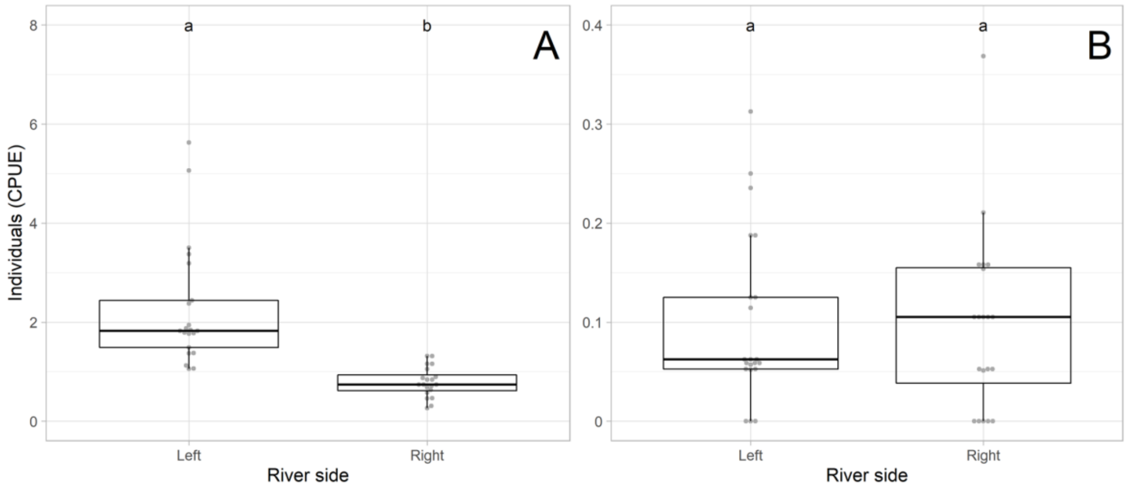

Figure 3.14. CPUE of all fish caught using the stow net sampling in April 2021 in Germany based on the difference between riverside for all fish (A) and diadromous fish (B). The letters indicate significant differences.

3.5 Time of day of downstream migration Atlantic salmon and Eel

The density and CPUE of diadromous fish caught using the stow net fishing did not differ between day and night. This corresponds to the time of day at which Atlantic salmon and Eel outfitted with a NEDAP transponder move past receivers in the Upper Rhine (Municipality of Xanten) and the river Waal (near the Municipality of Brakel). The likelihood of Atlantic salmon passing was slightly lower at night (21:00 to 02:00) while during the day the likelihood is close to the expected percentage if timing was random (Figure 3.15A). Migration of Eel outfitted with a NEDAP transponder did not differ between day and night (Figure 3.15B). The shore channel passing time is affected by the low number of passes that actually occurred (n = 11 and 16 for Atlantic salmon and Eel, respectively), skewing the passing time.

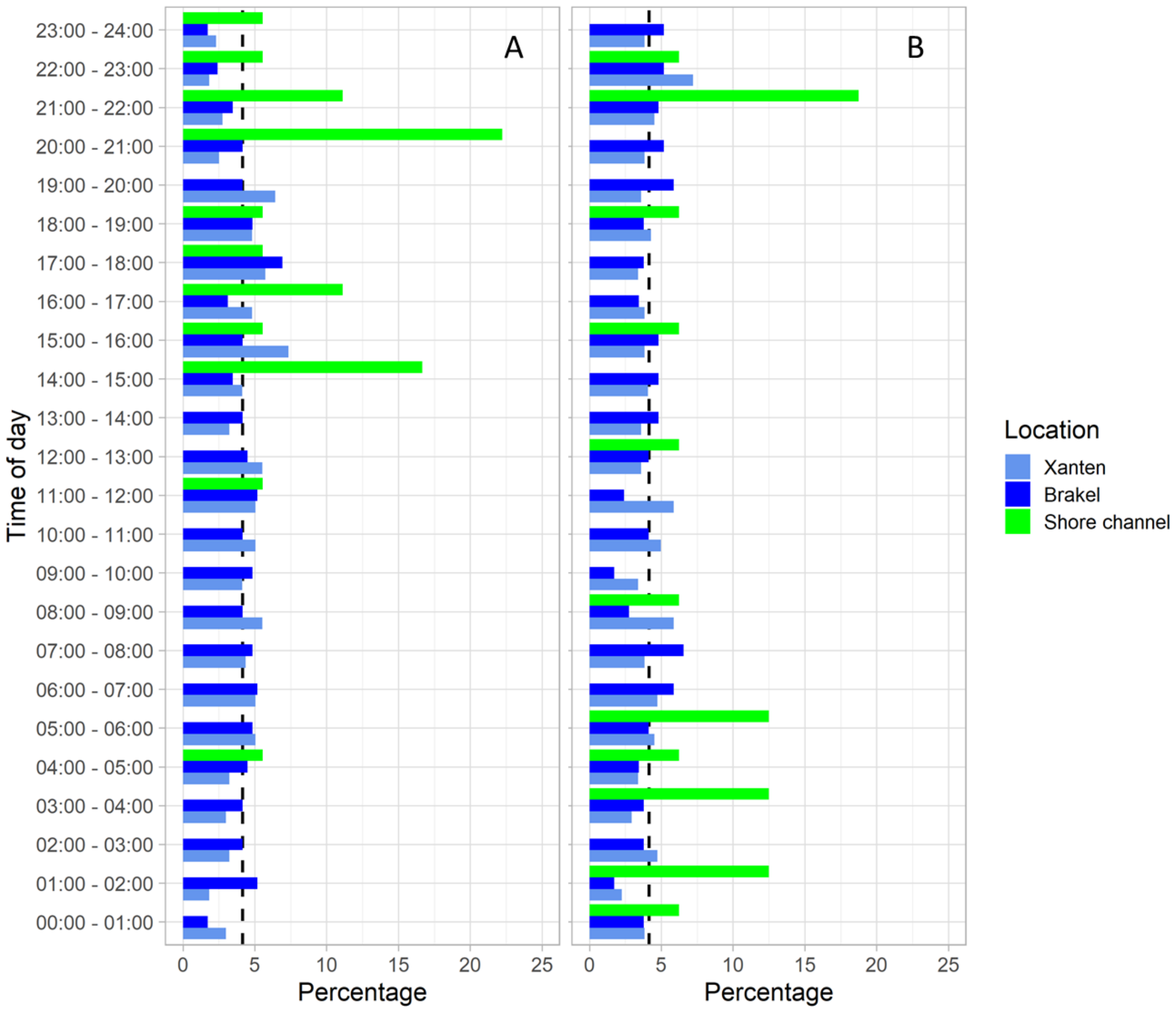

Figure 3.15. The percentage of recorded downstream fish migration based on fish equipped with a NEDAP transponder crossing a receiver cable at Xanten in Germany, Brakel in the Netherlands and behind the shore channels over the period 2010 – 2020 for Atlantic Salmon (A; n = 742) and Eel (B; n = 749). The dotted line indicates the expected percentage if the species have no distinct preference in time of day migration.

3.6 Downstream migrating fish numbers

Based on the observed CPUE of Atlantic salmon the median downstream migrating individuals during the two weeks of stow net fishing in the river Waal was expected to be 2063 individuals (95% confidence interval: 1695 – 2487; Figure 3.16A). The maximum and minimum numbers of fish were respectively 1446 and 2743 fish. This is likely an overestimation as the fit of the CPUE distribution was skewed due to the high amount of zero catches.

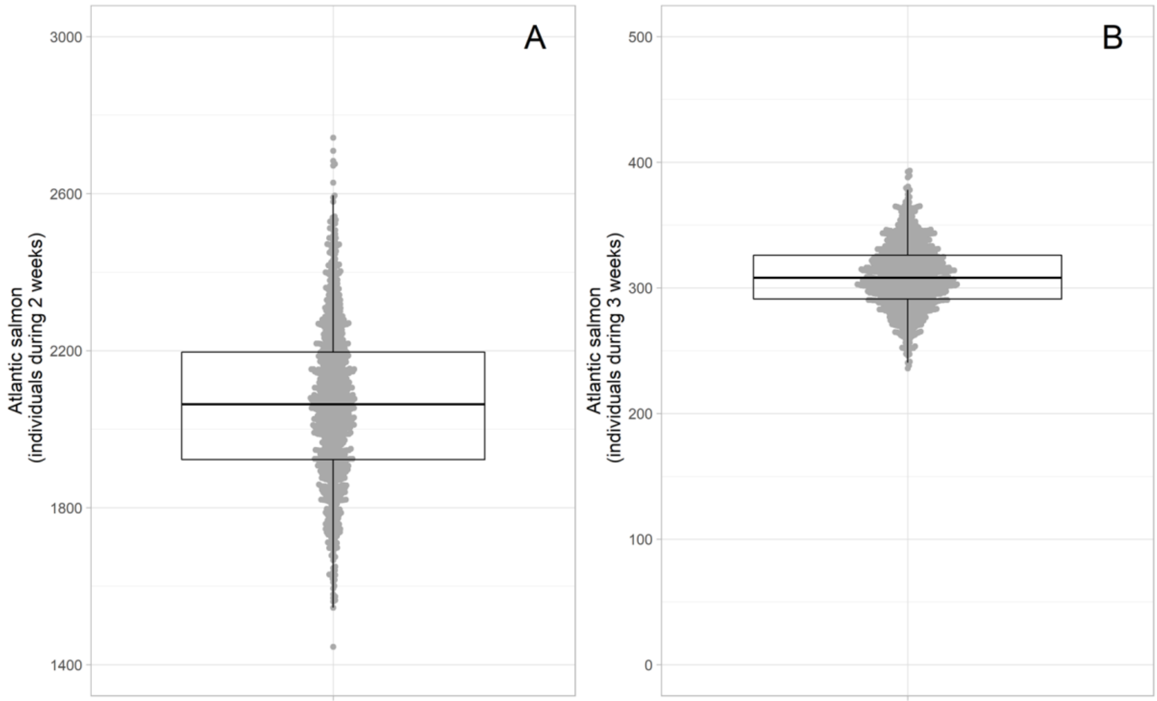

Figure 3.16. The downstream migrating Atlantic salmon through (A) the river Waal during the two-week sampling period in April 2021 and (B) the river Rhine during a three week sampling period in April – May 2021 derived using a bootstrapping approach.

In the Lower Rhine in Germany the observed CPUE of Atlantic salmon resulted in a median of downstream migrating individuals during the three weeks of stow net fishing of 308 (95% confidence interval: 261 – 363; Figure 3.16B). The maximum and minimum number of individuals were respectively 236 and 393 fish. The downstream migrating individuals are likely an overestimation as the fit of the CPUE distribution was skewed due to the high amount of zero catches.

The number of individuals migrating downstream during the German sampling was reduced compared to the Netherlands. This might be due to two separate migratory groups of Atlantic salmon right after each other of which the second group was smaller. Additional sampling is necessary for validation. When comparing the CPUE of Atlantic salmon catches in 2021 with the CPUE in 1951 (Figure 3.17) a similar pattern of a main group of migrating Atlantic salmon and a subsequent smaller group.

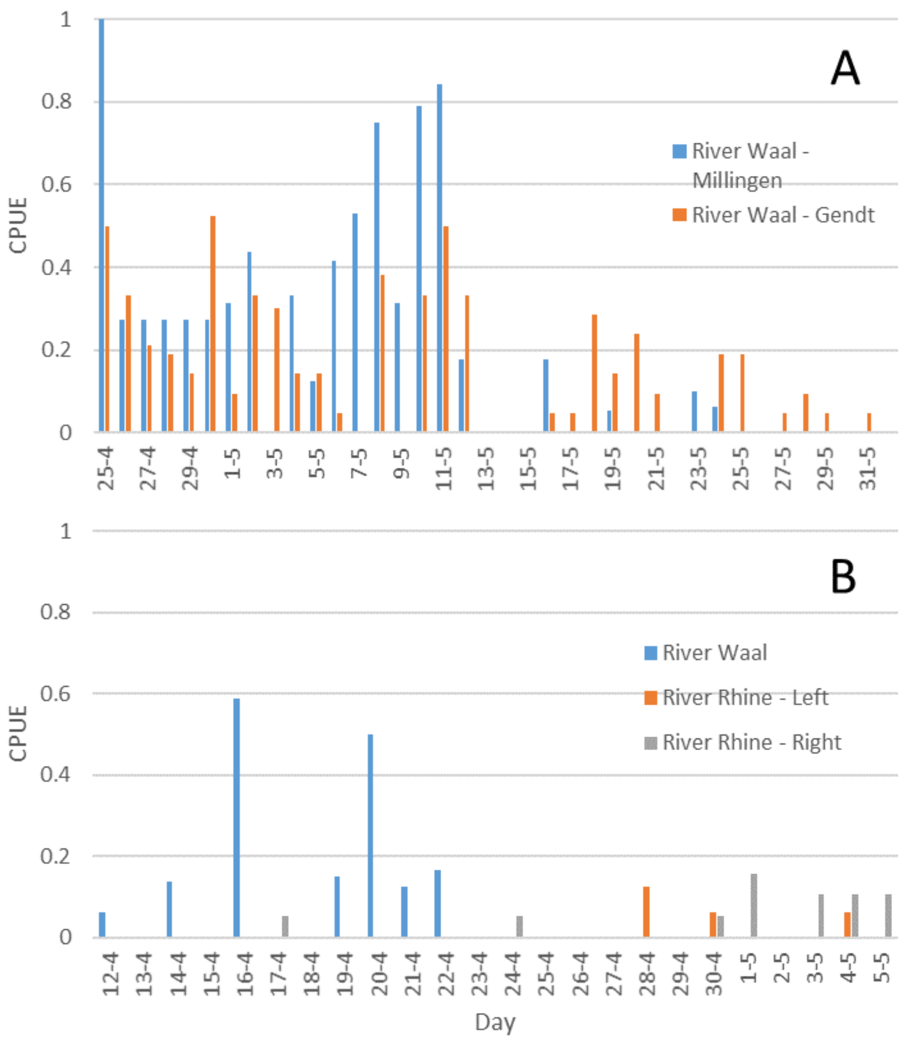

Figure 3.17. CPUE of Atlantic salmon in (A) 1951 and (B) 2021 in the river Waal and river Rhine (left and right side of the main channel). In 2021 the stow net was used in the river Waal from 12 to 22 April and in the river Rhine from 14 April to 05 May. In 1951 stow net fishing was continuous from 25 April to 01 June.

3.7 Fish lengths

<u>Comparison Netherlands versus Germany</u>

Based on simultaneous fishing during the month of October 2020 and April 2021 fish lengths were compared between the stow net fishing in the Netherlands and in Germany. Only fish that were frequently found were included. Average fish lengths for Ide and Eel did not differ (Figure 3.17; 3.18). At the German location caught individuals of Bleak, Barbel and Nase were larger than at the Dutch location. Overall, the stow net catches both juvenile and adult individuals of various fish species (Figure 3.17; 3.18).

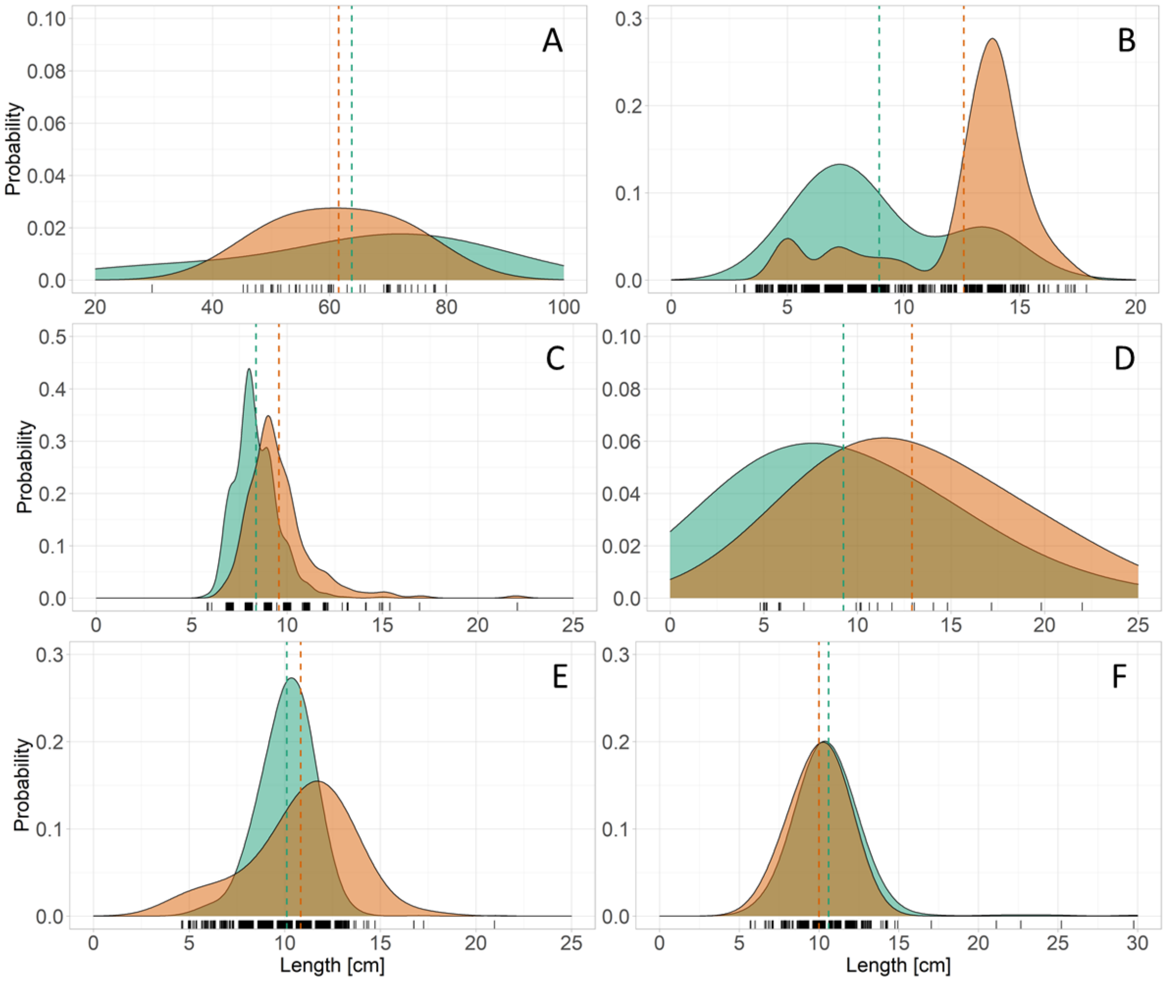

Figure 3.17. Length frequency distribution of Eel (A), Bleak (B), Perch (C), Barbel (D), Nase (E) and Ide (F) during October 2020 in the Netherlands (blue colour) and in Germany (orange colour). The coloured vertical lines indicate the mean fish length, the black vertical lines beneath the x axis are lengths of fish caught.

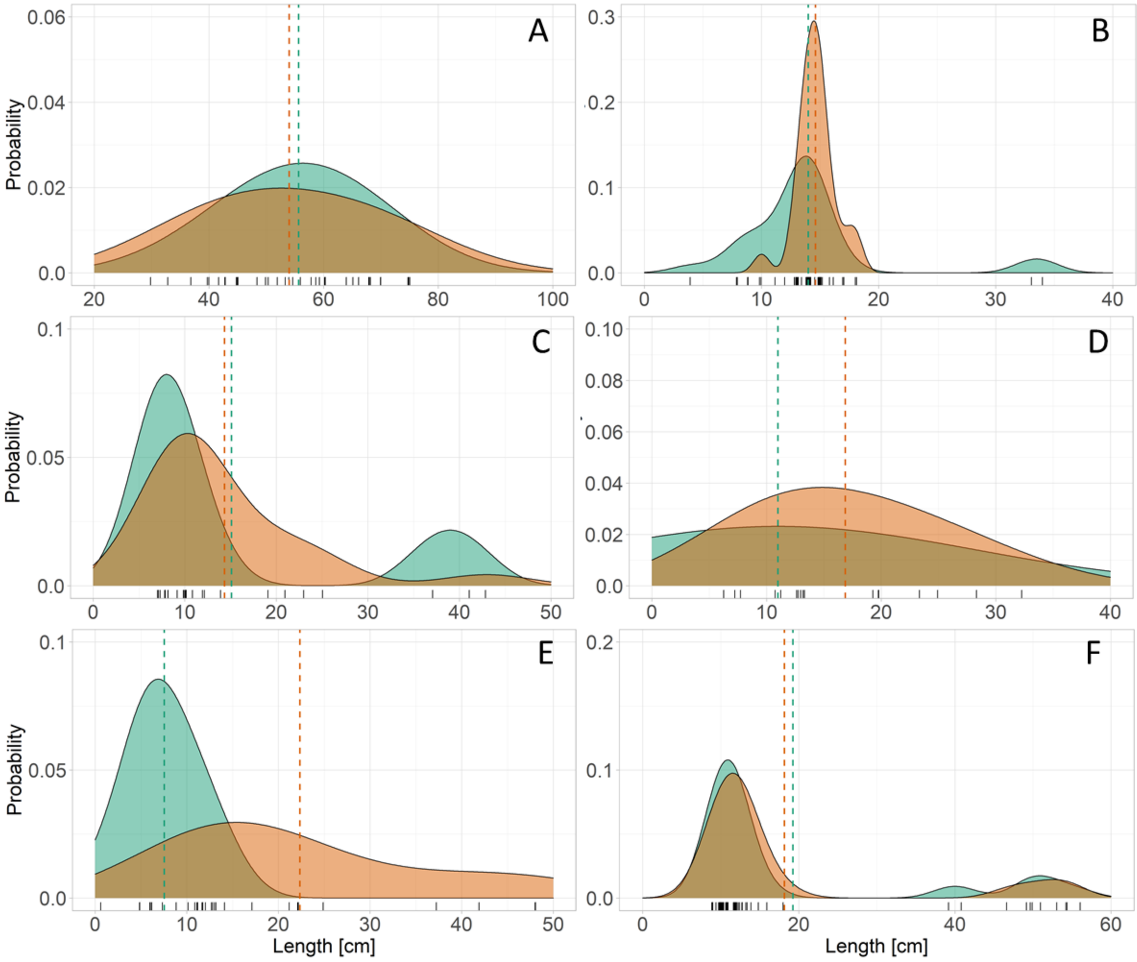

Figure 3.18. Length frequency distribution of Eel (A), Bleak (B), Perch (C), Barbel (D), Nase (E) and Ide (F) during April 2021 in the Netherlands (blue colour) and in Germany (orange colour). The coloured vertical lines indicate the mean fish length, the black vertical lines beneath the x axis are lengths of fish caught.

<u>Fish length diadromous fish species</u>

For several diadromous species, only limited numbers of individuals were caught biasing the length frequency distribution (Figure 3.19). In case of Allis shad and Eel the length frequency distribution was unimodal. The Houting, River lamprey and Sea lamprey length frequency distributions were bimodal. For these three species two distinct age classes were caught. When comparing the recent Atlantic salmon size frequency distribution with the historical distribution it appears that the individuals caught recently are larger than the individuals caught in 1951. For both the recent and historic dataset the majority of individuals was caught in the months April and May thereby sampling month is not affecting the length frequency distribution. The lengths of Seatrout caught in 1951 and more recently deviate due to the presence of more relatively smaller and larger individuals in 1951 than in the recent catches. This could be the effect of a relatively small sample size recently (n = 8) compared to historical (n = 482).

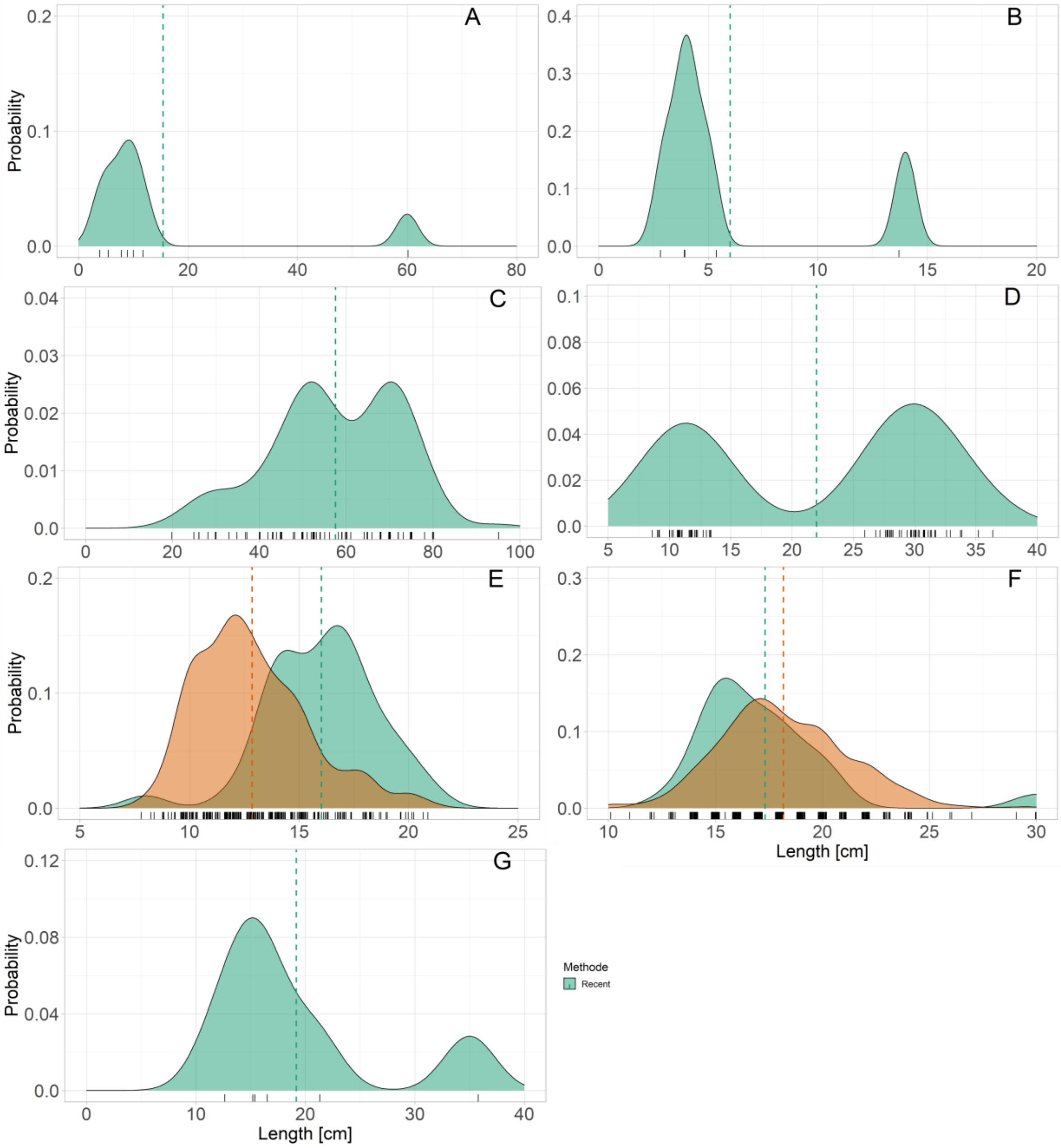

Figure 3.19. Length frequency distribution of Allis shad (A), Houting (B), Eel (C), River lamprey (D), Atlantic salmon (E), Seatrout (F) and Sea lamprey (G) during the recent (blue) and historical (orange) stow net fishing in the Netherlands and in Germany. The coloured vertical lines indicate the mean fish length, the black vertical lines are lengths of fish caught. Historical data derived from Anonymous (1951).

3.8 Historical overview stow net fishing

Based on various historical published and unpublished sources catches of diadromous fish using stow net fishing since the 2nd world war could be reconstructed. The catches from the period 1946 to 1971 were more anecdotal but they give a good indication of which species were caught using the stow net (Table 3.3). Despite the deteriorated water quality of the river Rhine Sea and River lamprey as well as Atlantic salmon and Sea trout were regularly caught. In the period 2018 – 2021 all diadromous fish species that were historically caught using stow net fish were caught (Figure 3.20) except for the Twaite shad. Since the 2nd world war no references were found of a European sea sturgeon caught using stow net fishing. However, the species was caught using a stow net in 1902 on the river Waal near the city of Ochten (https://steuren.ark.eu/).

Table 3.3. Overview of diadromous fish sightings using stow net fishing in the rivers Waal and Rhine after the second world war up to 2021. The blue colour indicates that a species was found, whereas the red colour indicates that a species was not found. Years for which no statement was made about a specific species are indicated with the question mark.

Species	1946	1947	1948	1949	1950	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1984	1985	1986	1987	1988	1989	1990	1991	1997	1999	2018	2019	2020	2021
Sea lamprey	?	?	rare		increasing before 1963													?	?	?	?	?	?	+	+	?	+	-	?	+	+	+	?	-	-	-	-	+	+	+
River lamprey	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	gradual decrease					?	?	?	+	+	?	+	+	+	?	-	-	+	-	+	+	+
Allis shad	?	?	several individuals a year												-	-	-	-	-	-	-	-	-	-	+	?	+	-	?	-	-	-	?	-	-	-	-	+	+	+
Twaite shad*	?	?	occasional catch												?	?	?	?	?	?	?	?	?	?	?	?	+	-	?	-	-	-	?	-	-	-	-	-	-	-
Atlantic salmon	?	?	-	-	+	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	+	?	?	+	+	?	+	+	+	?	-	-	-	-	+	+	+
Sea trout	common		several		several individuals a year													-	-	-	-	-	-	-	-	-	+	+	?	+	+	+	?	+	-	+	-	+	+	+
Smelt	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	no individual since 1962										-	-	?	-	-	-	?	-	-	-	-	-	+	-
Flounder	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	-	-	?	-	-	-	?	-	+	-	-	+	+	+
Eel	?	?	?	?	?	fairly common												substantial decrease									-	-	?	-	-	-	?	-	+	+	+	+	+	+
Houting	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?		-	-	?	-	-	-	?	-	-	-	-	+	-	-

* The record of Twaite shad is debated by the authors that published the data.

Sources: Oomen and Van Wijck 1978; Cazemier unpublished, a and b; Anonymous 1951; Wiegerinck et al. 1997; Stam et al. 1999; data included in this report for both the Netherlands and Germany.

Figure 3.20: An Allis shad collected during the stow net fishing in the river Rhine near Grieth (April 2021).

The months in which the diadromous fish species were caught historically up to the current year clearly show the months in which downstream migration occurs (Table 3.4). Based on the overview table stow net fishing for diadromous fish is most efficient in the months April/May and September/October.

Table 3.4. Overview of the months in which diadromous fish were caught using stow net fishing (blue) and based on the NEDAP monitoring (green) in the river Waal and Rhine after the second world war up to the current year. The dark colour highlights months in which the majority of individuals were caught whereas the light colour indicates months with lower numbers.

Species	January	February	March	April	May	June	July	August	September	October	November	December
Sea lamprey				x	x	x	x		x	x		
River lamprey				x	x	x	x		x	x	x	x
Allis shad									x	x	x	
Twait shad										x		
Atlantic salmon			x	x	x	x	x					
Sea trout				x	x	x	x				x	x
Smelt									x			
Flounder				x	x				x	x		
Eel	x	x	x	x	x	x	x	x	x	x	x	x
Houting					x				x			

3.9 Anecdotal information

- Throughout the stow net fishing dead or nearly dead Eel were caught with wounds on their body. Of the 51 caught eel in the river Waal, 8 were critically injured or dead (16%). In Germany there are no counts available but the impression of the professional fisherman is that one third to half of the caught eel were critically injured or dead. The exact reason for the wounds is unclear. They could be inflicted by passing a hydropower station, a pumping station or being hit by a ship hull or propeller.
- The number of caught eel was quite low during sampling days, this implies that sampling did not take place during silver eel migration.
- Three out of the 17 caught Atlantic salmon in the river Waal were obviously not able to survive further downstream migration. Two of them were heavily covered with mold spots, one Atlantic salmon was already dead when caught (Figure 3.21).

Figure 3.21. Dead Atlantic salmon that was caught using the stow net sampling in April 2021 in the river Waal in the Netherlands.

- In April 2021 in the shore channel of Ophemert several adult River lampreys were found that had the characteristic mating wound at their tail (Figure 3.22). This implies that this species locally spawned. This shore channel is characterized by presence of gravel and high flow velocities thereby indeed providing potential spawning habitat for river lamprey (Collas et al. 2020). Previously, river lamprey larvae (1.2 cm) have been found in the Dreumel shore channel (Dorenbosch et al. 2019). Therefore, it is likely that the shore channels along the river Waal provide suitable spawning habitat for River lampreys.

Figure 3.22. Characteristic mating wound at the tail of caught river lampreys in April 2021 in the river Waal in the shore channel of Ophemert in the Netherlands.

- During the stow net fishing, a lot of plastic was caught (Figure 3.23). This plastic has been collected and was counted as part of another research project (Oswald et al. 2020; Collas et al. 2021). The stow net is not only a good monitoring method for diadromous fish but also for the plastic present in the water column of fast flowing parts of rivers.

Figure 3.23. Uncleaned sample from the stow net with clearly visible a multitude of plastic pieces and organic material.

4. Conclusions and recommendations

Conclusions regarding research questions

- The stow net is a valuable fishing technique to monitor diadromous fish species in fast flowing parts of rivers. Moreover, this technique also allows to monitor non-diadromous fish species.
- Roach, Bleak and Bream were the most abundant caught fish species in the river Waal using the stow net fishing. In the Lower Rhine in Germany, the most abundant fish species was Bream followed by Roach, Nase and Perch.
- Fish diversity in the shore channel along a longitudinal training dam was higher than in the main channel. This effect was also found for diadromous fish species.
- Fish density was higher during the night than during the day both in the shore channel and in the main channel. For diadromous fish, density did not differ between day and night. The highest overall fish density was found in October and the highest density of diadromous fish was found in September.
- The CPUE of all fish species, and of diadromous fish species in particular, in April 2021 did not differ between left and right bank of the river. For all fish, the CPUE was higher during the night than during the day.
- Species composition and CPUE differed between the five sampled months (April, May, September, October and November), showing every season has it's own dynamics.
- Atlantic salmon and Eel migration occurs throughout the day. The catches of both species using the stow net indeed did not differ during the day and at night.
- The number of downstream migrating Atlantic salmon through the river Waal in April was estimated to be 2062 during the two sampling weeks (95% confidence interval: 1692 – 2480). In the Lower Rhine in Germany, downstream migrating Atlantic salmon during sampling were estimated to be 308 individuals (95% confidence interval: 261 – 363).
- Bleak, Perch, Barbel and Nase were smaller in The Netherlands than in Germany. The length of recently caught Atlantic salmon was larger than that recorded in fish length data for the year 1951.
- All species caught using stow net fishing in the past were also caught in our project (2018-2021). After the 2nd world war the catches of diadromous fish decreased.

Recommendations for future research

- The relationship between downstream migration of diadromous fish and the river discharge remains unknown due to limited sampling data during periods with above and below average discharges. A continuous stow net monitoring during an entire year will aid in understanding when species migrate.
- Stow net fishing has not been performed in the middle of the main channel. It would be interesting to attempt to fish there to assess the entire horizontal variation in fish diversity and density from river shore to river shore.
- If the research goal is to catch as many diadromous fish species as possible, it is key to perform the sampling in April / May and September / October. During these periods, fishing can be performed during the day or night.
- The large number of mainly juvenile Roach, Bream and Nase during sampling in October could be an indication of local migration to winter habitat. As far as we know, this is not documented yet but could be important information for optimizing river management in favour of fish.

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7. Supporting information

Table S1: Overview of the English, Dutch, German and Latin name of all fish species collected using stow net fishing in the period November 2018 – April 2021.

English name	Dutch name	German name	Latin name	Describer	Guild	Diadromous
Bleak	Alver	Ukelei	*Alburnus alburnus*	(Linnaeus, 1758)	Eurytopic	No
Perch	Baars	Flussbarsch	*Perca fluviatilis*	Linnaeus, 1758	Eurytopic	No
Barbel	Barbeel	Barbe	*Barbus barbus*	(Linnaeus, 1758)	Reophilic	No
Bitterling	Bittervoorn	Bitterling	*Rhodeus amarus*	(Bloch, 1782)	Limnophilic	No
Roach	Blankvoorn	Rotauge	*Rutilus rutilus*	(Linnaeus, 1758)	Eurytopic	No
Vimba	Blauwneus	Zährte	*Vimba vimba*	(Linnaeus, 1758)	Reophilic	No
Flounder	Bot	Flunder	*Platichthys flesus*	(Linnaeus, 1758)	Reophilic	Yes
Bream	Brasem	Brachse	*Abramis brama*	(Linnaeus, 1758)	Eurytopic	No
Danube bream	Donaubrasem	Zobel	*Ballerus sapa*	(Pallas, 1814)	Reophilic	No
Three-spined stickleback	Driedoornige stekelbaars	Dreistachliger Stichling	*Gasterosteus aculeatus*	Linnaeus, 1758	Eurytopic	Yes
Allis shad	Elft	Maifisch	*Alosa alosa*	(Linnaeus, 1758)	Reophilic	Yes
Houting	Houting	Nordseeschnäpel	*Coregonus oxyrinchus*	(Linnaeus, 1758)	Reophilic	Yes
Gibel carp	Giebel	Giebel	*Carassius gibelio*	(Bloch, 1782)	Eurytopic	No
Carp	Karper	Karpfen	*Cyprinus carpio*	Linnaeus, 1758	Eurytopic	No
Bighead goby	Kesslers grondel	Kessler-Grundel	*Ponticola kessleri*	(Günther, 1861)	Eurytopic	No
Coregonus spec.	Coregonus spec.	Coregonus spec.	Coregonus spec.	-	-	Yes
White bream	Kolblei	Güster	*Blicca bjoerkna*	(Linnaeus, 1758)	Eurytopic	No
Chub	Kopvoorn	Döbel	*Squalius cephalus*	(Linnaeus, 1758)	Reophilic	No
Caucasian dwarf goby	Kaukasische dwerggrondel	Kaukasus-Grundel	*Knipowitschia caucasica*	(L.S. Berg, 1916)	Eurytopic*	No
Eel	Paling	Europäischer Aal	*Anguilla anguilla*	(Linnaeus, 1758)	Eurytopic	Yes
Tubenose goby	Marmergrondel	Marmorgrundel	*Proterorhinus semilunaris*	(Heckel, 1837)	Eurytopic	No
Wels catfish	Meerval	Europäischer Wels	*Silurus glanis*	Linnaeus, 1758	Eurytopic	No
Monkey goby	Pontische stroomgrondel	Flussgrundel	*Neogobius fluviatilis*	(Pallas, 1814)	Eurytopic	No
Ruffe	Pos	Kaulbarsch	*Gymnocephalus cernua*	(Linnaeus, 1758)	Eurytopic	No
Gudgeon	Riviergrondel	Gründling	*Gobio gobio*	(Linnaeus, 1758)	Reophilic	No
River lamprey	Rivierprik	Flussneunauge	*Lampetra fluviatilis*	(Linnaeus, 1758)	Reophilic	Yes
Asp	Roofblei	Rapfen	*Leuciscus aspius*	(Linnaeus, 1758)	Eurytopic	No
Dace	Serpeling	Hasel	*Leuciscus leuciscus*	(Linnaeus, 1758)	Reophilic	No
Nase	Sneep	Nase	*Chondrostoma nasus*	(Linnaeus, 1758)	Reophilic	No
Pike	Snoek	Hecht	*Esox lucius*	Linnaeus, 1758	Eurytopic	No
Pikeperch	Snoekbaars	Zander	*Sander lucioperca*	(Linnaeus, 1758)	Eurytopic	No
Smelt	Spiering	Stint	*Osmerus eperlanus*	(Linnaeus, 1758)	Reophilic	Yes
Sunbleak	Vetje	Moderlieschen	*Leucaspius delineatus*	(Heckel, 1843)	Limnophilic	No
Ide	Winde	Aland	*Leuciscus idus*	(Linnaeus, 1758)	Reophilic	No
Whitefin gudgeon	Witvinriviergrondel	Stromgründling	*Romanogobio belingi*	(Slastenenko, 1934)	Reophilic	No
Salmon	Zalm	Atlantischer Lachs	*Salmo salar*	Linnaeus, 1758	Reophilic	Yes
Sea trout	Atlantische forel	Forelle	*Salmo trutta*	Linnaeus, 1758	Reophilic	Yes
Sea lamprey	Zeeprik	Meerneunauge	*Petromyzon marinus*	Linnaeus, 1758	Reophilic	Yes
Round goby	Zwartbekgrondel	Schwarzmund-Grundel	*Neogobius melanostomus*	(Pallas, 1814)	Eurytopic	No

* Van Treeck et al. (2020) assigned the species to limnophilic but in the Netherlands it was caught under fast flowing and standing water conditions. Therefore, the species was considered a eurytopic species

Table S2. Overview of the best models regarding fish density used in this study.

				Explanatory variables						Best model characteristics		
Question	Subset	Endpoint	Fish groups	Time of day	Month	Year	Location	River side	Time of day:Location	Distribution	AIC	R^2
1. Effect of time of day and location	2019 and 2020 (Sept. and Oct.)	Density	All fish	**< 0.001**	**< 0.001**	-	**< 0.05**	n.r.	**< 0.001**	Gamma	167.7	0.92*
			Diadromous	0.06	**< 0.001**	**< 0.001**	-	n.r.	n.r.	Gamma (+0.001)	-649.32	0.58*
2. Effect of sampling month, year and location	May, Sept. Oct. Nov.	Density	All fish	n.r.	**< 0.001**	-	0.64	n.r.	n.r.	Normal (log10 + 0.001)	149.87	0.36
			Diadromous	n.r.	**< 0.001**	-	**< 0.001**	n.r.	n.r.	Gamma (+0.0001)	-784.92	0.75*
3. Effect of time of day, river side and location	April 2021	CPUE	All fish	**< 0.001**	n.r.	n.r.	-	0.08	n.r.	Gamma	166.62	0.45*
			Diadromous	0.16	n.r.	n.r.	-	-	n.r.	Gamma (+0.001)	27.14	0.08*

Appendix 1

Locations of stow net fishing. Germany: Rees (site DL-Rees right) , Grieth (site DL-Grieth left). The Netherlands: IJzendoorn (Site C), Dreumel (site D and D2), Ochten (site E and F), Tiel (site G) and Ophemert (site H). Red stars indicating frequently monitored locations, gray stars indicating occasional monitoring locations.


C
0 200 400 600 800
Meters
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community; Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community


Tiel
Vluchthaven
Tiel
Waal
West Maas en
G
D
Inundatiekanaal
0 200 400 600 800
Meters
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community; Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community


Tiel
West Maas en Waal
D2
Bovenste Zennewijnensche Wetering
Waal
Zennewijnen
0 200 400 600 800
Meters
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community; Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community


De Heuning
Leigraaf
Ochten
E
Neder-Betuwe
Druten
F
Waal
De Bosoven
Industrieterrein
Excluton
0 200 400 600 800
Meters
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community; Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community


Hoogveldsche Watering
H
Dreumel
De Kil
Neerijnen
West Maas en Waal
0 200 400 600 800
Meters
Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community; Esri, HERE, Garmin, (c) OpenStreetMap contributors, and the GIS user community