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A large-scale passage evaluation for multiple fish species: Lessons from 82 fishways in lowland rivers and brooks

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ABSTRACT

River networks worldwide are highly fragmented and this is particularly prevalent in the human-dominated lowland landscape of the Netherlands. Fishways function as measures to facilitate passage alongside barriers for fish communities and have been evaluated mostly in single case studies. We compared fish monitoring data of 82 fishways with data of fish observed in adjacent water stretches, conducting the first nationwide study on passage for the full spectrum of fish species present. In total, 35 out of 38 (92%) native species recorded in fishways' surroundings used fishways, while per fishway the median was 59% related to a variety of factors (fish behaviour, fishway type, monitoring design). The species using fishways most frequently were perch *Perca fluviatilis* (71/78 of fishways present), roach *Rutilus rutilus* (70/79) and gudgeon *Gobio gobio* (68/77). Logistic regression models showed the effect of monitoring duration and timing in detecting specific fish species ascending fishways. This large-scale analysis highlights the need to consider all native fish species during the design and monitoring of fishways. The obtained information from this study can be used by water managers for improving monitoring schemes and river connectivity which is an essential component for achieving the European Water Framework Directive goals.

1. Introduction

River landscapes worldwide are highly fragmented, with numerous barriers constructed to serve various purposes such as irrigation, flood control, power generation, and navigation (Belletti et al., 2020; Nilsson et al., 2005). River infrastructure not only alters a river hydrologically and geomorphologically (Birnie-Gauvin et al., 2017; Nilsson et al., 2005), but also restricts fish species' movements, and is one of the primary causes of the decline or extinction of migratory fish populations (Limburg and Waldman, 2009; WWF, 2021).

In the European Union today, conservation and restoration of fish diversity are of high priority in the international and national agendas with multiple frameworks and regulations aiming to achieve that (Brevé et al., 2014). Notably, the EU Water Framework Directive (WFD) (Directive No 2000/60/EC) targets the protection and restoration of surface waters by committing the member states to achieve "good ecological status" by 2027. Freshwater fish are one of the biological quality elements to achieve the good ecological status of freshwater bodies. Accommodating unhindered movements of fish is essential for accomplishing the objectives of the WFD. Restoring river connectivity can be achieved by the removal of barriers or by facilitating fish passage in or alongside water control structures. As many barriers are essential to support services such as water storage, flood protection and navigability, barrier removal is not always feasible. Consequently, the construction of fishways has been a common routine to compensate for connectivity loss (Katopodis and Williams, 2012). The provision of a fishway does not always guarantee successful passage of fish species, as demonstrated in many cases worldwide, (Foulds & Lucas, 2013; Hahn et al., 2022; Knaepkens et al., 2007; Rolls et al., 2018). Therefore, fishways must be monitored not only to ensure their functionality and if necessary adjust the operation or design, but also to provide technical and biological knowledge that will support the development of future fishways (Travade and Larinier, 2002). The most commonly used method of fishway monitoring is by recording fish in and/or ascending the fishway by direct sampling (Hatry et al., 2013; Lira et al., 2017; Silva et al., 2018).

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Fishway construction and monitoring were biased towards economically and socially important diadromous species such as salmonids (Roscoe and Hinch, 2010). However, there is growing awareness that facilitating the movement of all native species, including small, weak swimmers is necessary to serve local migrations, avoid population isolation, enable recolonization after local extinction or increase genetic diversity (Junker et al., 2012; Raeymaekers et al., 2008; Wilkes et al., 2019). Such multi-species passage has been investigated mostly in single case studies (Rolls et al., 2018). These case studies, while valuable in providing in-depth information for fishway effectiveness, obviously focus on specific locations or fishway designs. On the other hand, large-scale studies can be particularly useful to identify patterns in fishway design and passage that would eventually improve decision-making and fishway development (Hatry et al., 2013). However, existing large-scale studies are limited to describing trends in fishway construction and monitoring status (Hatry et al., 2013; Lira et al., 2017; Shi et al., 2015) without looking closely into fishway passage by the full spectrum of native fish species.

The lowland, heavily anthropogenically altered landscape of the Netherlands is characterised by one of the highest barrier densities in Europe (Belletti et al., 2020). Many fish species populations became locally extinct or are in decline, with river connectivity disruption by barriers contributing greatly to this (de Groot, 2002). With the WFD in place, the Dutch water authorities have developed a database of bottlenecks to fish migration 'Nationale Visroutekaart' (National Fish Roadmap), as a prioritization tool for barrier mitigation. A total of 2664 barriers have been identified as problematic for fish movement (Kroes et al., 2017). Many of these barriers were made passable by a variety of migration facilities, and more are planned for mitigation by 2027 (Brevé et al., 2014). It is estimated that 29% of the implemented measures have been monitored regarding their functionality (Kroes et al., 2017). With the increased notion that fishways should allow the migration and movement of all native fish species, monitoring schemes should be able to assess fish passage for the widest possible spectrum of species. However, in the absence of national fishway monitoring guidelines water managers and practitioners have chosen various monitoring schemes at numerous studied sites. This may lead to debatable results and may also influence the detection of specific species ascending fishways. The focus of monitoring is primarily on upstream passage since downstream passage of barriers in Dutch flowing waters, mainly low-head weirs or discharge sluices, is less hindered (Winter and Van Densen, 2001). This large number of monitored fishways in the Netherlands provides a good opportunity to identify patterns in fish passage at a large scale for lowland rivers and brooks and provide suggestions for optimizing monitoring.

In this study, we compiled fishway monitoring studies from the rivers and brooks in the Netherlands and compared the results with the national database of fish distribution (Dutch Fish Atlas; DFA) to evaluate fishway use for the whole spectrum of native species and different fishway types. Methodological aspects were taken into consideration to address the consequences of variation in timing and duration of monitoring.

2. Materials and methods

2.1. Study area

The rivers and brooks in the Netherlands are part of the delta of four major transboundary river basins comprising the rivers Rhine, Meuse, Scheldt and Ems. Their cumulative length is estimated at 6850 km (Kroes et al., 2017), of which 100% of the rivers and 70% of brooks are designated as WFD water bodies. These are classified into 18 different types, but only 13 WFD types are included in the prioritization map for barrier mitigation. For each WFD type, the number of barriers and fish passage facilities is given according to the national barrier prioritization map (Table 1). Not all fish passage facilities concern the implementation of fishways and they may include other measures such as adaptive sluice management.

2.2. Fishway monitoring data

To collect monitoring data on upstream fishway passage, we contacted the fish migration experts of all 22 regional and national water authorities requesting data on fishway monitoring conducted in their jurisdictional area. Our request was met with a positive response from all, showing their interest in a nationwide evaluation. The obtained

Table 1
Realised and planned fish passage facilities along with the number of studies and fishways included in the analysis per WFD water body type (R) according to the Netherlands typology for brooks and rivers (van der Molen et al., 2016).

		Barriers*	Realised fish passage facilities (up to 2021)	Planned fish passage facilities	Number of studies collected	Fishways included in the analysis
WFD Type	Description	N	N	N	N	N
R3	Temporary brook, slow-flowing, upper reach, sand	13	3	–		–
R4	Brook, slow-flowing, upper reach, sand	417	209	28	25	20
R5	Brook, slow-flowing, middle and lower reach, sand	728	540	31	46	34
R6	Slow-flowing small river, sand/clay	114	96	2	43	20
R7	Slow-flowing large river, sand/clay	31	27	3	20	6
R8	Large freshwater tidal river, sand/clay	7	7			–
R12	Brook, slow-flowing, middle and lower reach, bog, Organic–peat	18	10	8	6	2
R13	Brook, fast-flowing, upper reach, sand	34	8	4		–
R14	Brook, fast-flowing, middle and lower reach, sand	11	10	–		–
R15	Fast-flowing small river, gravel	2	2	–	4	–
R16	Fast-flowing large river, sand-gravel	2	2	–		–
R17	Brook, fast-flowing, upper reach, lime	16	7	–		–
R18	Brook, fast-flowing, middle and lower reach, lime	33	12	10	1	–
		1426	933	86	145	82

* The total number concerns only those in rivers and brooks. The remaining prioritized barriers are in other water bodies types (lakes, canals, transitional waters). The status of 396 barriers is unknown and for 11 barriers no facility is foreseen.

information consisted entirely of grey literature reports. We screened the collected reports and selected only studies for fishways located in rivers and brooks (so-called R-type waters) resulting in 145 relevant monitoring studies. The most common method used in fishway monitoring was fyke-net sampling (122), followed by fish counter (14), telemetry (4), mark-recapture (3) and video (2) (Fig. 1). The number of fishway studies increased per 5-year interval up to 2015. However, fewer studies have been conducted recently (2016–2020). Moreover, an increase in more technologically advanced methods of fishway monitoring is observed during the last 20 years.

The obtained studies were filtered using five criteria (Fig. 2). Because most of the studies used fyke-net monitoring, which is also a suitable method to determine passage for a wide spectrum of fish species, we focused our analysis on these data. As most reports focused on upstream migration during February–June; here we use the term "spring"; we excluded the very few year-round and autumn/fall studies. Since, most fishways were constructed after the WFD came in force in 2000, we included evaluations covering the period 2000–2020. Studies investigating upstream passage through all types of fishways, excluding combination of fishways in a row and other man-made obstructions (e.g. culverts,siphons) were considered. If a fishway was monitored more than once, the data of the most recent study were used. For the studies that met the criteria above, we recorded the fishway location (longitude and latitude in WGS84 coordinates), the unique obstacle number assigned by National Fish Roadmap, barrier type, fishway type, WFD type and name of the waterway, evaluation year, starting and ending date of the evaluation, duration of monitoring, species captured at the upstream exit of the fishway and number of individuals at species level. Duration of monitoring concerns the time period between the monitoring starting and ending dates in days. Structural dimensions and/or hydraulic conditions of the studied fishway were given only rarely, and therefore not included in the database. Moreover, we did not include mesh sizes in the database due to the various fyke-nets used and the occasional absence of mesh size reporting. Fishways were categorized into the following types i) Vertical slot; ii) Dutch pool and orifice; iii) Nature-like; iv) Pool and weir; v) Pool and weir with vertical slot; vi) Fish locks. Dutch pool and orifice category included de Wit and Meyberg fishways, while Nature-like included fishways with no steps such as rock ramps and by pass channels with no steps. Further information about the specific fishways and type categorization can be found in the Supplementary material (Tables S1-S3; Figs. S1-S8).

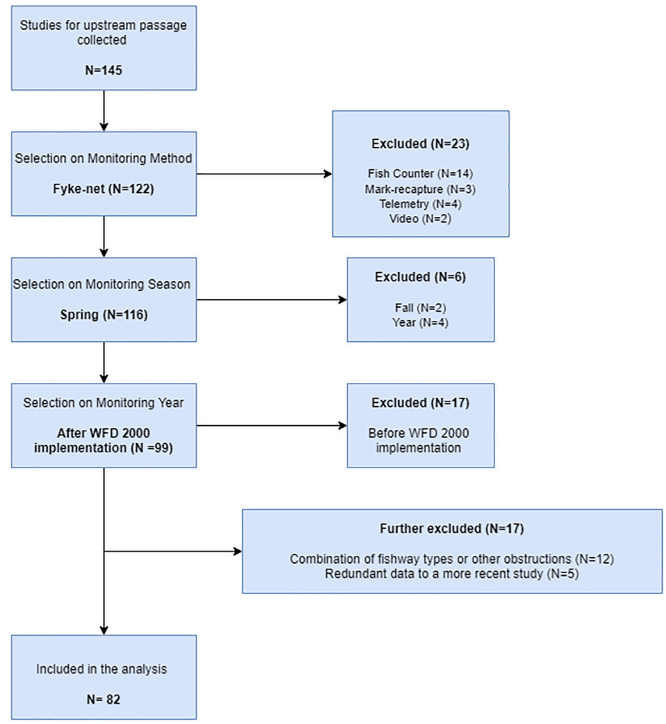

Fig. 2. Flowchart showing the methodology used for filtering the collected fishway studies.

2.3. *Dutch National Fish Atlas (DFA)*

Most fishway reports did not provide any information about the fish community present in the surroundings of fishways and thus potential

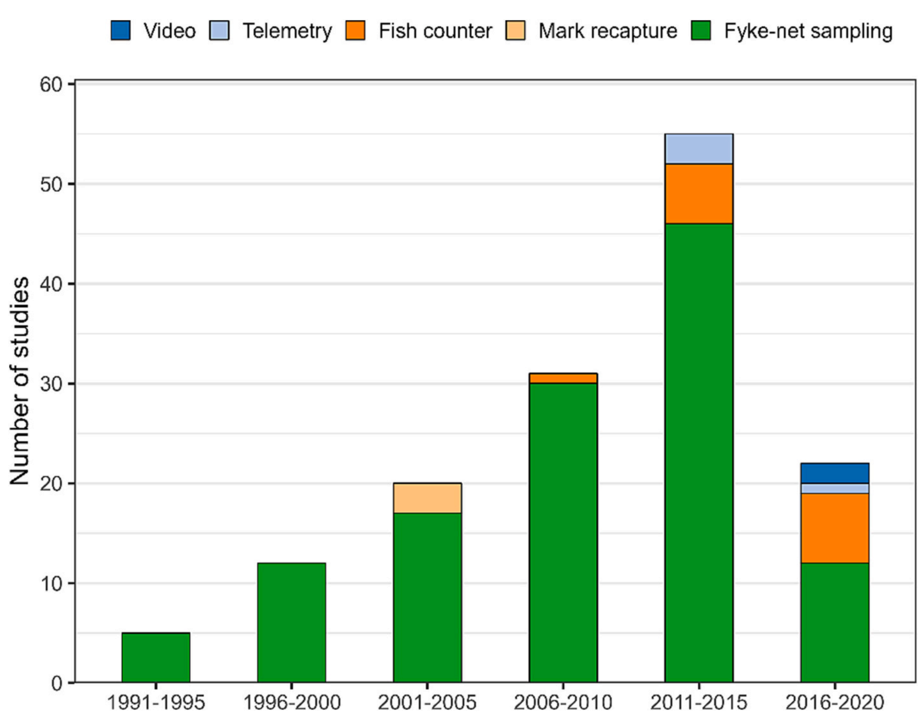

Fig. 1. 5-year interval bar graph showing the methods used in fishway monitoring in the flowing water bodies.

"users". To acquire information on the presence of fish species in the surroundings of fishways, we used the database underlying the DFA (Kranenbarg et al., 2022) that was obtained from RAVON (https://www.ravon.nl/English), an NGO concerned with the conservation of reptile, amphibian and freshwater fish in the Netherlands. The database contains fish monitoring data from the local authorities, volunteers, and anglers from 1990 to 2020 and has a spatial resolution of species occurrence per 1 × 1 km grid cell covering the whole of the Netherlands. Grid cells within a 1 km distance from a monitored fishway were assigned with the unique obstacle number of the fishway, using spatial join (Join Attributes by Nearest) operation in QGIS (QGIS Development Team, 2009). The maximum nearest neighbours were specified as 4 and maximum distance to 1000 m. Grid cells in the joined layer without an obstacle number were removed. Because of the dense waterway network in the Netherlands and to avoid including fish species occurrence data from neighbouring water bodies, we screened the remaining grid cells and manually selected only the ones within 1 km of the river reach (upstream and downstream) where a fishway was located (Figs. S9-S11). Only presence-absence was considered as species abundances regularly lacked. For each fishway, the period of the DFA data used included fish occurrences from 1990 up to the year of monitoring the fishway. If a fish species was observed only during the fishway monitoring, it was automatically added to the surroundings' dataset.

2.4. Data analysis

2.4.1. Fishway use

Combining the separate datasets of species presence in the surroundings of fishways (DFA) and of species captured ascending, we examined whether passage was observed for the native fish species present in the surroundings of fishways. For this feasibility assessment we use the term "fishway use". Hence, this study is explicitly not looking into fishway efficiency, as the nature of the data could not yield such a metric. Additionally, the species-specific use per fishway type was calculated. Fish species were classified in two groups, native and alien. As most alien species first appeared in the Netherlands after 1990 or have very limited distribution were excluded from the analysis. The native fish species were further classified based on habitat guilds (rheophilic, limnophilic, eurytopic) according to Aarts and Nienhuis (2003). Scientific and common names for all native species can be found in Table 3 and for alien species in Table S4.

2.4.2. Effect of fishway monitoring duration on the number of fish species observed

To investigate how the monitoring duration affected the proportion of present fish species observed passing fishways, a regression model was built with monitoring duration (days) as predictive variable and the proportion of fish species passing as response variable, assuming a Beta distribution ("betareg" function from the "betareg" package). Beta regression models assume values in the open standard unit interval (0,1) and one of the proportion values were equal to 1, we transformed the proportion values as follows: $(y (n - 1) + 0.5)/n$ where n is the sample size (Smithson and Verkuilen, 2006).

2.4.3. Effect of timing and duration of monitoring in species-specific detection

To explore whether the variable timing and duration of monitoring in the Netherlands influenced the probability of observing specific species ascending fishways, three species that spawn in early spring at relatively low temperatures, pike *Esox lucius,* ide *Leuciscus idus* and dace *Leuciscus leuciscus* (Kroes et al., 2005), were selected to examine whether the monitoring starting date and duration had an effect in the probability of their detection. Similarly, for three late spring spawners, carp *Cyprinus carpio,* tench *Tinca tinca* and white bream *Blicca bjoerkna* (Kroes et al., 2005) duration and ending date of monitoring were examined. These variables were used as explanatory variables in species-specific multiple logistic regression species-specific models. The response variable equaled to 0 when a species was recorded in the surroundings of a fishway but was not detected ascending and 1 if it was detected. Variable selection with backward elimination based on the lowest Akaike's information criterion (AIC) was performed to identify the most relevant explanatory variables among the ones considered (Venables and Ripley, 2002), while in the final selected models significance of variables ($p < 0.05$) was assessed. Potential multicollinearity issues between predictors in the initial set was assessed by computing the variance inflation factor (VIF; R package 'car'; (Fox and Weisberg, 2019). VIF values were lower than 2.98, confirming a lack of any multicollinearity among variables.

All data analysis was performed using R version 4.1.0 (R Core Team, 2021). Maps were prepared using administrative boundaries from the Database of Global Administrative Areas (GADM) and shape files with water body information obtained from waterkwaliteitsportaal.nl. Maps and figures were created in R using the package 'ggplot2' (Wickham, 2016).

3. Results

3.1. Fishway monitoring overview

Most of the fishways (Fig. 3) were located in middle and lower reach brooks (R5 WFD bodies-34 fishways), followed by fishways in upper reach brooks (R4) and small rivers (R6) (both 20 fishways), then large rivers (R7–6 fishways) and middle and lower reach brooks in bog (R12–2 fishways). Thirty-five native and thirteen alien species were captured ascending at least one fishway (Fig. 4). For 13 native species (eel *Anguilla anguilla*, perch *Perca fluviatilis*, roach *Rutilus rutilus*, bream *Abramis brama*, white bream *Blicca bjoerkna*, ruffe *Gymnocephalus cernuus*, gudgeon *Gobio gobio*, ide *Leuciscus idus*, stone loach *Barbatula barbatula*, spined loach *Cobitis taenia*, bleak *Alburnus alburnus*, river lamprey *Lampetra fluviatilis*, sunbleak *Leucaspius delineatus* and sea lamprey *Petromyzon marinus*), the number of individuals ascending exceeded 100 in at least one fishway (Fig. 4).

3.2. Fishway use

When the fishway monitoring data were combined with the DFA, it revealed that 35 out of 38 (92%) native species recorded in fishways' surroundings used fishways (Table 3). The percentage of the species observed passing ranged between 9%–100% with a median value of 59% per fishway (Fig. 5, Table 2). Pool and weir with vertical slot fishways had the highest percentage of species passing with a median value of 73% (Table 2). The lowest percentages of species passing were observed in fish locks and Dutch pool and orifice fishways with median values 50%. There is, however, also a substantial difference in the monitoring duration between the types which can affect the observed number of species passing, ranging between a median of 33 days for fish locks to 75 for pool and weir with vertical slot fishways.

A total of 19 species known to be present in the surroundings were found using more than half of the fishways, with perch having the highest percentage of fishway use (71 out of 78 fishways), followed by roach (70/79) and gudgeon (68/77) (Table 3). The only three fish species with a confirmed presence in the surroundings of fishways that were not captured ascending any fishway were burbot *Lota lota*, smelt *Osmerus eperlanus* and minnow *Phoxinus phoxinus*. Small-bodied species were also observed using fishways; stone loach (32/70), spined loach (13/59) and sunbleak (10/51); but when compared to the number of passages present in the surroundings, their overall use percentages were all below 50% (Table 3).

Eurytopic species dominated both the surroundings and fishway use. For the rheophilic species, only four species (gudgeon, ide, spined loach and stone loach) were present in more than half of fishway surroundings and only one species observed passing >50% of all fishways (gudgeon, 68/77). Sea lamprey *Petromyzon marinus*, salmon *Salmo salar*, barbel

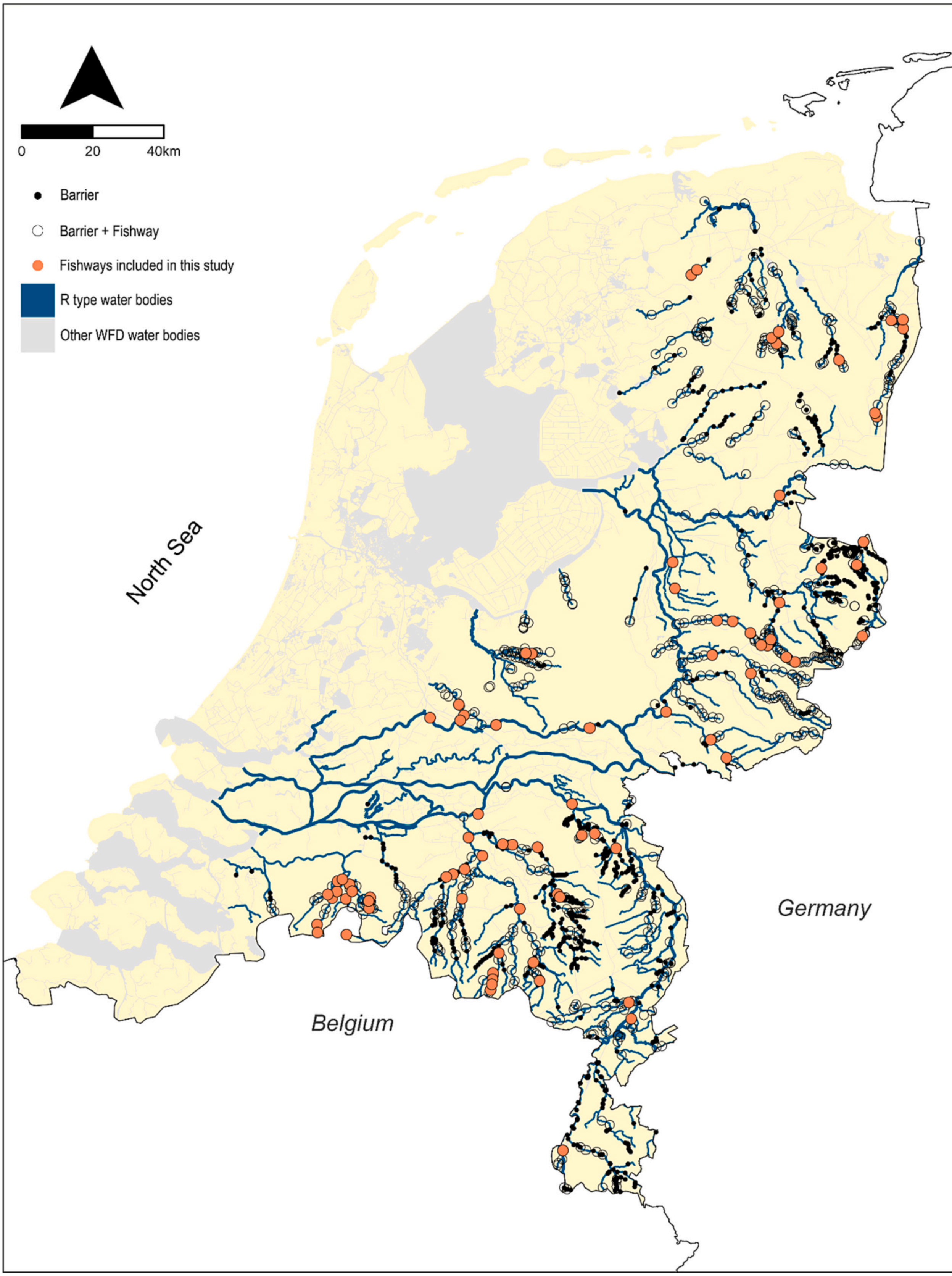

Fig. 3. Map showing the distribution of the 82 fishway locations included in this study (orange circles). Open circles represent barriers with and black dots without fish passage facilities based on the National Fish Roadmap 2019.

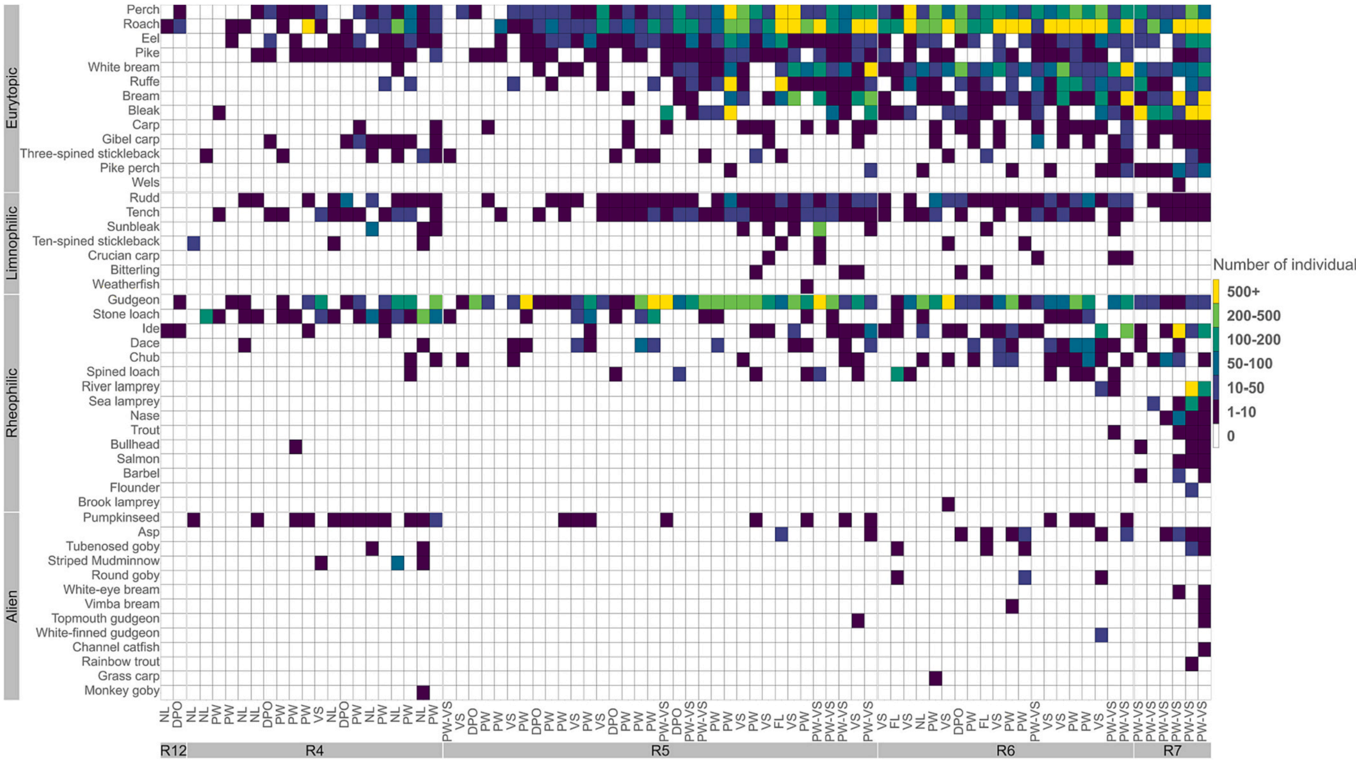

Fig. 4. Species-by-fishway study count matrix across 82 fishway sites. Rectangles representing at least one individual ascending per fishway are colored; White rectangles indicate that species were not recorded. Fish species are grouped into native and alien, native species are grouped further into habitat guilds. Fishways are grouped by WFD water body types. DPO: Dutch pool and orifice, NL: Nature-like, PW: Pool and weir, PW-VS: Pool and weir with Vertical slot, VS: Vertical slot, FL: Fish lock.

Barbus barbus and flounder *Platichthys flesus* were found exclusively ascending fishways in large rivers (Fig. 4).

When species-specific fishway use was analysed per fishway type, small-bodied, weak swimmers typically had low use percentages below 50%, irrespective of fishway type (Fig. 6), with some exceptions such as stone loach which showed a relatively higher fishway use in nature-like fishways, passing 8 out of 9 fishways present. Pool and weir with vertical slot fishways were used more frequently than other types by bleak (15/15), carp (10/13), pike-perch (9/12), and bream (14/17). Tench and eel were found ascending in all Dutch pool and orifice fishways known to be present (6/6), whereas chub used vertical slot fishways most (9/10).

3.3. Effect of fishway monitoring duration on the number of fish species observed

Monitoring duration in studies ranged 10-fold from 13 to 130 days, with a median of 70 days. Beta regression showed that longer duration of monitoring was associated with higher proportion of species observed passing ($\beta = 0.0153$, $z = 4.406$, $p < 0.001$, Fig. 7). This indicates that many studies with short monitoring duration most likely underestimate the range of species using fishways.

3.4. Effect of timing and duration of monitoring in species-specific detection

For pike*,* the best model included the starting date of monitoring, with earlier starting dates significantly increasing the probability of detection (odds ratio = 0.94, Fig. 8). For late spring migrants, white bream and tench, a later ending date significantly increased the probability of their detection (odds ratio = 1.07 and 1.04 respectively, Fig. 8). For carp, monitoring duration significantly increased the probability of detection (odds ratio = 1.05, Fig. 8). Neither monitoring start nor monitoring duration were selected in the best models for dace and ide.

4. Discussion

This study combined fyke-net monitoring data from 82 fishways and the Dutch National Fish Atlas (DFA) to obtain a comprehensive overview of the full spectrum of native fish species passage in a diversity of lowland rivers and brooks in the Netherlands. We found that 92% of the fish species recorded in fishways' 1 km surroundings (DFA) used fishways. Only three fish species were not observed using any fishway (i.e. burbot, smelt, and minnow) which are all rare in the flowing water bodies of this study (Kranenbarg et al., 2022). Fishway use by species present in the surroundings of the 82 fishways varied between 9%–100%. Several underlying causes may have contributed to this variation in fishway use, such as suboptimal fishway performance, biased monitoring methods or lack of motivation of some species to move beyond the barriers facilitated by fishways (Bunt et al., 2012; Kemp, 2016; Roscoe and Hinch, 2010; Silva et al., 2018). These will be discussed below.

Relatively abundant movements (over 100 individuals) of small-bodied, considered as "resident" fish species such as stone loach, gudgeon, and spined loach, were observed in >30 fishways, with a peak of over 1000 gudgeons ascending a pool and weir with vertical slot fishway. Similar high-intensity movements of "resident" species have been observed in fishways in Germany (Jansen et al., 1999; Pander et al., 2013). This new evidence from a large number of fishways makes it obvious that these fish species are less resident than generally perceived (Birnie-Gauvin et al., 2019). However, when compared to other fish, many small-bodied species were observed less frequently ascending irrespective of fishway type. This may be influenced by possible

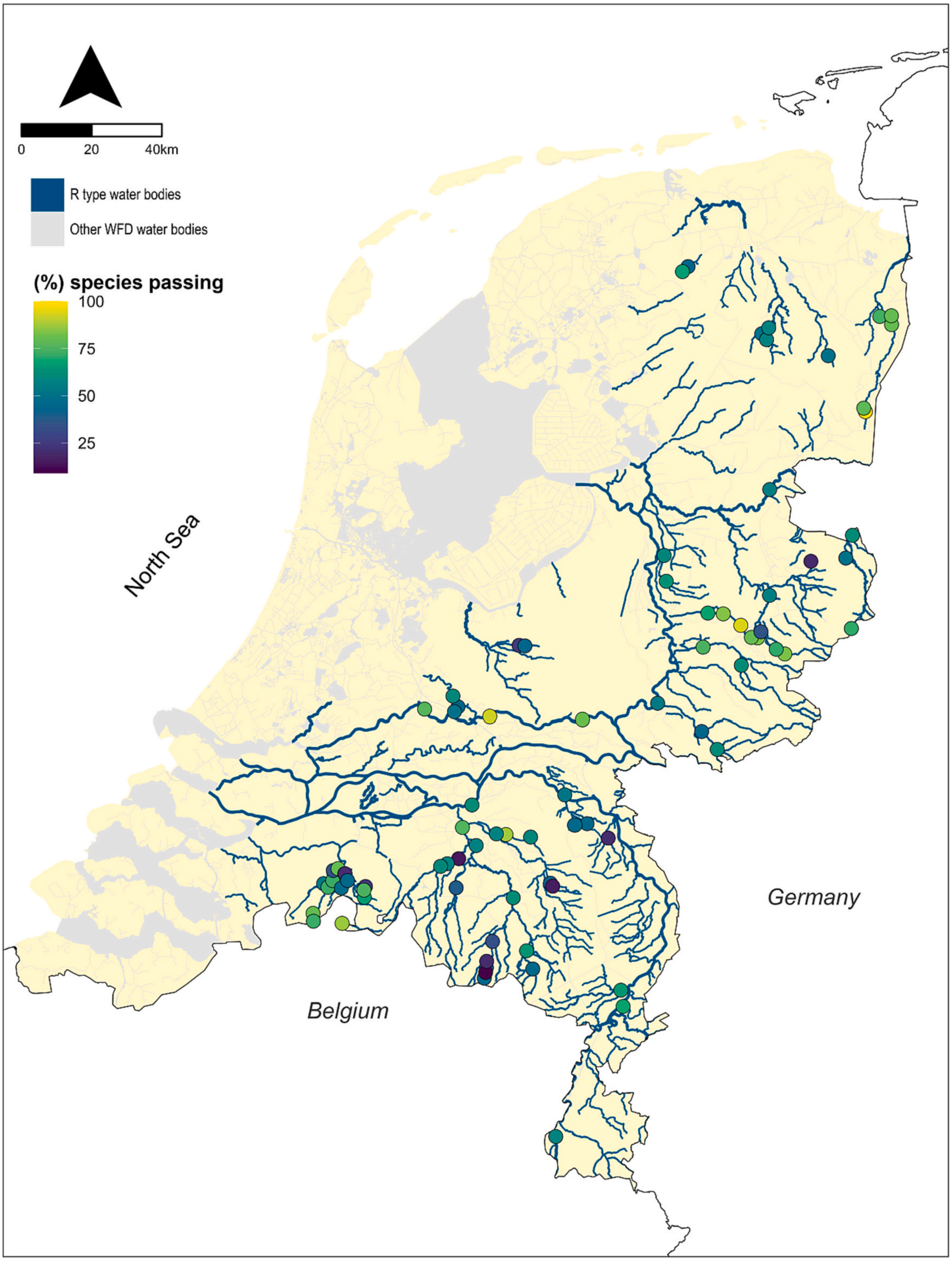

Fig. 5. Map showing the percentage of fish species observed passing fishways compared to those recorded within 1 km vicinity of fishways in the national fish atlas.

escapement of small-bodied fish from fyke–nets due to gear selectivity of the used mesh sizes. The presence/absence approach followed in this study, however, reduces such bias. Many small-bodied species have lower swimming capacities compared to other potamodromous species (Tudorache et al., 2008) and even small barriers/steps (5–17 cm) can prevent these species from moving upstream (Jones et al., 2021). Inability of fishways to provide conditions suitable for their passage or lack of migration motivation might further explain their absence. Additional scientific research into movement behaviour (Birnie-Gauvin et al., 2019; Knaepkens et al., 2004) and fishway efficiency (Knaepkens et al., 2007) for these understudied species, will help us understand better under what conditions these species move through fishways and support to develop more effective solutions and better fishway performance assessment.

The results of the present study showed that timing (starting or ending date of the study) explains better species-specific detection than monitoring duration. If a study was synchronised with the spawning windows of pike, tench, and white bream, they were more likely to be

Table 2
Overview (median, 10th–90th percentiles) of monitoring duration and fishway use per fishway type.

Fishway type	N	Monitoring duration (days)	Native Species present	Native Species passing	Species passing (%)
Dutch pool and orifice	8	44 (22–79)	14 (10–17)	7 (4–11)	50 (39–68)
Fish lock	3	33 (21 – 103)	21 (16–23)	12 (10 – 12)	50 (44–74)
Nature-like	10	58 (44–87)	17 (4–25)	6 (2 – 11)	55 (19–75)
Pool and weir	28	71 (35–87)	18 (13 – 22)	10 (4–13)	57 (31–81)
Pool and weir with vertical slot	17	75 (54–114)	22 (15–28)	14 (11 – 22)	73 (54–89)
Vertical slot	16	73 (46–81)	18 (16–24)	13 (6–16)	61 (34–82)
All types	82	70 (32–88)	18 (11–25)	11 (4–16)	59(26–81)

observed ascending fishways. Other confounding factors such as fishway type and effectiveness or upstream habitat may have also affected the results, however the limited sample size did not allow us for the inclusion of more explanatory variables in the models. Moreover, the results agree with other fish movement studies confirming the importance of monitoring timing in species detection. Recent multi-annual research in similar lowland settings confirms the periodicity of fishway use for adult white bream and tench during spring, with a clear peak in migration during May (Benitez et al., 2022). According to telemetry studies, pike individuals began their upstream migration in February–March and reached spawning habitats no later than the beginning of April (Ovidio and Philippart, 2005). This supports the results of this study, which found that fishway monitoring studies that begin later in spring have a lower probability of detecting pike ascending fishways, as the upstream migration window of pike was most likely missed. Despite dace and ide having a spawning migration early in spring (Kroes et al., 2005) neither starting date nor duration of the monitoring study had a significant effect on their probability of detection. This may be explained by the fact that both juveniles and adults may move upstream throughout spring similar to what was observed in fishways in the Meuse (Benitez et al., 2022).

In different reviews on fish passage, telemetry studies (Bunt et al., 2012; Hatry et al., 2013; Silva et al., 2018) are proposed to determine fishway efficiency. However, most practitioners in the Netherlands, also in recent years, opted for traditional fyke-net sampling when monitoring fishways. This corresponds with what is observed throughout the world with most studies using direct sampling of fish within/or at the exit of fishways (Hatry et al., 2013; Lira et al., 2017; Silva et al., 2018). Telemetry studies enable quantifying and standardising passage metrics, such as attraction efficiency, passage efficiency, delay, but they are costly and limited in serving the full spectrum of species and life stages. Especially, for many small-bodied species telemetry techniques are not always suitable. A combination of methods will be needed to properly evaluate fishway effectiveness for the whole native fish community at different levels (Tummers et al., 2016).

We showed that when fyke-net monitoring duration is too short, the number of species using fishways will be quite likely underestimated, and also monitoring timing influenced species-specific detection probability. Therefore, the value of fishways for native species is expected to be even higher than the monitoring data demonstrate. Developing national and regional guidelines for monitoring methods including fyke-net sampling (mesh size, duration, timing) that account for the entire range of fish species present and different life stages is recommended. In Austria, existing guidelines set a minimum monitoring in spring for fishways, depending on their location in the river system (Woschitz et al., 2020), and provide assessment criteria based on the species present. They suggest a minimum monitoring duration of 2 months for fishways in hyporhithral and 2.5 months in potamal regions in the period March to June. The development of similar tailor-made recommendations worldwide will assist practitioners in better decision-making when planning for fishway monitoring and better performance assessment. Insights from this study can be used towards developing general guidance regarding multi-species fishway monitoring in particular for lowland rivers and streams during spring migration.

In addition to working towards a standardized monitoring system, we also would like to highlight the need for more comprehensive reporting of technical characteristics of fishways in grey literature studies. The included studies rarely provided information on the technical characteristics of fishways (e.g. length, slope, mean water velocity, water level drop between pools, pool size, for pool and weir fishways, and other types in general). Similar challenges with inconsistent reporting were also described in a national-scale analysis in Canada (Hatry et al., 2013) and a meta-analysis on fish passage efficiency (Noonan et al., 2012). This precludes more in-depth analyses regarding the effect of such factors on fishway performance. If we want to gain a more thorough understanding of the performance of existing fishway designs which will also facilitate the development of more effective future fishways, it is pivotal that future studies consistently report such technical characteristics.

There remain limitations to consider when interpreting the results of this study. By focusing our approach on a multi-species level for 82 locations in a variety of rivers and brooks, we achieved an unprecedented broad overview of fishway use. However, true presence of fish species in both the DFA and during fishway monitoring might be missed. Given the variation in monitoring, i.e. duration and timing, and lack of data on abundance of fish approaching the monitored fishway sites, determining and evaluating fishway efficiency is beyond the scope of this study. This study should therefore be seen as a screening assessment for the suitability of fishways to provide passage for all native fish species.

Restoring connectivity by fishway construction and demonstrating their functionality are important steps towards improving the ecological status of lowland rivers. Yet, the effects of river infrastructure on riverine habitats and other anthropogenic impacts such as pollution can impede the success of fishways in restoring fish communities. This is especially important for rheophilic fish communities, as they require flowing and oxygen-rich waters and barriers in lowland streams tend to create long impounded zones due to the low gradient slope (Birnie-Gauvin et al., 2017). In lowland streams in the Meuse basin, where some of the fishways in this study are also located, it was observed that the stream sections with more critical rheophilic species such as dace and chub present, had significantly higher velocity and water quality when compared to those where only more tolerant rheophilic species (gudgeon, ide, stone loach) occurred (van Puijenbroek et al., 2021). This may explain that although fishways have improved connectivity in the "flowing" waters in the Netherlands, more critical rheophilic species were still rare in the surroundings and passage of fishways (Table 3). To maximize the gain through improved connectivity with fishway development, a more holistic approach that addresses all anthropogenic impacts in freshwater bodies is required, as van Puijenbroek et al. (2021) stated "fish passages do not improve habitat quality".

In this study, we present a transferable methodology for identifying patterns in fishway use by the full spectrum of native species and providing insights for improved fishway monitoring using site-level quantitative data and qualitative (presence/absence) data. Furthermore, this approach may be used to detect potentially poorly performing fishways by comparing them to other similar fishways using fish presence data in their surroundings. With the river and stream monitoring resulting from WFD obligations and national fish distribution datasets existing around Europe (Brunken and Vatterrott, 2020; U.K. Environmental Agency, 2019), countries can utilize fishway monitoring data

Table 3
Species specific occurrence in the surroundings of and passing fishways. Species observed passing are ordered by descending percentage of fishways within each habitat guild.

Common Name	Scientific Name	Presence in the surroundings of fishways (N)	Fishways observed passing (N)	Fishways observed passing (%)	Median relative abundance in fishways observed passing (%)
Eurytopic					
Perch	*Perca fluviatilis*	78	71	91%	8.4
Roach	*Rutilus rutilus*	79	70	89%	33.0
Eel	*Anguilla anguilla*	74	61	82%	2.0
Ruffe	*Gymnocephalus cernuus*	57	41	72%	1.3
White bream	*Blicca bjoerkna*	64	46	72%	2.5
Pike	*Esox lucius*	81	55	68%	0.6
Gibel carp	*Carassius gibelio*	35	23	66%	0.2
Bleak	*Alburnus alburnus*	47	28	60%	3.2
Bream	*Abramis brama*	69	36	52%	1.4
Carp	*Cyprinus carpio*	62	27	44%	0.3
Pike perch	*Sander lucioperca*	39	14	36%	0.2
Three-spined stickleback	*Gasterosteus aculeatus*	56	19	34%	0.6
Wels	*Silurus glanis*	7	1	14%	0.1
Limnophilic					
Rudd	*Scardinius erythrophthalmus*	75	58	77%	1.0
Tench	*Tinca tinca*	75	54	72%	0.8
Bitterling	*Rhodeus amarus*	19	5	26%	0.2
Crucian carp	*Carassius carassius*	22	5	23%	0.2
Sunbleak	*Leucaspius delineatus*	51	10	20%	0.3
Weatherfish	*Misgurnus fossilis*	7	1	14%	0.2
Ten-spined stickleback	*Pungitius pungitius*	72	7	10%	0.2
Rheophilic					
Salmon	*Salmo salar*	3	3	100%	0.0
Sea lamprey	*Petromyzon marinus*	4	4	100%	0.8
Gudgeon	*Gobio gobio*	77	68	88%	12.4
Nase	*Chondrostoma nasus*	5	4	80%	0.2
Dace	*Leuciscus leuciscus*	34	24	71%	1.7
River lamprey	*Lampetra fluviatilis*	6	4	67%	1.7
Chub	*Leuciscus cephalus*	34	22	65%	0.4
Ide	*Leuciscus idus*	55	29	53%	0.5
Barbel	*Barbus barbus*	6	3	50%	0.1
Flounder	*Platichthys flesus*	2	1	50%	0.3
Stone loach	*Barbatula barbatula*	70	32	46%	5.7
Trout	*Salmo trutta*	12	4	33%	0.1
Bullhead	*Cottus perifretum*	17	4	24%	0.1
Spined loach	*Cobitis taenia*	59	13	22%	0.2
Brook lamprey	*Lampetra planeri*	6	1	17%	0.2
Burbot	*Lota lota*	1	0	0%	–
Minnow	*Phoxinus phoxinus*	1	0	0%	–
Smelt	*Osmerus eperlanus*	4	0	0%	–

Table 4
Monitoring variables selected in the final species-specific logistic regression models for the detection probability for four species in fishways.

Species	Explanatory variables in final model	OR	95% CI
Pike	Start of monitoring study (DOY)	0.94	0.90 — 0.97
White bream	End of monitoring study (DOY)	1.07	1.02 — 1.12
Tench	End of monitoring study (DOY)	1.04	1.01 — 1.08
Carp	Duration of monitoring study (days)	1.05	1.02 — 1.08

and follow the proposed methodology to gain an overview of multi-species fishway use in their jurisdiction. A similar exercise in other European countries will provide additional data on multi-species passage and enable comparison between sites and fishway types that will support water managers and scientists worldwide in planning future fishway development projects.

In conclusion, our results provide new insights into fishway use by many understudied and often considered "resident" fish species and reveal for the first time from a large-scale perspective the need for an approach that considers the full native fish species spectrum during fishway construction and monitoring. Implications of our findings for fishway practice: (a) Fishways can clearly benefit the whole native fish community, not only obligatory migrants (b) Fishway monitoring schemes should consider the different morphological and phenological traits present in all native fish species.

CRediT authorship contribution statement

Panos Panagiotopoulos: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Anthonie D. Buijse:** Conceptualization, Funding acquisition, Methodology, Supervision, Visualization, Writing – review & editing. **Hendrik V. Winter:** Conceptualization, Methodology, Supervision, Visualization, Writing – review & editing. **Leopold A.J. Nagelkerke:** Formal analysis,

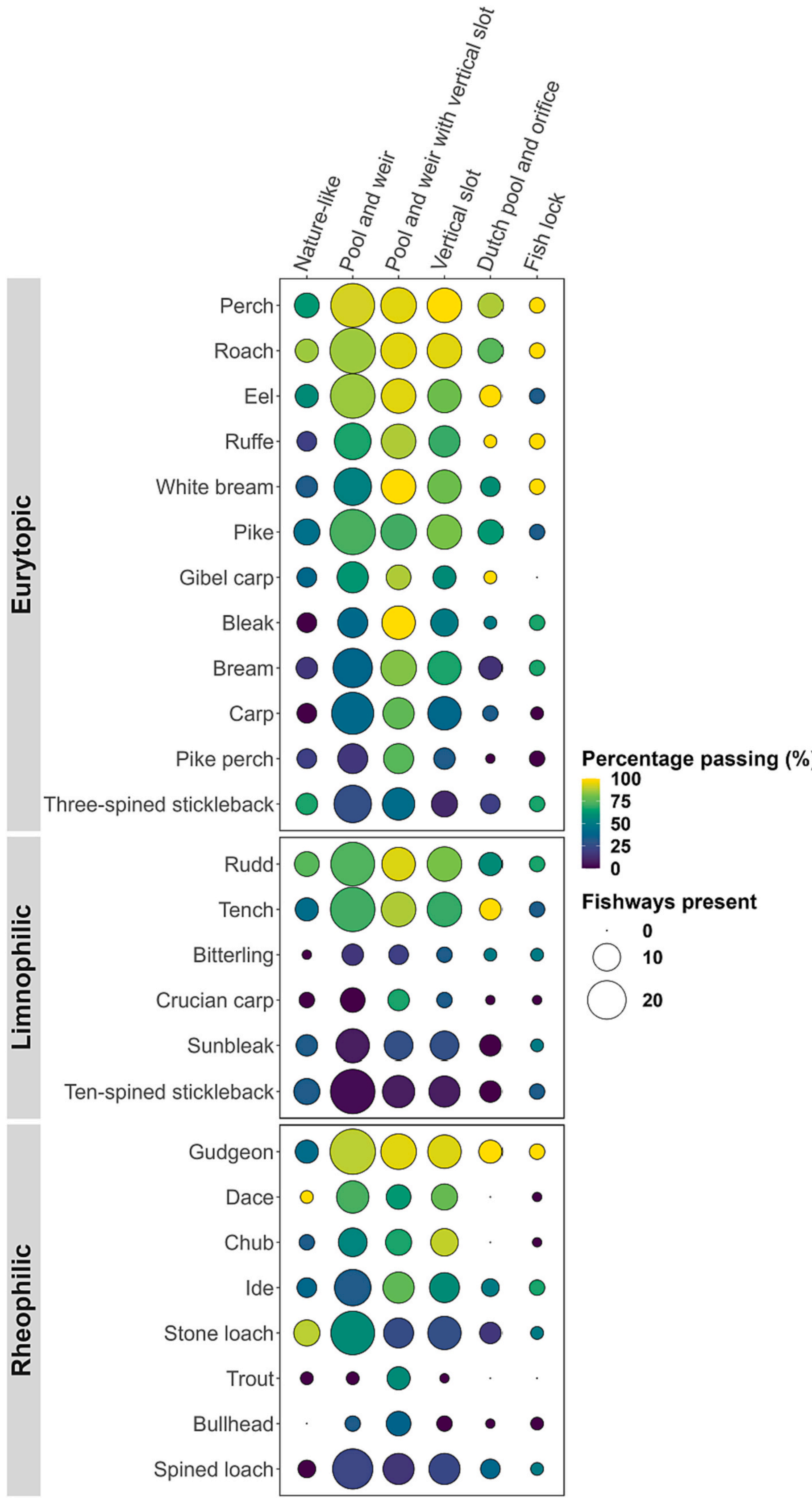

Fig. 6. Bubble plot showing species-specific usage per fishway type (%). Circle radius indicates the number of fishways with a fish species present in the surroundings while the colour gradient the percentage observed passing. Fish species per habitat guild are arranged by descending overall fishway usage percentage (see Table 3). Only species observed in >10% of the surroundings are shown.

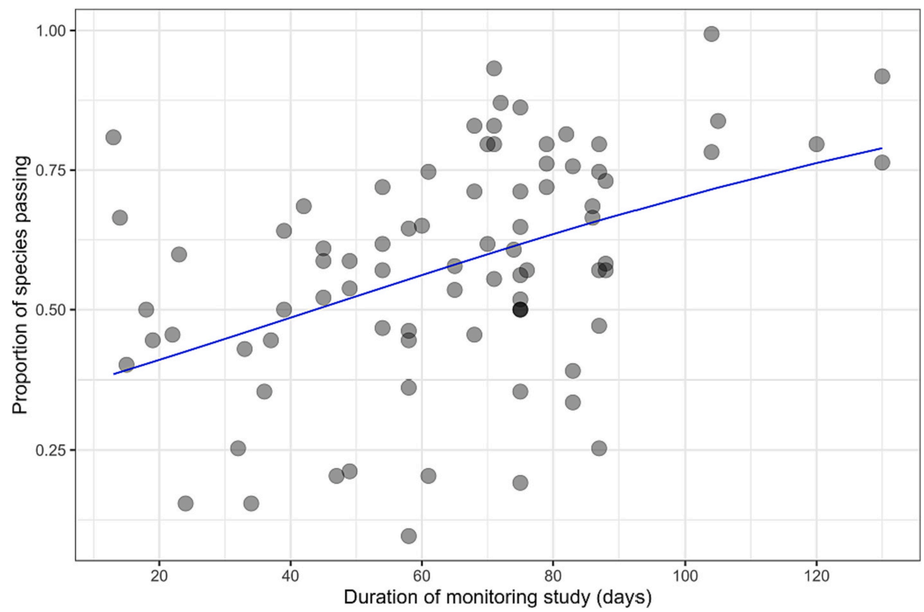

Fig. 7. The proportion of species observed passing plotted against the duration monitoring. Each dot represents one individual fishway study. Fitted curve corresponds to beta regression.

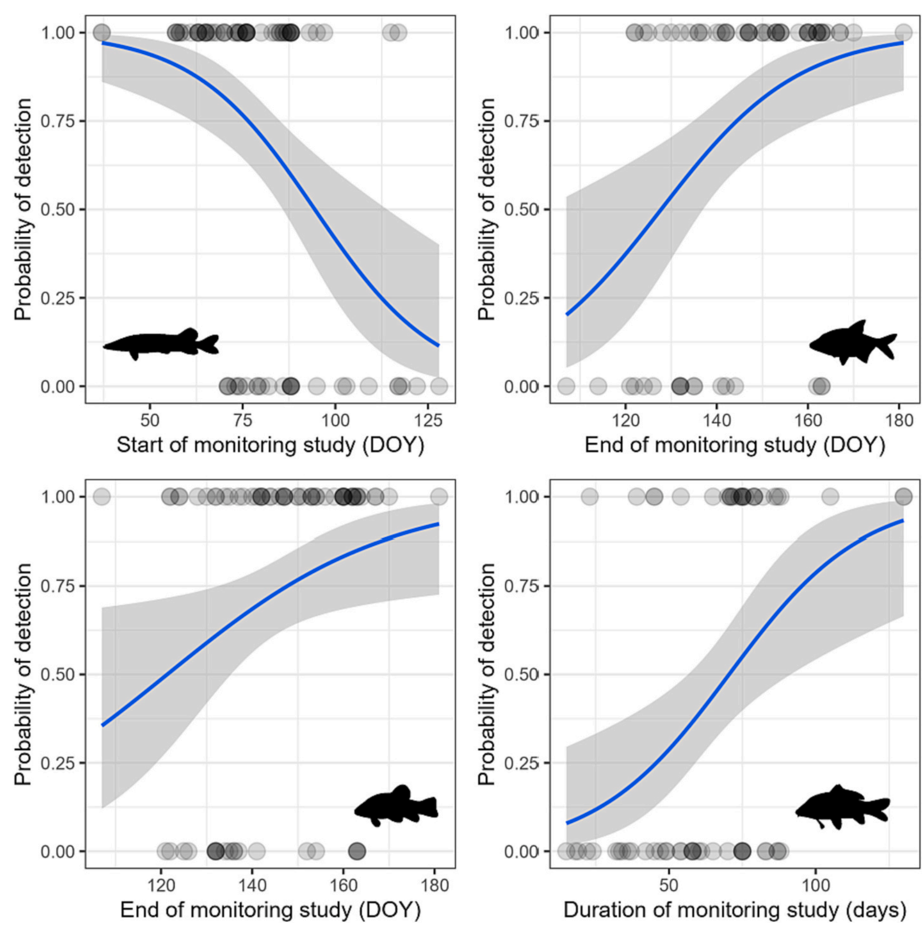

Fig. 8. Predicted detection probability for four species (pike (top left), white bream (top right), tench (bottom left) and carp (bottom right)) as function of the monitoring variables selected in the best model. (DOY: Day of the year). The best logistic regression model per species was determined using backward selection based on AIC. (see Table 4).

Methodology, Software, Supervision, Visualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoleng.2023.107158.

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