Small Eels, Big Barriers

Employing Open Data to Assess the Effects of Dam Removals and Nature-like Fishways on Juvenile Eel Migration

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Swedish University of Agricultural Sciences, SLU
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Abstract

The critically endangered and diadromous European eel, *Anguilla anguilla*, has had its freshwater habitat greatly reduced as a consequence of dam development in European waters. Fishways of different kinds and removal of dams are management measures used to restore connectivity in freshwater systems. Recent work have shown that fishways are not equal in their ability to restore connectivity for many fish species in general and for the European eel in particular, and that they can be highly ineffective. This study investigated how the upstream migration of juvenile eel is affected by the implementation of nature-like fishways and dam removals. Open GIS data on dams, dam removals, fishway solutions, and monitoring data from electrofishing were combined and used to assess whether upstream migration of juvenile eel in freshwater is affected by dam removal and the construction of nature-like fishways. Confounding effects, such as water temperature, electrofishing effort, distance travelled from the sea, and eel restocking were controlled for. I found that the data available could neither confirm nor deny that dam removal or the construction of nature-like fishways restore connectivity for juvenile eel, based on assessing eel occurrence upstream and downstream of a dam before and after dam removal or construction of a nature-like fishway. The completeness and quality of the open data used in this study was scrutinized and discussed.

Keywords: connectivity, *Anguilla anguilla*, dam removals, nature-like fishways, open data

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1. Introduction

Across Europe, freshwater fish species are under the threat of invasive species, habitat loss and degradation, eutrophication, overfishing, and reduced connectivity, putting almost half of the European species in the *threatened* categories on the IUCN red list (Costa et al. 2021). A majority of European freshwater fish species are negatively affected by dams and other hydromorphological changes (Costa et al. 2021). Inland waters are rife with dams, weirs, and other man-made structures that act as novel migration barriers (Duarte et al. 2021). Diadromous fish species, which migrate between freshwater and marine ecosystems, represent an especially sensitive group to reduced connectivity between and within aquatic systems (Merg et al. 2020). The diadromous European eel, *Anguilla anguilla* (Linnaeus, 1758), is no exception.

The European eel has been listed as critically endangered by the IUCN since 2008 (Pike et al. 2020). In the latest international ICES assessment of the eel, estimates show a decrease by >90 % in glass and yellow eel recruitment within its distribution area, compared to the reference period of 1960-1979 (ICES 2024b). The decrease in recruitment is most pronounced in the North Sea ecoregion, where it is estimated to have decreased by 98.9 % (ICES 2024b). To understand the sharp decline of this once very common species, one must understand the complex life history of the European eel and the threats that have emerged within the last century.

1.1 A complex life history with complex threats

Eel most likely reproduce somewhere in the Sargasso Sea from where its leaf-shaped leptocephalus larvae spread with the Gulf Stream and North Atlantic drift to the shores of Europe and North Africa (Schmidt 1923; Miller et al. 2019; Wright et al. 2022). The duration of this migration is still not settled, but it is in the range of seven months up to three years (as reviewed by: Righton et al. 2024). Reaching the shores of Europe, the larvae have metamorphosed into small, translucent glass eels (Grassi 1896). Glass eels colonize coastal waters, estuaries, rivers, and lakes (Harrison et al. 2014). As they come into shallow waters, they form pigments, becoming yellow eels. After reaching a size of 200-300 mm, yellow eel tend to settle in a smaller home range where they eat and grow, until it is time to go back from where they came (Laffaille et al. 2005a; Imbert et al. 2010). Female eels and male eels are usually 4-20 years and 2-15 years, respectively, when they initiate the migration back to their birthplace to spawn (as reviewed by: Tesch & Thorpe 2003). For the long journey ahead the eel changes its form yet again; turning silver, increasing salt tolerance and fat storage, and growing longer pectoral fins and larger eyes (as reviewed by: Thillart 2009). Many details regarding the reproduction of the European eel are still unknown, such as how many individuals reproduce, how many die on their spawning migration, and exactly how and where they reproduce.

A multitude of novel anthropogenic threats to the eel has emerged within the last century. Among them are toxins, invasive parasites, increased eel fisheries, habitat loss due to migratory barriers, and possibly climate change affecting oceanic currents (Drouineau et al. 2018). Singling out the contribution of each threat to the eel decline has proven hard, as it is not yet feasible to follow how each factor impact the eel throughout its complex life cycle. Since the reproductive success of individuals cannot be measured, the amount of silver eels leaving continental waters are used as a proxy in following the trends for the reproductive proportion of the population. The EU target for eel restoration is to reduce human-caused mortalities so that 40 % of silver eels can migrate and have the opportunity to reach their spawning grounds, compared to the amount migrating at a natural state without any human impact (European Council 2007). In practice, many of the management actions taken to reach this target have focused on decreased fisheries, translocating juvenile eels (restocking), and restoring connectivity to increase habitat availability. This thesis will evaluate the effect of the latter.

1.2 Migratory barriers

Changes in hydrology and connectivity, such as wetland drainage and dams, have changed the availability of freshwater habitats throughout the eel's distribution range (Kettle et al. 2011). This habitat fragmentation results in juvenile eel being unable to fully colonize exploited catchments. Dam structures are among the most important factors that limit eel distribution as they often block upstream migration (Halvorsen et al. 2020; Briand et al. 2022). In Europe, 0.4 % of all catchments are affected by large dams (i.e., dams with a height of >15 m), and 69.5 % of all large catchments are partly blocked (Duarte et al. 2021). The prevalence of smaller dams and weirs is much greater, as they make up > 90 % of all barriers in Europe (Belletti et al. 2020).

After the installation of large dams (>15 m), occurrence rates of eel drop dramatically (Podda et al. 2022). However, not all dams are absolute barriers to migration (Tamario et al. 2019). Several studies have shown that small eels can be good climbers, as long as they have a wet, rough surface to climb on (Legault 1988; Kerr et al. 2015; Kume et al. 2022). This ability makes it difficult to define what is an absolute migratory barrier for young eel. Smaller barriers do limit the eel in its upstream migration, but the height of the barrier is important to the extent of their impact (Briand et al. 2022). One study suggests that habitat degradation and loss have played an especially important role in the decline of the eel population in the North- and Baltic sea region, where an estimated 79 % of freshwater habitats has been lost due to dams (Bevacqua et al. 2015). Therefore, I have focused on migration barriers and management efforts in Sweden, which is within this region.

1.3 Restoring eel migration in Swedish waters

To restore connectivity to Swedish waterways, several means are used. These can be roughly categorized into the following groups: technical fishways, nature-like fishways, and dam removals. Fishways are man-made structures made with the intention to aid fish in circumventing dams and other barriers, while the barrier is kept intact. Technical fishways are engineered for the specific function of getting fish past a barrier. Nature-like fishways are often designed as a bypass mimicking a natural stream. A dam removal is exactly what it sounds like; the dam is removed and so is its function, meaning that the waterway is free and the waterflow is returned to a natural regime.

The number of restoration measures aiming to aid eel specifically in Swedish rivers has increased in the last 30 years, albeit with large variation between years (Länstyrelserna 2024) (Figure 1). Nature-like fishways and dam removals have been the most common in recent years, although technical fishways still make up the bulk of installations targeting eel (Länstyrelserna 2024) (Figure 1 A & B). An important note to these numbers is that they include both measures implemented to aid juvenile eel on their upstream migration and adult eel on their downstream spawning migration. These are two very distinct life stages, with their own limitations and needs (Turek et al. 2016). There is no data on which specific life stage these measures target.

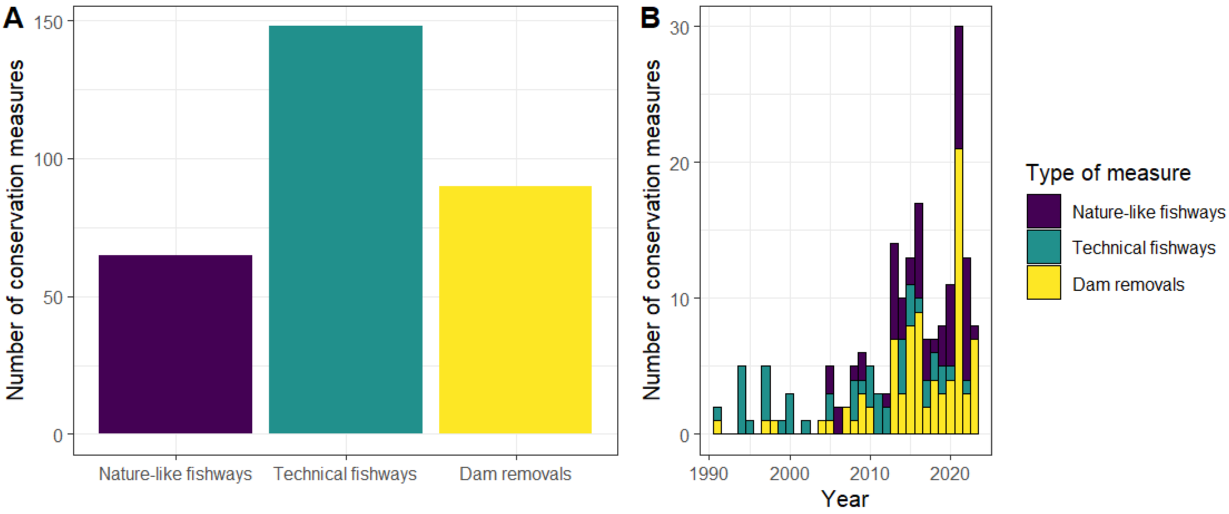

Figure 1. A: Total number of restoration measures directed at the European eel per type conducted between 1990 and 2023. B: Number of measures with eel as a target species per year (1990-2023) divided by type. Modified from:(Länstyrelserna 2024)

1.3.1 Technical fishways

There are multiple designs of technical fishways that vary greatly in function (Noonan et al. 2012). There is mixed evidence whether such solutions aid eel in their upstream migration (Laffaille et al. 2005b; Tamario et al. 2019). One reason for this is that many technical fishways are designed for adult salmonids which differ in their swimming behaviour compared to a small eel (Solomon & Beach 2004; McCleave 2006; Noonan et al. 2012). There are however technical fishways that are designed specifically to aid upstream migration of eel, so called eel ladders. A study by Tamario et al. (2019) showed that dams equipped with eel ladders had equal negative effects on juvenile eel migration as dams without any eel ladders, but there are multiple instances where they have been reported to work (Solomon & Beach 2004; Briand et al. 2005; Schmidt et al. 2009; Drouineau et al. 2015). This suggests that the efficiency of eel ladders is dependent on ladder design, maintenance status, or both.

1.3.2 Nature-like fishways

How effective nature-like fishways are in aiding eel upstream migration is not well explored. One study found indications that they are not very effective (Tamario et al. 2019). Non-salmonids in general are not able to use them very efficiently, but this might not be transferable to eel (as reviewed by: Noonan et al. 2012;). What is clear, is that juvenile eel require nature-like fishways with lower flow-rates than most other fish species (Turek et al. 2016). This means that the specific design and construction of a nature-like fishway could be a determining factor for which species can utilize it.

Both technical fish ways and nature-like fishways require maintenance and oversight. As shown by several surveys, fishways in Sweden are often functionally flawed (for all species), either due to bad design or lack of maintenance (Nöbelin 2014; Broman 2018; Nilsson 2019; Olsson 2020).

1.3.3 Dam removals

Removal of large dams has been shown to effectively restore connectivity for eel smaller than 300 mm (Hitt et al. 2012). However, there is little to no literature describing when dam removal should be prioritized over other measures or what factors are important for the effect on juvenile eel migration. For example, the effects on upstream eel migration of removing smaller dams and weirs is not well known, although there are some indices that it does increase (Länstyrelsen Skåne 2019). As smaller weirs and dams inhibit juvenile eel migration, the removal of these should be beneficial (Briand et al. 2022). A clear benefit of a dam removal is that it's a permanent solution, unlike fishways that need maintenance and oversight.

1.4 Research questions

The scientific basis for dam removals and nature-like fishways as means to restore upstream migration for eel in exploited systems is weak. There are far too few case studies on their efficacy to quantify their presumed benefit to eels. Their function seems to be taken for granted, as these two measures are becoming increasingly common in eel-targeted restoration aiming to increase connectivity. Here, I will investigate whether it is possible to utilize openly available data to assess the effects of the construction of nature-like fishways and dam removal on eel upstream migration. Since eel under 300 mm make up the bulk of upstream migrating individuals, this study focuses on them. Eel under 300 mm will from here on be referred to as juvenile eel. To limit the scope of this study none of the designs of technical fishways will be included, even though this diverse group still make up the bulk of fishways targeting eel.

Data from environmental monitoring programmes can be a robust tool for detecting long-term ecological changes. National databases for dam structures, electrofishing surveys, eel restocking, and riverine restoration measures are all openly available in Sweden. However, the massive amounts of data available could prove to be unsuitable to answer these kinds of questions, as intentions of usage, completeness, accuracy, overlap in time and space among data sources and data collection methods does vary both within and between these databases. With this in mind, I asked:

1. Can the extensive supply of open data be used to assess effects of the construction of natural fishways and dam removals on migrating juvenile

eel (<300 mm) in freshwater systems by comparing occurrence rates before and after the measure was implemented?

2. Does the construction of nature-like fishways and removal of dams affect the length composition of eels upstream?
3. What are the limitations of using open data when answering specific questions like the ones above, and are the data used suitable in regard to quality and completeness?

2. Method

This study required electrofishing data from locations with either the construction of a nature-like fishway or a dam removal, before and after the measure was conducted, and with data downstream serving as control. In addition to the electrofishing dataset of presence/absence data for juvenile eel (eel < 300 mm), variables of importance to explain eel occurrence were needed. This study included the potentially confounding effects of temperature during electrofishing, yearly variation and temporal trends of eel occurrence, distance of the electrofishing site from the sea, and nearby eel restocking. To investigate the limitations of using open data in freshwater restoration, I evaluated to which extent the used datasets could be matched, how many discrepancies there were between the datasets, and the limitations of individual datasets. To accomplish this, I employed the data described below under point 2.1.

2.1 Data sources

Open data were used for the analysis, with the exception of data on restocking numbers and sites, which are publicly available upon request via the Swedish University of Agricultural Sciences, Department of Aquatic Resources (SLU Aqua) (Table 1). Data on electrofishing eel captures and sites were downloaded from the Swedish electrofishing database (Database for electrofishing in streams, SERS). Data on dams, fishways, and dam removals were downloaded from the Swedish county portal for geodata through ArcGIS REST Service Directory. Data on catchment areas were downloaded from the Swedish Meteorological and Hydrological Institute, SMHI (Table 1). Data on restocking sites were provided on request by SLU Aqua.

Table 1. Full description of data sources, including information about what data were used in the present study (usage), distributor, database, date when the data was downloaded, whether the database is open source or not, and link to the database website.

Usage	*Distributor*	*Database*	*Downloaded*	*Open source*	*URL*
Electrofishing locales	SLU Aqua	SERS	2024-04-10	Yes	link

Dams	Länstyrelserna	Biotopkartering vandringshinder	2024-04-22	Yes	link
Fishways and dam removals	Länstyrelserna	Åtgärder i vatten	2024-01-17	Yes	link
Restocking sites	SLU Aqua	Sötebasen	2024-02-19	Available on request	link
Catchments	SMHI	SVAR 2016:8	2024-03-19	Yes	link

SERS – Swedish electrofishing database

The SERS database is the Swedish national database for electrofishing surveys. It is hosted by the Swedish University for Agricultural Sciences and launched in 1989 (Bergquist et al. 2014). Each survey is defined as separate occasion a location has been visited, which means that the data often include an aggregated result of several sequential passed over the same area. The database holds extensive information on the electrofishing method used, such as number passes, area fished, and equipment. Many environmental variables such as temperature and bottom substrate are also described. Lengths of captured individuals are available for most surveys.

Biotopkartering vandringshinder – barrier database

This *Biotopkartering* database (barrier database from here on) is administered by the county administrative board of Jönköping and was launched in 2010, but data has been collected since at least 1970 (Länsstyrelsen Jönköping n.d.). The county administrative boards' barrier database has national coverage, although the field inventories are locally managed at each county. The county administrative boards have common methods for this inventory, making the survey standardized between counties (Gustavsson 2017). The inventory includes all types of barriers, including natural barriers.

Åtgärder i vatten – restoration measures database

The *Åtgärder i Vatten* database (referred to as "restoration measures database" from here on), is administered by the Swedish Agency for Marine and Water Management and the county administrative boards as a public database (Spjut 2021).

Sötebasen- eel restocking database

SLU Aqua store data on eel restocking throughout the country. The data is collected in part from self-reporting by the actors that restock eel, but other sources seem to be used as well.

SVAR 2016:8 – River network

The river network from SMHI is a product that simplifies rivers and lakes into lines that together make up a continuous network. It contains all Swedish rivers that are deemed to be *"*discrete and significant*"*, which is defined as rivers with catchments larger than 10 km^2 (*Havs- och vattenmyndighetens föreskrifter* 2017; Danielsson 2023). The network does not include smaller rivers or ditches.

2.2 Spatial analysis

The spatial analysis of this work aimed to establish a spatial relationship between datasets with different origins, join databases, extract variables important for eel occurrence, and pick out enough electrofishing data in the vicinity of locations with dam removals or nature-like fishways to describe their effect on the likelihood of catching eel under 300 mm. The spatial analysis was performed using ArcGIS Pro 3.1 (Esri 2023).

2.2.1 Filtering data

Many of the datasets used contained data that were outside of the interest or scope of this study. Therefore, datasets were reduced based on location and attributes.

Electrofishing surveys

To reduce the large amount of electrofishing data, only electrofishing surveys conducted between 1990 and 2023 were used. There are earlier records, but these were not used in this analysis as standardized data recording was implemented with the creation of SERS in 1989 (Bergquist et al. 2014). As I was interested in eel, the data was further reduced to include only catchments where there had been electrofishing captures of eel, resulting in a total of 14 072 electrofishing surveys, 1 878 of which had occurrences of eel (Figure 2).

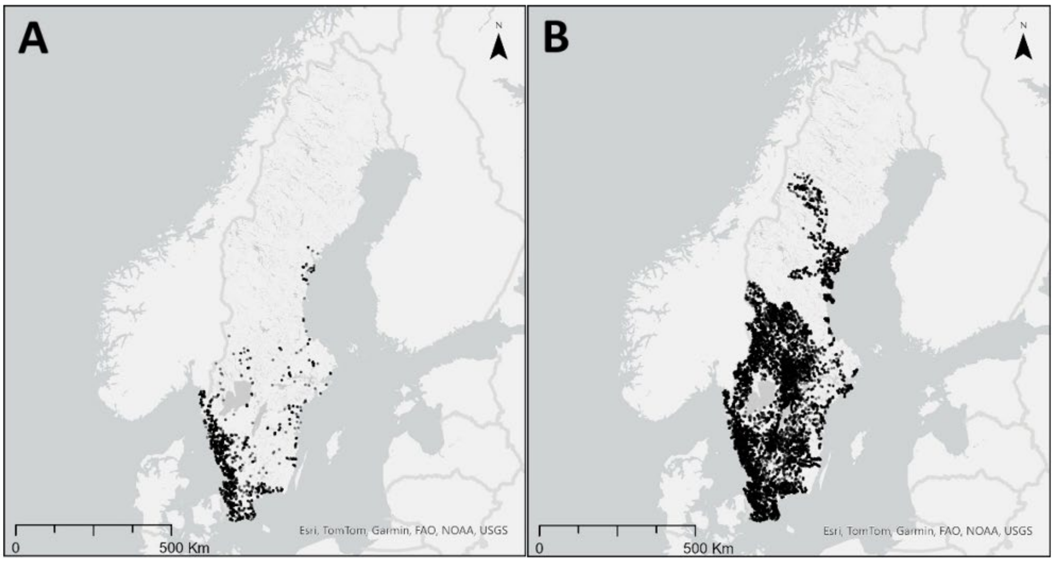

Figure 2. Map with black data points indicating A) the 1 878 electrofishing surveys with eel captures in Sweden, 1990-2023 and B) the 14 072 electrofishing surveys within catchments with eel presence, 1990-2023 (modified from: Database for electrofishing in streams, SERS, 2024).

Barriers in rivers

For the 26 715 migration barriers in the barrier dataset, dams were filtered out. The database includes many kinds of barriers, for example, road culverts, road passages and even old eel traps, but these were not of interest in this study. Dams differed in their categorization within the database; dams in the category "dam" included most dams from mills, factories, and hydropower, there were however 671 cases of barriers in an "other barrier type"-category that had their earlier use defined as milling or hydropower. As these are likely dam structures, they were kept in the analysis even if they were not in the "dam" category. Beaver dams and other natural barriers, which were in some cases listed as dam structures, were removed from the analysis. Spatial duplicates, i.e. barriers sharing the same coordinates, were removed. This resulted in 12 858 dam structures in Sweden in total (Figure 3).

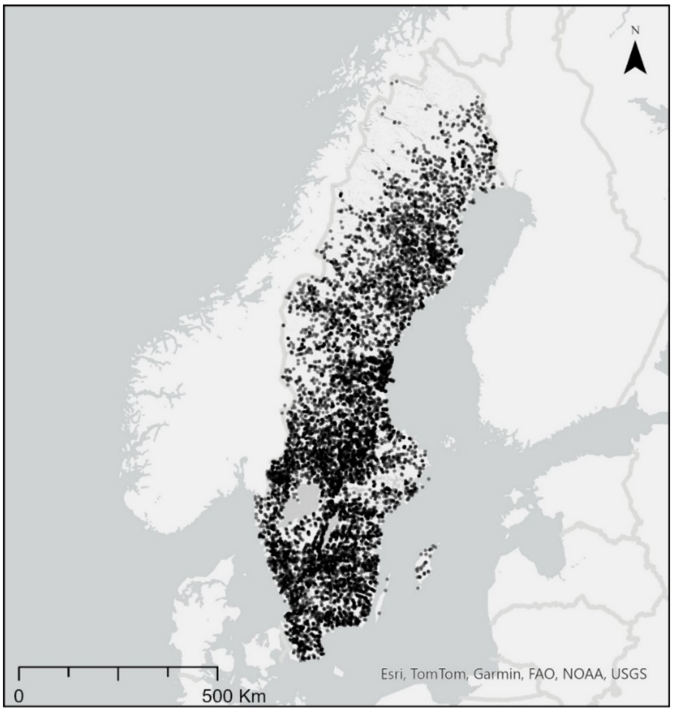

Figure 3. Map with black datapoints indicating the 12 858 inventoried dams in Sweden, after removal of beaver dams and other natural barriers (modified from: Biotopkarteringsdatabasen 2024).

Measures

In the measures database, the measures categorized as technical fishways, nature-like fishways, and dam removals were selected, resulting in a total of 1 810 reported restoration measures, distributed across 1 691 unique sites (Figure 4). Some dams had more than one fishway.

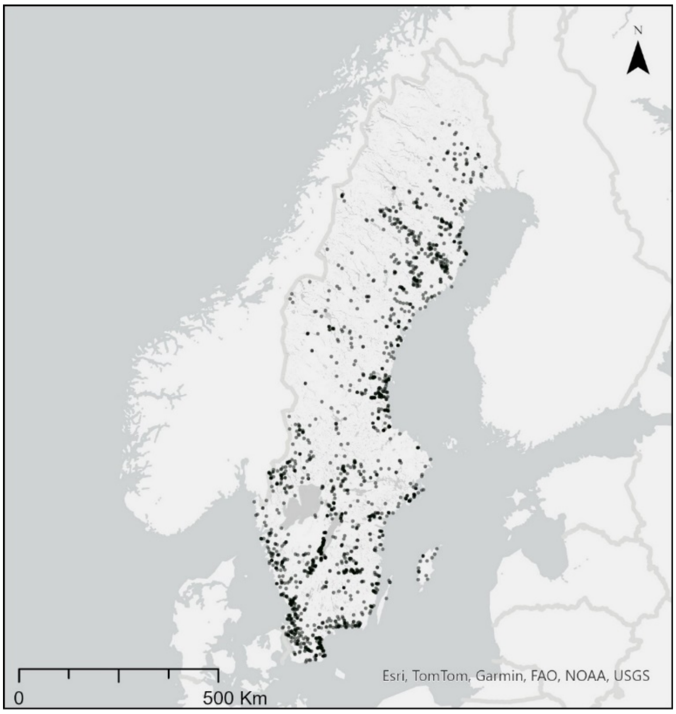

Figure 4. Map with black datapoints indicating the 1 810 reported restoration measures in the three categories: dam removals, technical fishways, and nature-like fishways, in Sweden, located in 1 691 unique sites (modified from: Åtgärder i Vatten, ÅiV, 2024).

Eel restocking

Translocating juvenile eels into a river, i.e., restocking, will likely influence occurrence and abundance of eel in that river, and must therefore be accounted for in my analysis. The SLU Aqua database on restockings holds 558 restocking sites. Out of these, 43 either had no data on date, or no data on position (coordinates). Since data on both date restocking and position were needed for my analyses, these 43 entries were excluded in the analysis. In addition, 12 restocking sites that were not recorded in the restocking database were taken from restoration measure database, which also contains some restocking data.

River network

The river network from SMHI contains all Swedish rivers (with catchments larger than 10 km^2), which were all included in this study. In addition, rivers with Norwegian estuaries are found in the database, but these were removed from the analysis because none of the other datasets in this study cover Norwegian parts of rivers. The river network was dissolved (i.e., fused into unified lines) so that each catchment consisted of one linked feature.

2.2.2 Joining and reducing data

When working with large datasets, it is often necessary to reduce their extent to avoid unnecessary computation (Figure 5). After having performed data reduction (see details below), I established a spatial relationship between the datasets. In the data used here, each data point should be in a river. Hence, I placed the data points on the river network, as a common spatial reference for the data (Figure 5). For dams, fishways, and dam removals, it was important to determine which data referred to the same location, as these datasets naturally overlap, e.g. a fishway naturally shares location with the dam its designed to circumvent (Figure 5). For the eel occurrence data, two variables were calculated and added; distance from the electrofishing site to the sea, and information about whether an electrofishing data set was affected by restocking (see below and Figure 5). The joining of the datasets was done in a way trying to minimize data loss, while trying to avoid joining data that do not refer to the same location.

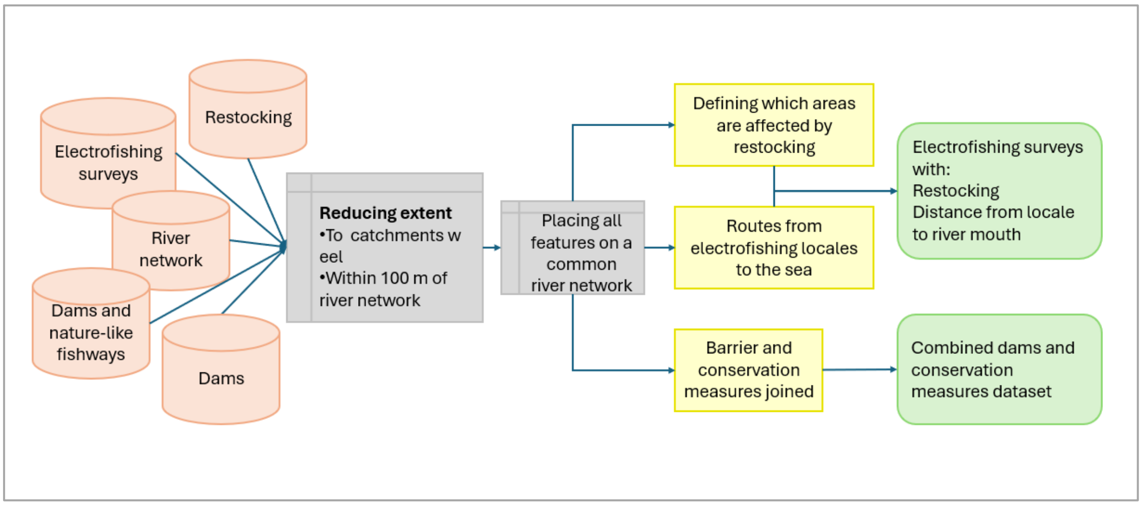

Figure 5. Conceptual figure showing the workflow of joining and reducing the data, with the five databases/datasets used (to the left in pink), the reduction parameters (grey left box), establishment of a spatial relationship between the datasets (common river network, grey right box), the order of joining relevant data and extracting spatial variables (in yellow), and the resulting datasets (to the right in green).

Finding a common spatial relationship for data

To establish how my data might interact with eel occurrence, it was important to determine the spatial relationship between dams, dam removals and fishways, and electrofishing sites (from here on denoted “features”). More specifically, I needed to determine which of these features are in the same river, and their order in the river system. This can be tricky when the data covering the river network and the data covering the other features (that should be located in the river) does not match. This is expected as the river network is a simplified digitalization of reality and the positional accuracies of the different features are unknown. Dams, dam removals and fishways, and electrofishing sites with coordinates placing them outside of the river network, but within 100 m of the river network, were assumed to be located in the rivers in the river network. The cut-off point of 100 m was chosen as this was the range which most data points were within (Figure 6). To place these features on the river network, I used the tool called “`snap`”, which relocates a feature to the closest point of another feature; the river network in this case. I did this for all data (i.e., dams, dam removals and fishways, and electrofishing sites), except restocking sites, as the coordinates for restocking sites were placed both within lakes and rivers (i.e., not just on the river network). The restocking sites were relocated to the river network by the nearest point on the river network which shared a common catchment identifier, still with the `snap` function but without the 100 m limit.

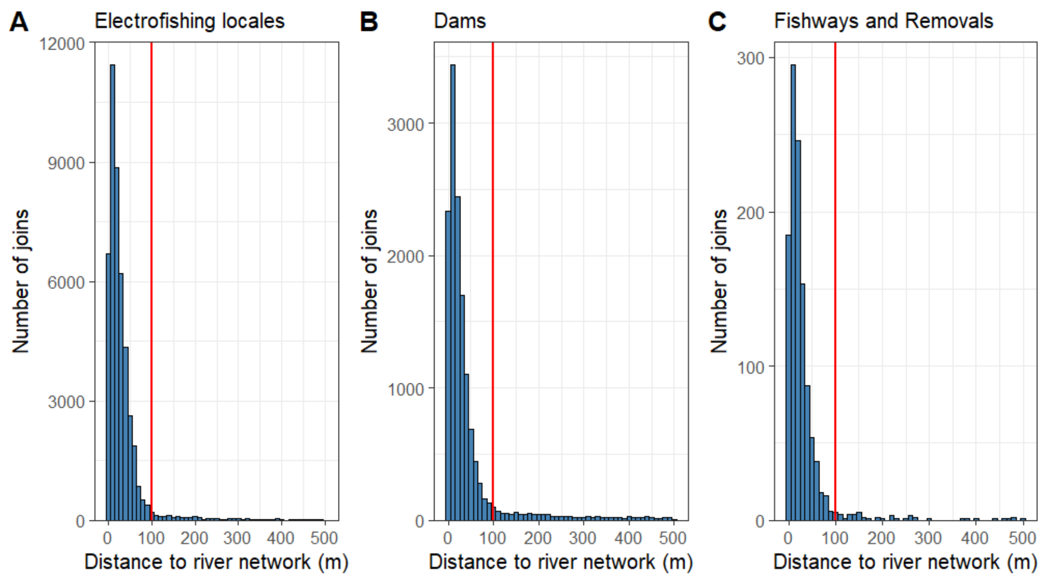

Figure 6. Comparison of the river network and the reported position of: A) electrofishing sites, B) dams, and C) dam removals and fishways, displayed as distance between river network and A) electrofishing locales, B) dams, and C) fishways and dam removals. If the different datasets matched, all features (i.e., all electrofishing sites, dams, and dam removals and fishways) would be placed within the river network, and the distance to river network would hence be 0. Note that most

of the electrofishing sites, dams, and dam removals and fishways had coordinates placing them within 100 m from the river network, and hence 100 m was selected as the cut-off point to relocate features to match the river network.

Joining dams, fishways and dam removals

Similar to the issue with features not matching with the river network dataset, dam removals and fishways did not always have coordinates that matched the coordinates of any dam location. To counteract this issue, incidences of dam removals and fishways were joined to the closest dam within a maximum distance of 100 meters. The cut-off point of 100 meters was chosen to avoid generating too many faulty joins, i.e., combining the wrong dam with the wrong fishway. This distance was determined by plotting the distance from dam removals and fishways to the closest dam and to the second closest dam. Each fishway and dam removal was assumed to belong to one dam, and hence the cut-off was chosen based on where the closest joins were much more common than the second closest joins (Figure 7). Fishways and dam removals for which the coordinates were not within 100 meters of a dam were still kept for the analysis, as this was assumed to be due to missing data in the barrier dataset. This did introduce some uncertainty into whether there actually is/was a dam on those sites or whether there is/was another kind of barrier, such as a sluice or a road passage.

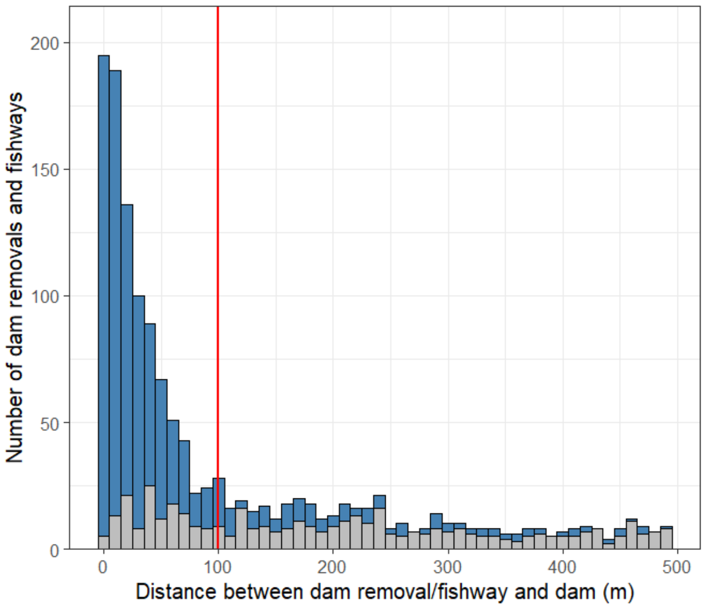

Figure 7. Comparison of the reported locations of dams and the reported locations of dam removals and fishways, displayed as distance between fishways and dam removal locations and the closest (blue) and second closest (grey) dam location. If the different datasets matched, all dam removals and fishways would be placed within close proximity to a dam. Note that most fishways and dam removals had the closest dam within 100 metres, whereas the distance to the second closest dam did not vary with distance to the same extent, presumably representing the distance between unrelated features.

Distance from electrofishing locale to the sea

The further upstream an electrofishing survey is conducted, the further an eel must have migrated from the sea to be caught in that survey. This means that further upstream, eels are older and larger on average (as it takes time to swim upstream), and there will be fewer individuals that have managed to get that far, compared to surveys conducted closer to the sea. Therefore, the distance from an electrofishing locale to the sea was calculated, so that this effect could be accounted for in analysis. The most direct route from the sea (from the river mouth), to each electrofishing site via the river network was calculated using the tool Closest facility. This tool calculates the shortest path from A to B within a network. If the electrofishing locales are A in this case, the point where a river meets the sea is B. To map estuaries (B), the endpoints of the network, points were generated along the ends of each catchment (Figure 8). Routes were created for all electrofishing locales. The lengths of the routes were joined to the electrofishing dataset.

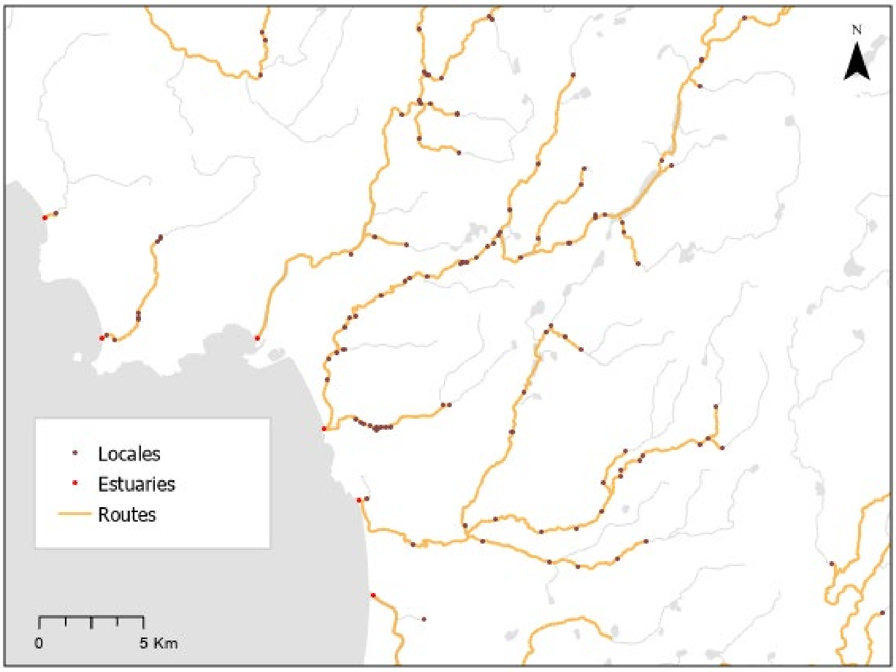

Figure 8. Example map showing how distance from the sea to the electrofishing locales was estimated, indicating routes (yellow lines), locales (black points), and estuaries (red points). The routes created from "closest facility" (in ArcGIS Pro) are the shortest paths along the river network from electrofishing locales to the closest estuary. The lengths of these routes were used as a proxy for how far an eel had migrated from the sea to the electrofishing locale.

Restocking

Translocating juvenile eels into a river, i.e., restocking, will likely influence occurrence and abundance of eel in that river, and must therefore be accounted for in my analysis. Restocking was assumed to have the greatest effect on eel occurrence in locales that were not cut off by any barrier. Therefore, the river network was split at every dam. Restocking and locales that were within the same part of the split network were joined. An electrofishing survey that had been conducted 0-10 years after a nearby restocking event was defined as being affected by restocking.

2.2.3 Finding data suitable for before and after study

Finding suitable data for a before and after study required finding dam removals and fishway sites with sufficient data on eel occurrence from electrofishing surveys upstream, to determine the effect of the restoration measures, and electrofishing surveys downstream, to serve as a control. These electrofishing surveys were selected while removing as many potentially interfering factors as possible (Figure 9).

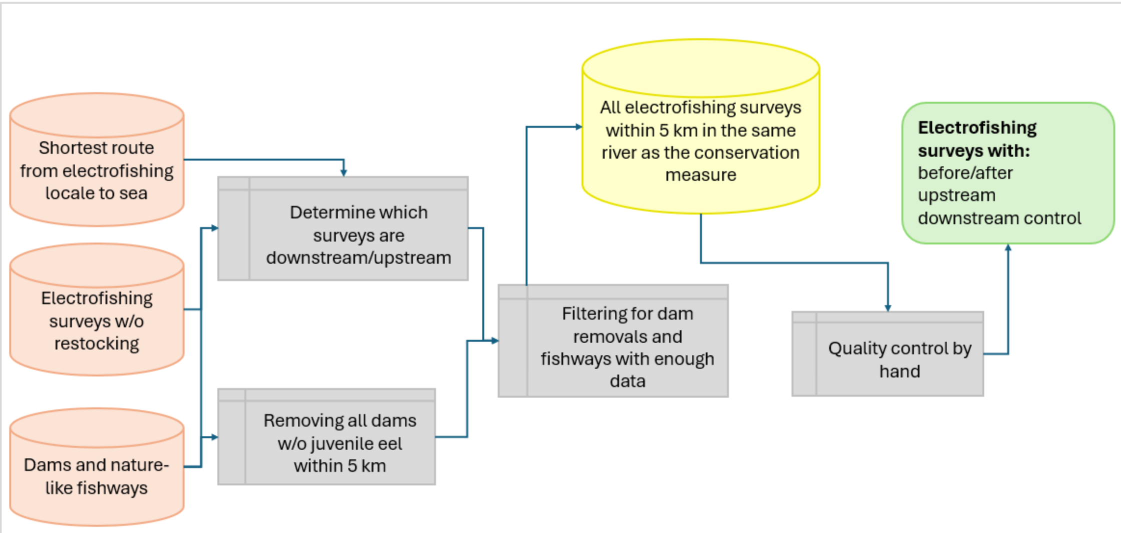

Figure 9. Conceptual figure showing the workflow of finding suitable data for a before and after analysis, with the input data in pink, intermediary data in yellow and the resulting datasets in green.

Filtering data

First, all electrofishing surveys that were affected by restocking of eel were filtered out. To reduce the interference of natural barriers in the data, the distance from electrofishing location and dam site were kept to maximum of 5 km. This was a trade-off between keeping variation to a minimum within a site and retaining data to analyse. Only fishways and dam removals that had at least one record of juvenile eel within 5 km were kept for further analysis. All dam removals and nature-like fishways that were missing data on year of construction were removed from further analysis.

Timeline and order within river

To achieve a correct timeline, all electrofishing surveys were joined to the closest fishway or dam removal to establish whether a survey had been done before or after the restoration measure. Sites were assigned whether they were upstream or downstream of a fishway or dam removal, depending on whether their previously calculated route towards the sea passed the site or not. All sites with less than five electrofishing surveys conducted before and after the dam removal or nature-like fishway construction, upstream of the restoration measure, were removed from the analysis. This was done to ensure a minimum sample size of five electrofishing surveys per dam site.

Interference from other restoration measures

In cases where multiple fishways or dam removals had been implemented within a system, I employed some rules as to not mix up the effects of different restoration measures. If there was a fishway, dam removal or dam upstream of the nature-like fishway or dam removal of interest, no electrofishing surveys past that measure was included. If there was a fishway or dam removal downstream of the measure I was interested in, no electrofishing surveys conducted before that action was implemented was included in analysis. For example, if there had been a fishway installed downstream in 2002, but the nature-like fishway I was interested in was constructed in 2013, all surveys before 2002 were removed from the analysis (Figure 10). In cases where downstream removals and fishways were missing the date of implementation, the site was discarded. This was done by hand.

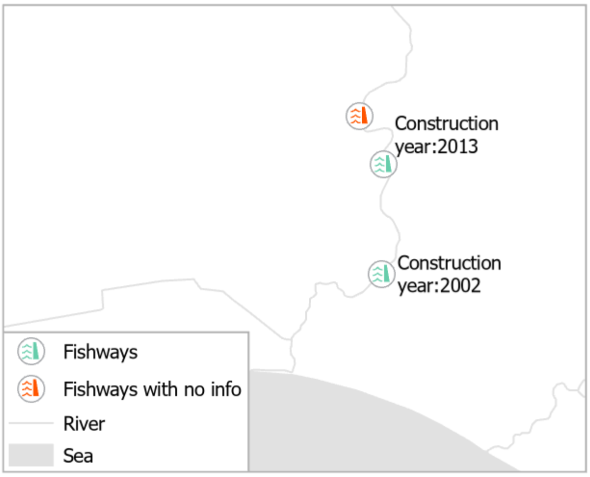

Figure 10. An example of how different fishways might be interfering in their effect on the occurrence of juvenile eels. In this catchment, there was a fishway constructed in 2002 near the river mouth, later in 2013 there was a fishway constructed further upstream. To estimate the effect of the 2013 fishway on juvenile occurence, all electrofishing surveys conducted before 2002 must be removed to exclude the effect of the fishway constructed in 2002.

Final quality control

To ensure some validity of the complete method of data filtering, reduction and joining, the results was compared to the original data sources to assess the integrity of my assumptions and data joins. These were compared to a more detailed river map to verify that they had been placed accurately in the river network. Some joins, of either electrofishing surveys, dams, or dam removals and fishways, had been placed at the wrong point at the river network, either disrupting the order in the river network or being placed on the wrong tributary within a catchment. This was most often due to there being small tributaries which were missing from the river network.

In the restoration measures database, dams and fishways have more detailed descriptions in the form of free-text comments. These were read, and unsuitable sites were removed from analysis. For example, one site was only an improvement of a nature-like bypass, where the data on the original restoration effort was missing from the dataset.

Electrofishing sites affected by restocking that were downstream of dam removals and nature-like fishways were reintegrated in the data.

After the final control and reduction in sites, there final dataset included electrofishing surveys from two nature-like fishways and three dam removals.

2.3 Statistical and descriptive analysis

The final dataset with electrofishing surveys (from SERS) was exported to R studio for statistical and descriptive analysis (R core team 2024). It was merged with the dataset on individual eel lengths (from SERS). In total, the analysed data consisted of presence/absence and length data from a total of 215 electrofishing surveys.

2.3.1 Descriptive analysis for length distributions, before and after dam removal and construction of fishways

When reviewing the entire length dataset from the database (not the analysed subset), it seemed that recorded eel lengths were often rounded to the nearest 5 cm (Figure 11), raw lengths were thus never treated as absolute but rather used to divide eel into length classes. I divided length into the following classes: <150 mm, 151-200 mm, 201-300 mm, >300 mm. The eel lengths from the 215 electrofishing sites were used to show any change in length distribution of eels due to dam removals or construction of nature-like fishways.

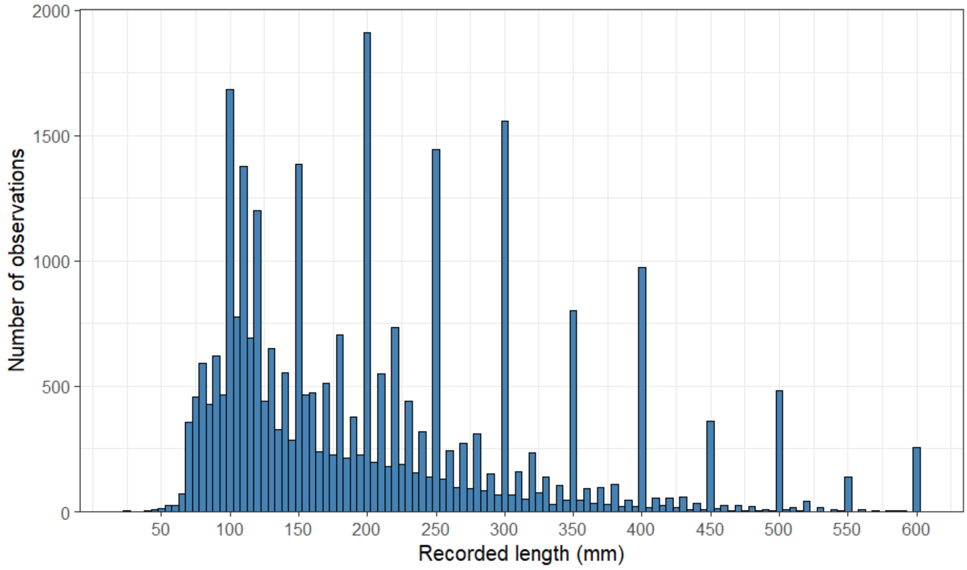

Figure 11. Histogram over all recorded eel lengths showing clear peaks at intervals of 50 mm, suggesting that lengths were often rounded to the nearest 5 centimetres. Data from the Database for electrofishing in streams, SERS, 2024.

2.3.2 Modelling effects of dam removals and nature-like fishways on presence/absence of eel

To draw conclusions if there are any general effects of dam removals and nature-like fishways on the incidence of juvenile eel, the effect of dam removal and nature-like fishways were modelled using a generalized linear model with presence-absence data of eel under 300 mm as the response variable.

The effects of a dam removal or nature-like fishway on the incidence of eel was included in the model using a binary categorical variable denoting whether an electrofishing survey was conducted before or after the implementation of the dam removal or nature-like fishway (Figure 12 & Table 2). To control for any underlying trends in incidence, a binary variable of whether an electrofishing survey was conducted down- or upstream the dam was included in the model (Figure 12 & Table 2). The interaction between the two binary categorical variables before/after and downstream/upstream was the effect I was interested in, as it could shows whether the restoration measure had any effect, whilst controlling for of trends in incidence of eel downstream of the dam. Distance from the sea, area fished, temperature, year, and number of passes in electrofishing were included as covariates (Table 2). The nature-like fishway or dam removal an electrofishing survey was in the vicinity of, denoted as "site", was included as nested effect to group the data (Figure 12 & Table 2).

As presence/absence data has binomially distributed errors, a mixed effects generalized linear model with binomial distribution was used. Distance from the sea, temperature, and year were assumed to have a linear relationship with presence of eel. All continuous variables were standardized so that effect sizes would be comparable.

Table 2. Summary of explanatory variables used in model selection

Variable	*Type*	*Levels (if categorical)*
Before/After	Categorical	Before/After
Downstream/Upstream	Categorical	Downstream/Upstream
Action	Categorical	Dam removal/Nature-like fishway
Site	Categorical/Nested	1/2/3/4/5
Distance from the sea	Continuous/Covariate	-
Year	Continuous/Covariate	-
Area	Continuous/Covariate	-
Temperature	Continuous/Covariate	-
No. of electrofishing passes	Categorical/Covariate	1/2/3

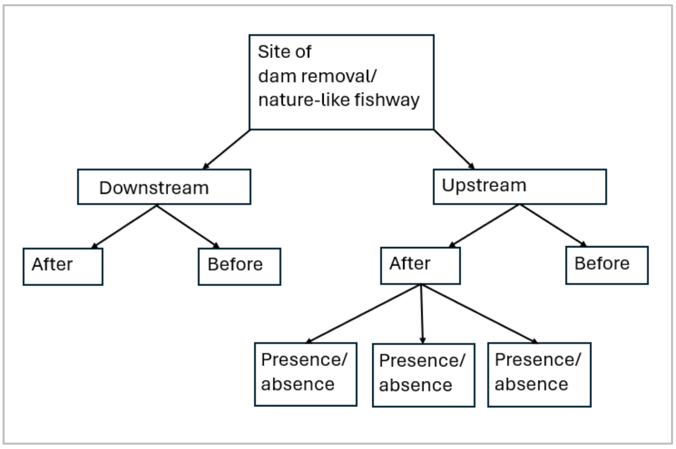

Figure 12. Data structure showing the main groupings of data.

Correlation between all numeric variables were checked using cor-function in base R package stats (R Core Team 2024). The results from seven surveys with missing temperature data were removed. Models were run using the glmer-function in the package Lme4 (Bates et al. 2015). The optimizer of the function was changed from the default to Nelder-Mead to solve a convergence error. The full model was defined as following:

*Presence/Absence~ Before/After*Downstream/Upstream+ Type of measure+ Temperature+ Year+ Distance from sea+ Number of passes during electrofishing+ Area fished+ (1 | Site)*

Given the scarcity of data, the model included too many explanatory variables to estimate any of them correctly. To reduce the full model to include only the most influential covariates, they were removed based on Akaike's Information Criterion adjusted for small sample sizes (AICc, from here on), from the package AICcmodavg (Mazerolle 2023). To test whether there was any potential effect of the construction of nature-like fishways or dam removals on juvenile eel occurrence, the best fitting model with the interaction was compared to the corresponding model without the interaction, using AICc.

2.4 Describing data quality

To describe data quality, a summary of join success and counts of missing data was made. Join success were defined as the percentage of data that should overlap that were within 100 m of the feature they should coincide with spatially. In this analysis, all data that should be within the river network, i.e., dams, fishways, dam removals, and electrofishing surveys, were included.

The problem of missing data is often unmeasurable. This was the case for restocking attempts, where it could not be known if eel has been released in a river without anyone reporting it to Sötebasen. However, for dams, dam removals and fishways I knew that some features should overlap completely if the data was complete. Nature-like and technical fishways are expected to totally overlap spatially with dams, as these are built to circumvent dam structures (Figure 13). Dams that are described in the barrier database as having fishways are expected to totally overlap with nature-like and technical fishways (Figure 13). If these only partially overlap it suggests that there are missing features in these databases. Dam removals are expected to at least partially overlap with dams, as dams that have been surveyed before being removed are expected to still be in the database (Figure 13). As I had previously established that most fishways and dam removals where within 100 m of a dam, presumably the one they are located at, I simply counted how many of the features that should overlap were within 100 m of each other.

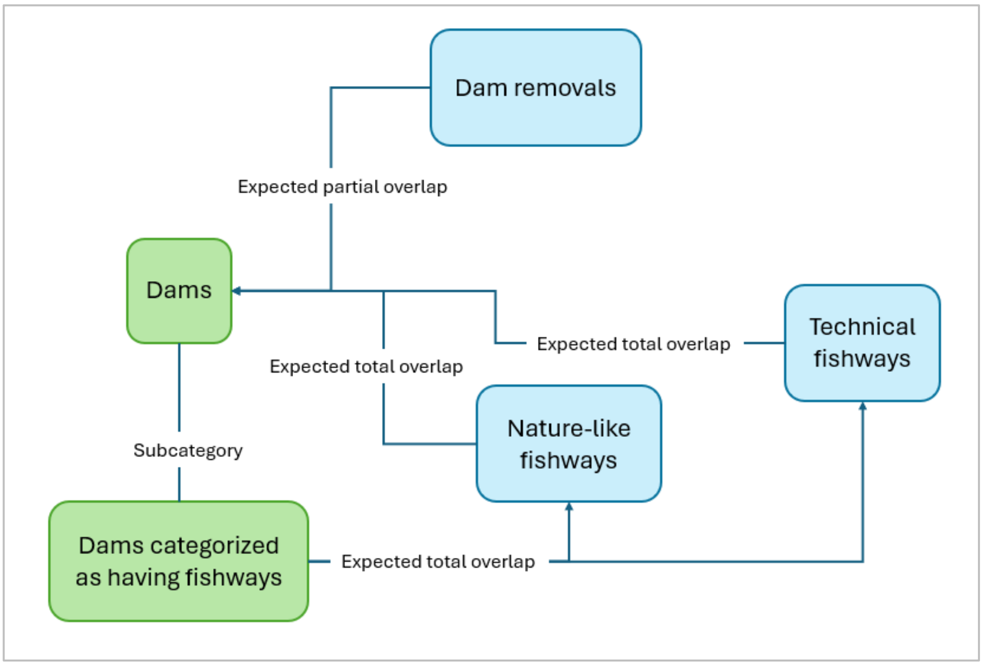

Figure 13. Expected spatial overlaps between the barrier database and the restoration measures database. Nature-like and technical fishways are expected to totally overlap spatially with dams. Dams that are described in the barrier database as having fishways are expected to totally overlap with nature-like and technical fishways. If these only partially overlap it suggests that there are missing features in these datasets. Dam removals are expected to at least partially overlap with dams, as dams that have been surveyed before being removed are expected to still be in the database.

3. Results

In total the results of 215 electrofishing surveys were included in the before-after analysis, 86 from two nature-like fishways situated in Säveån and Nybroån, and 129 from three dam removals situated in Lillån, Krogabäcken and Örebäcken (Figure 14). In these, juvenile eel was found in 50 surveys. The sites that qualified for analysis were all on the western or southern coast of Sweden (Figure 14).

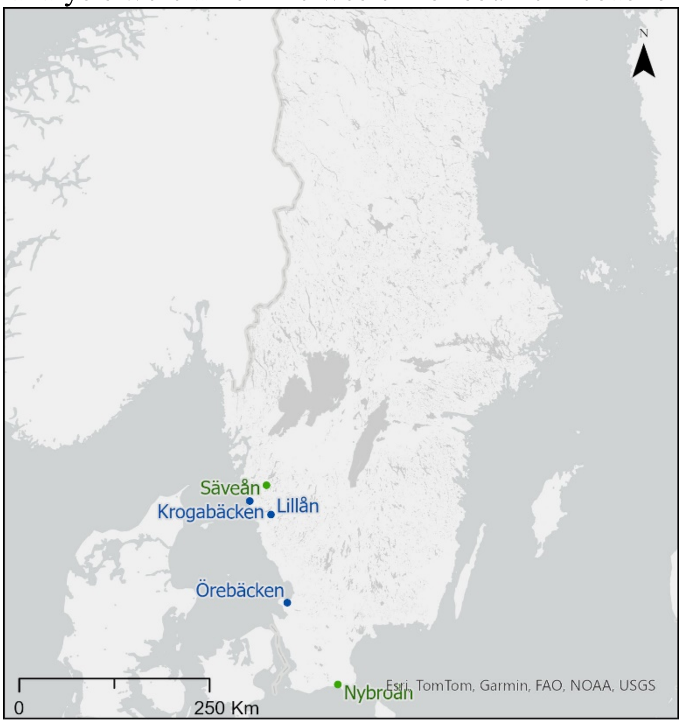

Figure 14. Sites with dam removals and nature-like fishway picked out for further analysis. Dam removals in blue and nature-like fishways in green.

The number of electrofishing surveys conducted at each site differed, with the largest difference in sample sizes in Örebäcken (Figure 15).

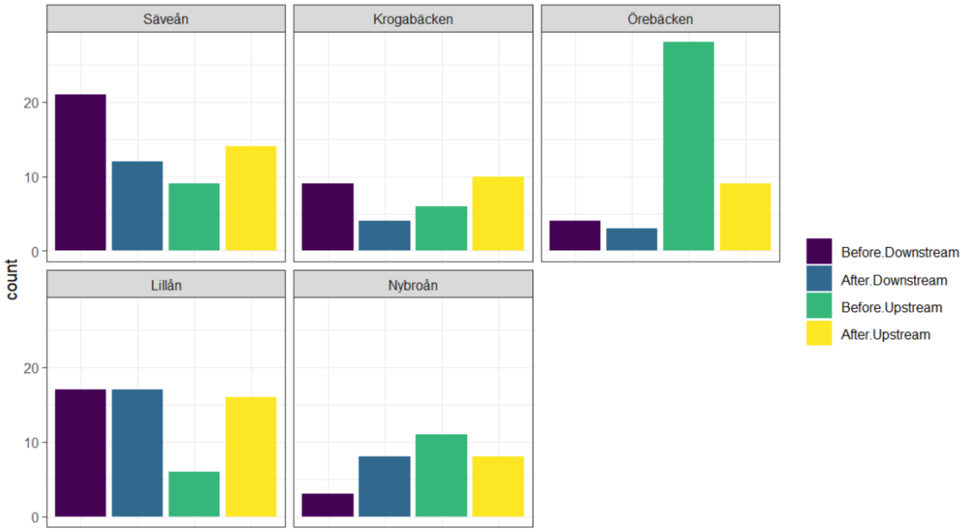

Figure 15. Number of electrofishing surveys per site by all combinations of whether a survey was conducted before or after, and upstream or downstream to a dam removal or fishway.

The proportion of electrofishing sites with presence of juvenile eel upstream and downstream barriers were generally lower after the construction of nature-like fishways and dam removals than before (Figure 16).

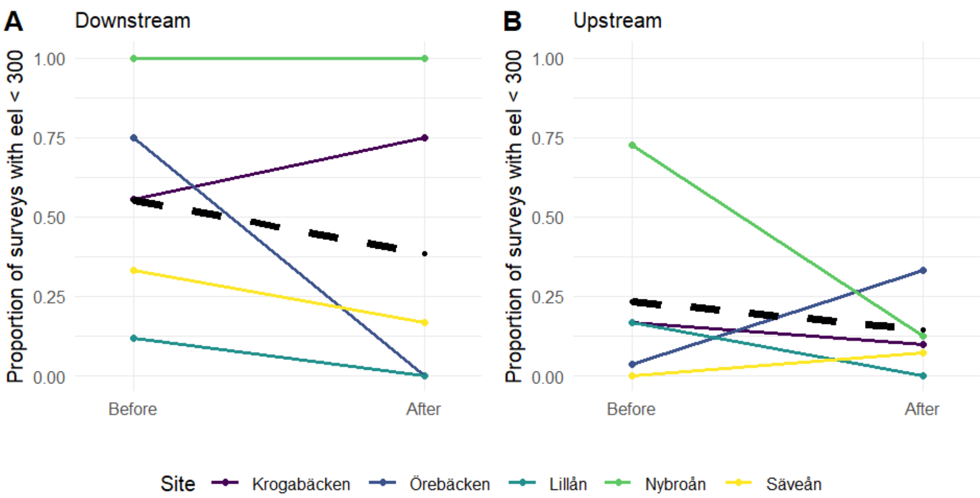

Figure 16. A) Differences in juvenile eel occurrence before and after the restoration measure in the downstream control. B) Differences in juvenile eel occurrence before and after the restoration measure upstream. Black dashed line represents the mean slope between these sites, giving the same weight to each group regardless of sample size.

3.1 Site descriptions

To give a more detailed picture of each site, I will here go through the specific surroundings of each nature-like fishway and dam removal to convey the limitations and complexity of each site as transparently as possible.

Dam removal in Krogabäcken

This dam was removed in 2019, before which there was a dam for unknown use with a height of 2.5 m (Figure 17). Upstream, juvenile eel were caught in 1/6 (12 %) of electrofishing surveys before and 1/10 (10 %) of electrofishing surveys after. Downstream, juvenile eel were caught in 5/9 (55 %) of electrofishing surveys before and 3/4 (75 %) after (Figure 18).

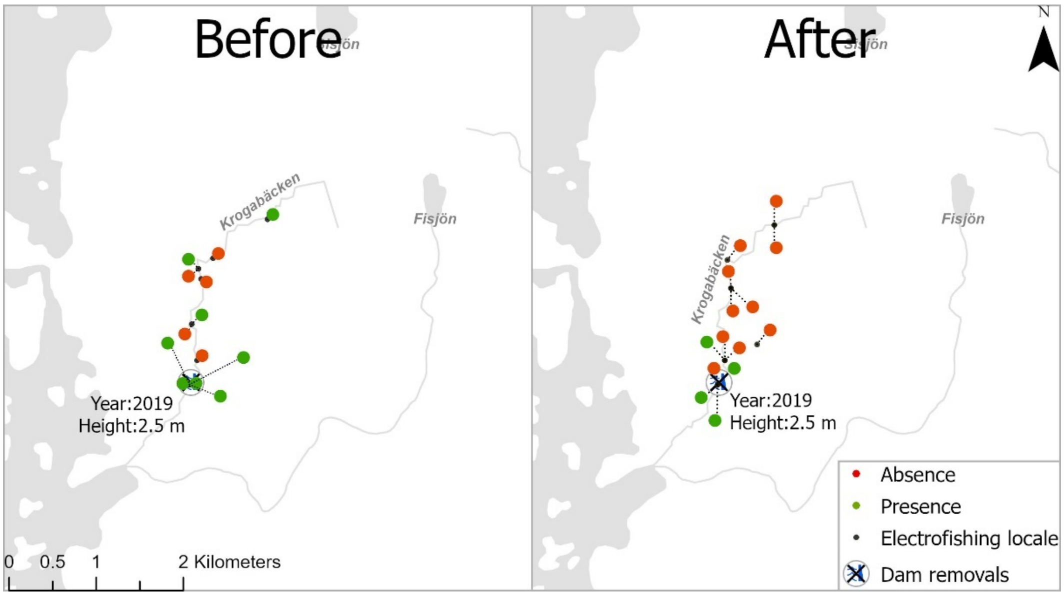

Figure 17. Map showing the dam removal in Krogabäcken before and after the dam removal.

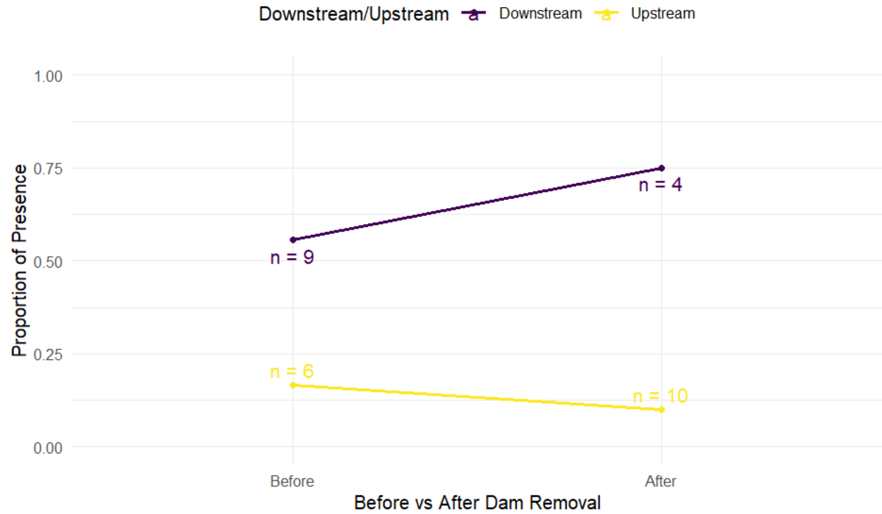

Figure 18. Proportion of electrofishing surveys catching juvenile eel before and after, downstream and upstream in Krogabäcken

Dam removals in Örebäcken

In Örebäcken, there was a series of dam removals in 2018. This part of the stream is running through the town of Båstad, Skåne. Before the removals, there had previously been two fishways built downstream in 1998 and 2002 (Figure 19). Therefore, the data included from this site are surveys conducted after 2002.

The dam removal closest to the sea was the removal of a dam called Korröds mölla, at a height of 7 m. Further upstream are two additional dam removals conducted in 2018 (Figure 19). As all dam removals were implemented the same year, they were treated as one dam removal and electrofishing surveys upstream any of them were included in the analysis.

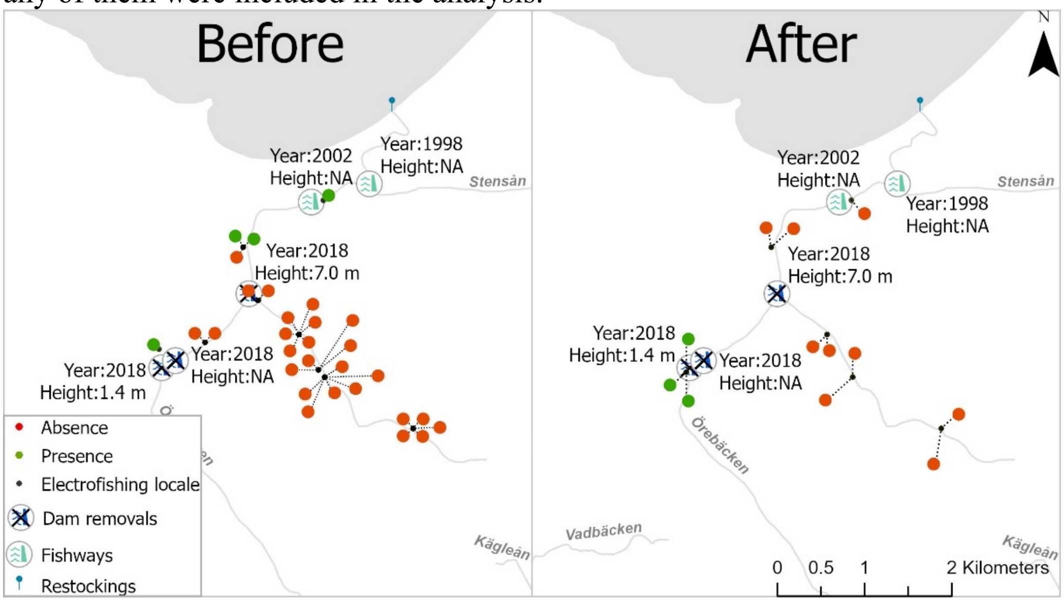

Figure 19. Map showing the dam removal in Örebäcken before and after the dam removal.

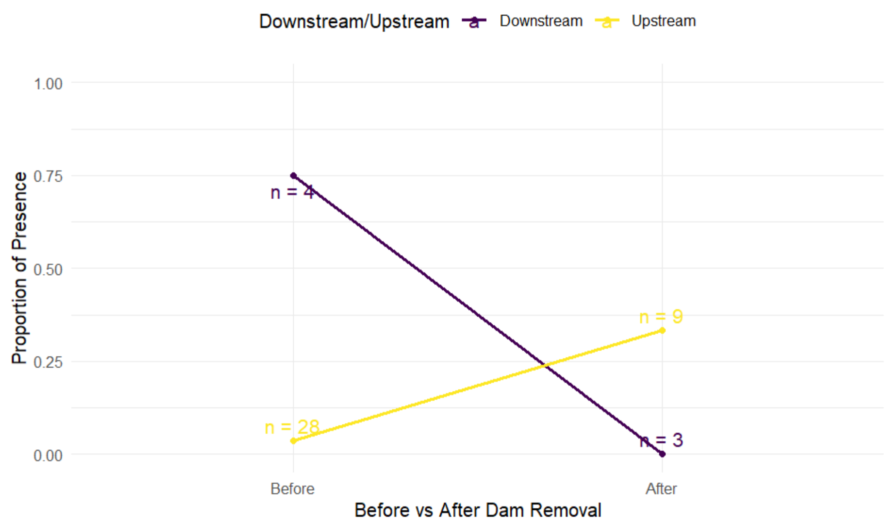

Figure 20. Proportion of electrofishing surveys catching juvenile eel before and after, downstream and upstream in Örebäcken

Dam removal in Lillån

This dam removal is somewhat of a mystery as there is no information of the original barrier in the dam database. The dam removal is in the restoration measures database, which states that a dam was removed in 2004 (Figure 21). 17 electrofishing surveys were conducted before the dam removal and 17 after, downstream. Upstream of the dam removal, there were 6 electrofishing surveys before and 16 after. For both upstream and downstream sites, there were juvenile eel before the removal and none after (Figure 22).

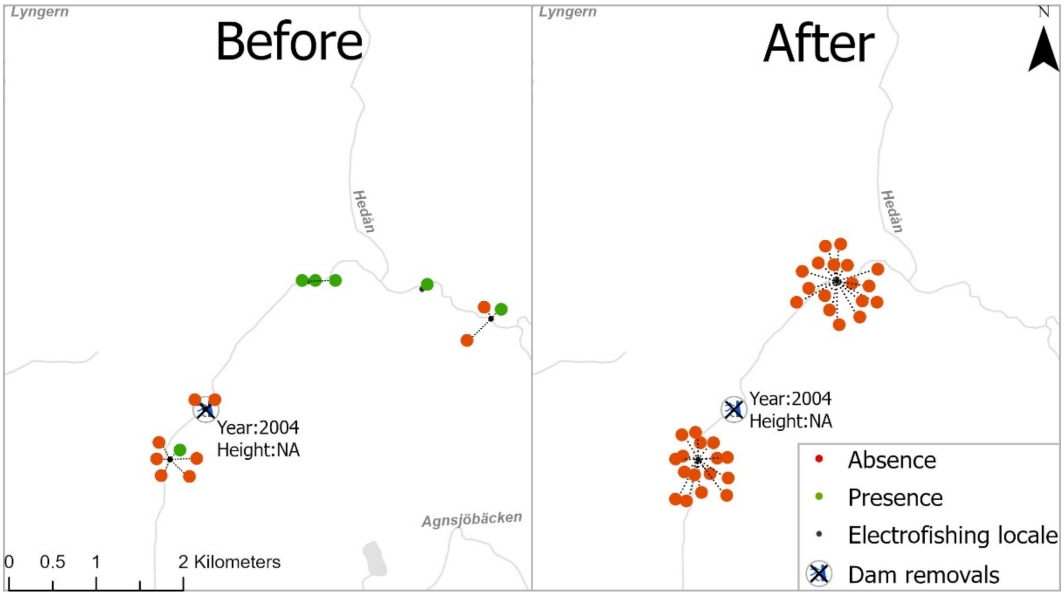

Figure 21. Map showing the dam removal in Lillån, before and after the dam removal.

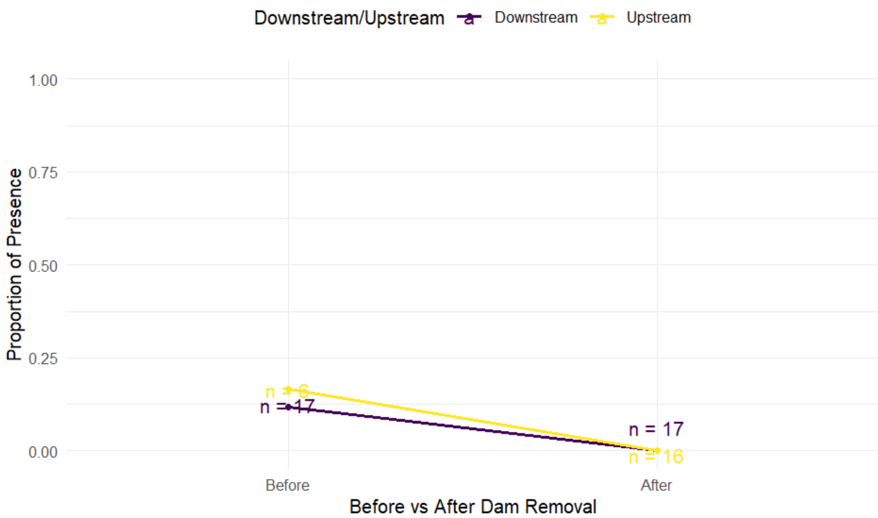

Figure 22. Proportion of electrofishing surveys catching juvenile eel before and after, downstream and upstream in Lillån

Nature-like fishway in Nybroån

This nature-like fishway in Nybroån is a bypass circumventing a 1 m high dam structure. The fishway was built 2013. Since there was a fishway built downstream in 2002, no surveys before that are included (Figure 23). Upstream are 2 dams that have fishways according to the barrier data set, but not the ÅiV, no surveys upstream of these are included. All electrofishing surveys downstream of the dam caught juvenile eel, both before and after. Upstream, juvenile eel was caught in 8/11 (72 %) surveys before and 1/8 (12 %) after (Figure 24).

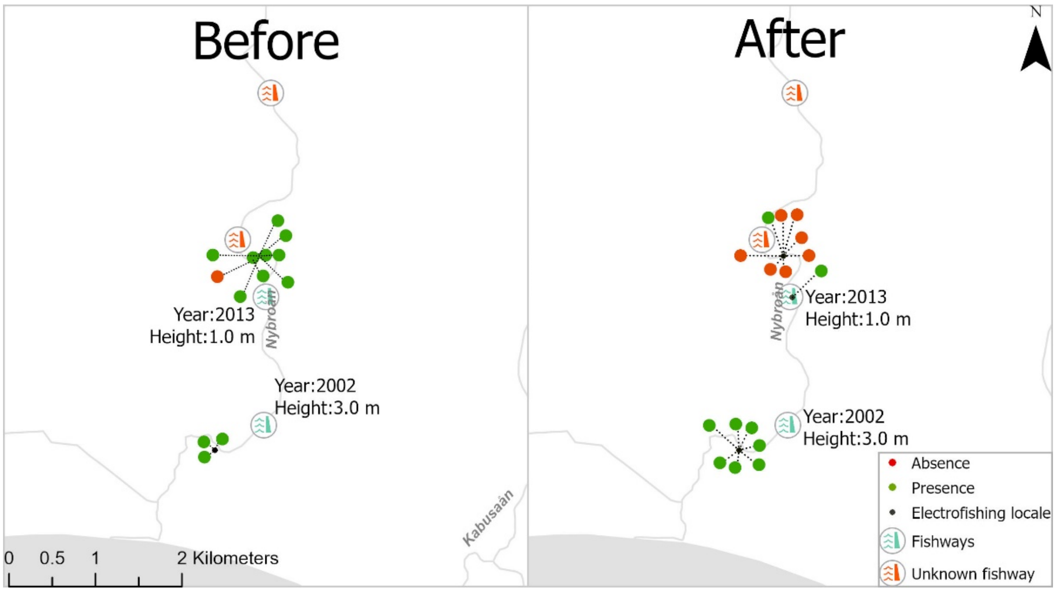

Figure 23. Map showing the nature-like fishway in Nybroån, before and after construction.

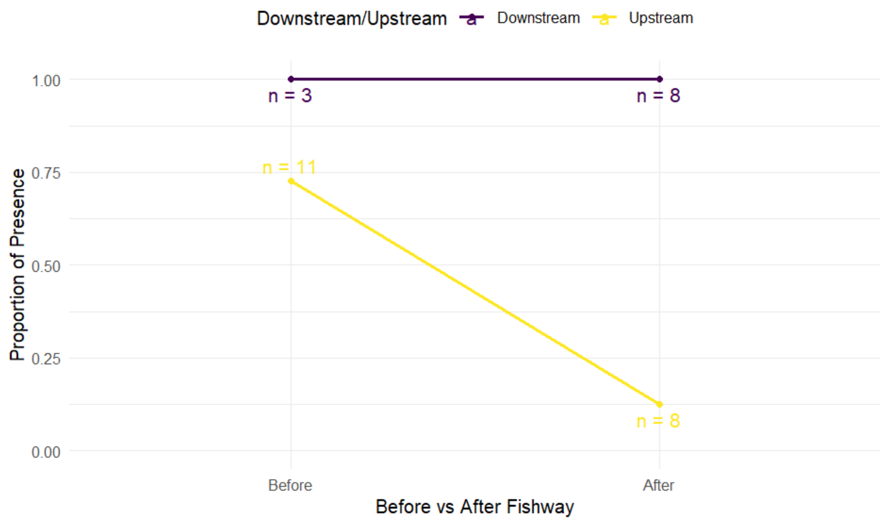

Figure 24. Proportion of electrofishing surveys catching juvenile eel before and after, downstream and upstream in Nybroån

Nature-like fishway in Säveån

This bypass in Säveån was constructed in 2010 past a 10 m high dam (Figure 25). No juvenile eel were caught upstream the dam before the fishway was constructed. After its construction 1/14 surveys caught juvenile eel (Figure 26). There are a couple of dams without fishways below this site, but it was included since there juvenile eel was present.

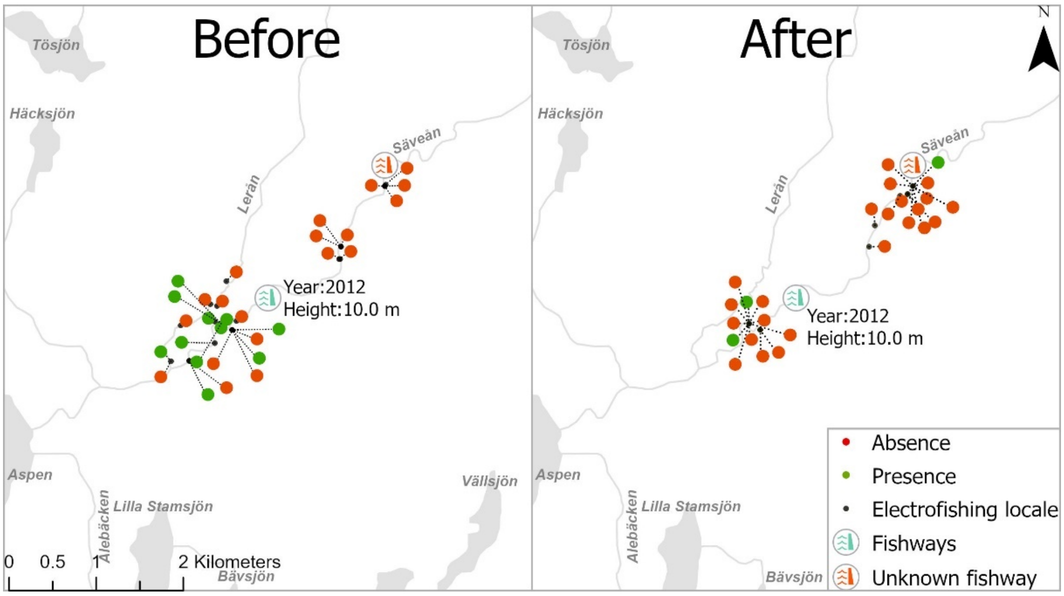

Figure 25. Map showing the nature-like fishway in Säveån, before and after construction

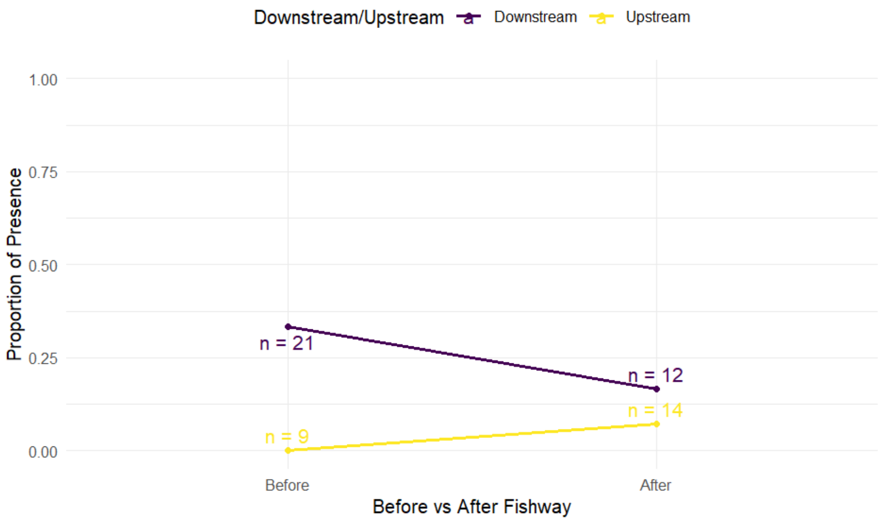

Figure 26. Proportion of electrofishing surveys catching juvenile eel before and after, downstream and upstream in Säveån

3.2 Length distributions before and after

There was length information available for 208 eels. Most of these eels were caught downstream of the dams, i.e. the control sites, 88 had been caught before removal or nature-like fishway was implemented, 67 had been caught after (Table 3). Upstream of dam removals and nature-like fishways, 32 eels were caught before and 21 after (Table 3).

Table 3. Total number of eels caught upstream and downstream, and, before and after, a dam removal or nature-like fishway.

	Downstream	*Upstream*
Before	88	32
After	67	21

The proportion of eels under 300 mm (juvenile eels) was consistent between before and after time periods in the downstream sites. In upstream sites, the proportion of eels under 300 mm was lower after a fishway or dam removal had been implemented (Figure 27).

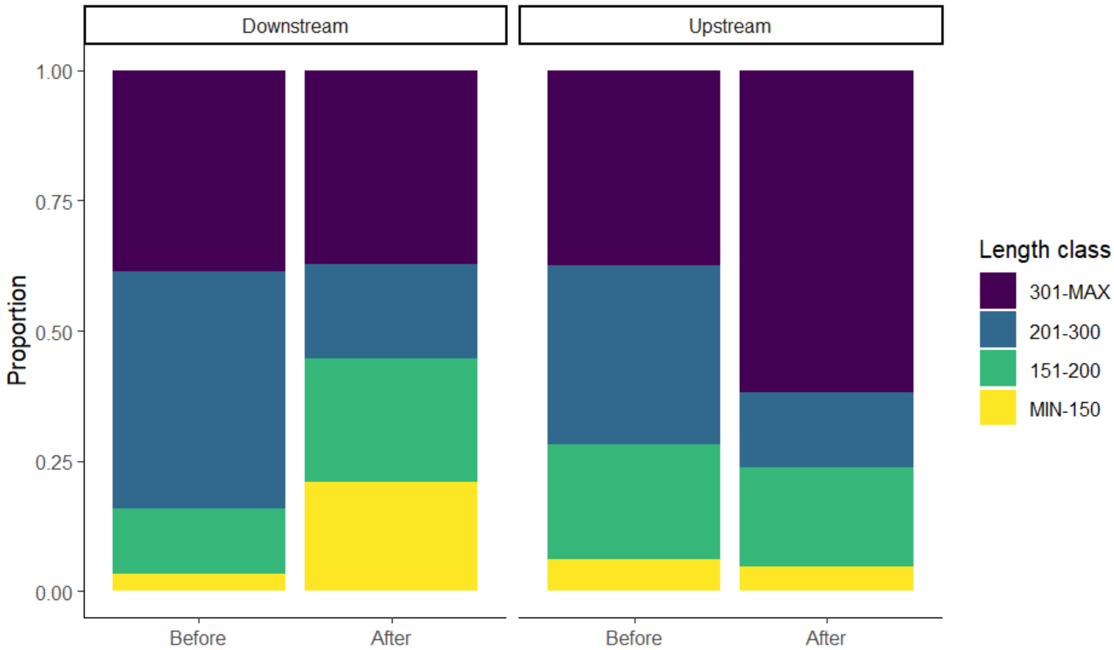

Figure 27. Proportion of different length classes caught downstream (control) and upstream a dam removal or nature-like fishway before and after its implementation.

3.3 Modelling juvenile eel occurrence

This data did not confirm that the implementation of a nature-like fishway or dam removal increases the incidence of eel under 300 mm, when controlling for eel occurrence downstream of a removal. The model with the interaction had a lower fit han the model without the interaction, according to AICc. This means that adding the interaction does not explain more of the remaining variation in the data than it would be expected to due to chance. Including the action variable, i.e. whether the restoration measures was removal or nature-like fishway, did not produce a better fit to the data either (Table 4). From the AICc analysis the best fitting model was: *Presence/Absence ~Before/After+ Down-/Upstream+ Temperature + Distance + Area + (1 | ID)*

Table 4. AIC-table, sorted from best to worst model. Text in bold denotes the difference between the model in question and the one above it in the table.

Model	*AICc score*
Before/After+Down/Upstream+ Distance+ Temperature + Area fished	172.40
Before/After*Down/Upstream	174.86
+ Years	174.86
+ No. of passes	178.40
+Action	180.66

3.4 Spatial overlap between data sets and missing data

5-13 % of features could not be associated to the river network due to them being further away than 100 m from the network (Table 5). The highest loss of data was among the electrofishing sites, with 132 eel sites being excluded and 1 825 out of all 14 072 electrofishing sites being excluded (Table 5).

Table 5. The spatial overlap between the river network and the features expected to overlap with it. Overlap was defined as being within 100 m of the river network.

Feature	*Percent within 100 m*	*Total*	*Excluded*
Dams	91.5 %	8 954	757
Technical fishways	94.4 %	498	28
Nature-like fishways	94.1 %	256	15
Dam removals	91.3 %	425	37
Electrofishing locales	87.0 %	14 072 (1 878 eel)	1 825 (132 with eel)

The features within the extent of this study that were expected to totally or partially overlap, did not do so to a high degree. 40 % of dams that were listed as having fishways in the barrier database, had a corresponding fishway in restoration measures database (Table 6). Conversely, 61 % of natural fishways, 61 % technical fishways, and 59 % dam removals, were not within 100 m of dam (Table 6). Of these, at least 154 of dam removals were explicitly stated as being removals of dams in their description.

Table 6. The spatial overlap between features expected share location. Overlap was defined as the closest feature being within 100 m.

Feature	*Expected overlap with*	*Percent overlap*	*Number overlapping*	*Total*
Dams with fishway	Nature-like and technical fishways	40 %	128	322
Nature-like fishways	Dams	61 %	156	256
Technical fishways	Dams	61 %	302	498
Dam removals	Dams	59 %	250	425

Data relevant to this kind of analysis were missing in all databases. In the restoration measures database, there were 22 nature-like fishways, 229 technical fishways, and 31 removals that had no completion year. Notably, only 3 out of the 86 eel ladders in the ÅiV have a completion date listed. In the barrier data, dam heights were missing for 6 235 out of 8 954 dams. In SERS, 284 of the sites with eel had no length data. In Sötebasen there were 43 restocking records without coordinates, of which four had no year of restocking.

4. Discussion

This study did not support that nature-like fishways or dam removal can function as a means of restoring connectivity for juvenile eel in freshwater systems in Sweden. This does not mean it is reasonable to assume that such measures do not have an effect, but rather that these environmental monitoring programmes along with SERS are not precise enough instruments to make inferences in this type of study.

4.1 Effects of dam removals and nature-like fishways

There was no effect of either dam removals or nature-like fishways on juvenile eel occurrence in the data analysed here, not from visual inspection nor from the statistical analysis. Instead, there was a weak tendency towards eel catches being less common after a dam removal or nature-like fishway both in the downstream control and upstream locales. We know that recruitment of juvenile eel has declined in the last decades, so this could be a manifestation of that (ICES 2023). As to why there is no effect of dam removal or nature-like fishways when controlling for this trend, I can only speculate. There are a multitude of possible causes, and I will cover the ones I expect to be the most significant.

4.1.1 Juvenile eel passing dams

As eel under 300 mm are the most likely individuals to migrate upstream, it is in this length class we would expect to see the largest effects of dam removals and nature-like fishways on migration. How large the effect would be, is entirely dependent on how much eel migration was limited in the first place and how common eel is within the river system. Four out of the five sites had occurrence of juvenile eel upstream of the dam before the nature-like fishways and dam removals were implemented. The implication of this could be one of two things. Either the dam was not an absolute barrier from the start, or the data in my analysis was missing important elements. The dams with height data present were not very tall (the highest was 7 m). They should still obstruct juvenile eel migration to some degree, but as eels do climb this could be the reason that eels are found above intact dams (Briand et al. 2022). Missing data could also explain why there was a high prevalence of juvenile eel upstream of intact dams, especially if information regarding prior fishways at these sites, restocking attempts and assisted migration is missing. The small evaluation of the data on dams, fishways and removals heavily indicated that these datasets are incomplete, as I discuss later. I do not have any on data to account for assisted migrations, so the probability of that interfering with my results is entirely unknown. I have no way to evaluate whether there are restocking attempts missing from the data.

4.2 Data structure and model assumptions

The use of statistics in this thesis is a bit problematic, most due to data structure and some assumptions that were done due to the small amount of data. None are however too detrimental to my general conclusions, but I will go through them here.

4.2.1 Too little data

For logistic regression, a general rule of thumb is to only include an additional variable for every ten events (eel presence in this case), to estimate their effect reliably (Chowdhury & Turin 2020). According to this rule I can not get a good estimate of the effects of all my covariates and the interaction between control (downstream/upstream) and treatment (before/after) with the data I have. 50 electrofishing surveys with eel catches would by this rule of thumb allow for estimating the effects for a maximum of five variables, and I start with ten. The risk of breaking this rule is overfitting the model to the data, i.e. risking overexplaining the random variance in the data with variables, that does not in reality explain that variance, by chance. As AICc penalizes complexity in models, it is a good method to avoid overfitting a model to data, but testing this many variables with so little data could produce a good fitting model by chance. This is why I do not want to draw any inferences about temperature, area fished and distance, which were present in the best fitting model. Including nature-like fishways and dam removals in the same model could be described as mixing apples and pears. With this small sample size, and the few nature-like fishway and dam removal sites, I included both in the same model to have the best prospect to estimate the effects of my covariates (area fished, distance, etc.).

4.2.2 Pseudo-replication

Another potential problem is the pseudo-replication in this analysis. Some electrofishing surveys conducted at same location are assumed be as independent as electrofishing surveys conducted at different locations, which they are not. Electrofishing surveys conducted in the same location share a number of environmental characteristics that could be of importance for eel occurrence, such as bottom substrate, water depth and flow rate. The model used only accounts for the similarity of surveys fished in the vicinity of the same dam removal or nature-like fishway, i.e. the nested site variable. As some electrofishing locales have only been surveyed once and there are so many locales in this analysis, a separate intercept for each location cannot be calculated and leads to a singular model (overfitting model to data). The possible effect of pseudo replication on the result would be a false certainty, due to less variation in the data, making the standard deviations of effect sizes smaller. It should not change the main result that the implementation of nature-like fishways and dam removals do not seem to matter according to the model.

4.3 Data quality and missing data

Open- data is a valuable resource, and it is fantastic that Swedish institutions provide this data for public use. The limitations and quality of these databases are however seldom well described. Dams and restoration measures introduced the most uncertainty in this analysis. This was due to them not matching well spatially, missing important variables, having unclear definitions and most likely being incomplete.

4.3.1 No information on positional accuracy

Positional accuracy was not defined for any of the datasets, i.e. how close the coordinates of a feature are to its true position on average. This was certainly a problem when trying to position features from different data sources together on a common river network, as it introduces uncertainty to which features should overlap and to what extent. The highest percentage of data loss with my method was due to data not being able to be placed on the river network. Whether this is due to low resolution in the river network or low precision in datapoints is impossible to quantify from these data alone. The loss of 5-13 % of features cannot be attributed to a single cause. This makes the possible impact on analysis hard to estimate.

Combining dams to dam removals and constructed fishways was not very successful. Many fishways and dam removals had no matching dams, and dams that were explicitly stated as having fishways had no matching fishways. As I do not know the positional accuracy of these datasets, I cannot know how much of this is attributable to either missing data or to low positional accuracy. There are however indices that it is mostly due dams, fishways and dam removals not being inventoried and thus missing from the databases.

4.3.2 Missing data

It would be good if the effort and methods involved in collecting data used in this study were more transparent. For the restoration measures database, there is no information on how restoration measures implemented before the existence of the database were reported or to which extent actors are required to report to the database. For the barrier database, there is no information of which stretches of rivers have been inventoried.

Missing dam structures is a known problem within the barrier database. One field survey that controlled a total of 121.8 km across 5 rivers and found 11 barriers, none of which were recorded in the database (Belletti et al. 2020). This speaks to there being a need for the counties to report which stretches are surveyed and which are not. For the restoration measures database, there are also known issues of missing dam removals and fishways (Nöbelin 2014). This confirm my findings, which strongly implies that both databases are missing features. The comparison of how well dams and fishways that should overlap completely actually do overlap, produced daunting results. Only 61 % of fishways overlapped with a dam structure, and only 40 % of dams noted as having fishways overlapped with a fishway. The most likely reason behind this is that data is missing.

In addition to missing fishways and removals, there is differing definitions for fishway classes and missing data on important attributes of removals and fishways in the ÅiV (Nöbelin 2014). Missing completion years for fishways and removals does limit the ability to follow up the effects of restoration. For eel ladders and eel traps, which could have been of interest to this study, the year of installation is listed for only 3 out of 86 measures, making any analysis of their effect on juvenile eel migration difficult.

4.3.3 Recommendations for open data usage

Taking these issues into account, I really recommend scrutinizing the quality of openly available data before utilizing it in research. Initial dialogue with the data providers can prevent misuse of data. I did not do that and used the open data in a way that relied on there being a high standard of data quality that is most likely not met.

4.4 Upstream migration of eel and management

The current wide-spread use of fishways seem to point to a general bias in restoration towards salmonids, which are better studied and are known to benefit from fishways more than most other species (as reviewed by: Noonan et al. 2012). When planning and researching how to increase connectivity in our rivers I would request an ecosystem-wide perspective. This would of course include eel, but also all the other species that disperse along rivers.

With the influx of nature-like fishways and dam removals as a way to aid eel migration, it is important to know whether these measures predominantly aid grown eel in their spawning migration or if they could aid juvenile eel upstream migration as well. As of now, there much more scientific literature on how to aid the downstream migrating eel (Piper et al. 2017; Fjeldstad et al. 2018; Calles et al. 2021). Additionally, the current Swedish eel management plan only targets downstream eel migration (*Förvaltningsplan för ål* 2008). This is with good reason, since downstream migrating individuals are closer to reproduction and thus the most valuable individuals in the population. However, given the current state of the eel population, I would argue that all life stages of the eel should be subject to conservation actions, as to not waste any opportunity to increase the population.

One could also argue that the natural recruitment of juvenile eel is so low, that we should focus on the survival of restocked eels instead. Currently, an estimated 90 % of eels in the Swedish inland population originate from restocking (Van Gemert et al. 2024). The issue with this is that The International Council for the Exploration of the Sea, which supplies scientifically based recommendations for restoration, now recommend against the eel fisheries that supply eel for restocking, arguing that the current system does more harm than good (ICES 2024a). So, I suggest that we should plan for how to keep the eel in Swedish waters in a changed status quo where translocated juvenile eels are no longer available. That would require aiding natural recruits in their upstream migration.

Thus, I would argue that a better scientific basis for how to best aid eel upstream migration is needed. This would preferably be done using a planned before-after study, with a control for trends in recruitment. The data used should be collected for the sole purpose of following up the effects of nature-like fishways and dam removals, to avoid dealing with differing methods and efforts statistically.

4.5 Conclusion

Reduced connectivity is not the only threat against eel, but it is one of the few that are completely within control. Therefore, the scientific community together with conservation practitioners should confirm that these common practices work, and that restoration is implemented where it works best. The data needed for this simple goal is not to be found in the databases included in this study. Instead, there is a great need of a concerted, well-planned effort in gathering data on eel occurrence both before and after these measures.

All of the datasets in this analysis have their own faults and limitations. Even the spatially limited use in this study was fraught with uncertainty due to the possibility of missing data. I would recommend anyone using the data on dams, fishways and dam removals to do so in a way that respects the limitations of these data. Given the strong indices that some dams and fishways are likely missing from these databases, the usage of this data would preferably be complemented by field inventories to ensure completeness.

The current focus on aiding eel in their spawning migration in eel management is probably rational, as it is pressing to increase spawner numbers right now. But, it is not a complete solution. Long-term it is essential that our rivers can support the whole freshwater stage of the eel, including its upstream migration.

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Popular science summary

The critically endangered European eel has had its freshwater habitat greatly reduced as a consequence of dam construction in the last century. Eel larvae hatch in the Sargasso Sea to embark on a long migration to European and North African shores where they colonize coastal waters, estuaries, rivers and lakes. Many rivers are rife with dams, weirs and other man-made structures which prevent small eels from colonizing river and lake habitat. Fishways, structures that help fish bypass a dam, and removal of dams are management measures used to restore fish movement within freshwater systems. In Sweden, the most commonly implemented measures to help eel specifically are nature-like fishways, which are fishways created with the intention to mimic natural habitat like a stream, and dam removals.

I wanted to confirm whether eels are helped in their colonization of rivers by nature-like fishways and dam removals, as there are so few studies on the subject. To investigate how the upstream migration of eel is affected by nature-like fishways and dam removals, I predominantly utilized data that are freely open on the web. Many Swedish institutions produce data and make it freely available: a treasure trove! These data on dams, dam removals, fishway solutions, and monitoring data from electrofishing were combined and used to assess whether upstream migration of juvenile eel in freshwater is affected by dam removal or construction of nature-like fishways. I did this by comparing the incidence of eel before and after the implementation of these measures.

I found that the data available could not confirm that dam removal or the construction of nature-like fishways aid juvenile eel in their upstream migration. The take-away is however not that these measures do not help. It is rather the case that boiling down these huge amounts of data to answer a very specific question left me with too little data to say anything with certainty.

So where does that leave us? Well, to know the effects of these restoration measures, one has to go out in the field and collect more data. The limits of open data to answer very specific ecological questions means that targeted data collection is sometimes necessary. This requires resources and time, but is fully worth it if it answers how well these restoration actions work.

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