Stocking eel or restoring routes?

A synthesis of their scientific foundation.

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Abstract

Evidence-based management is a term introduced to the field of conservation in the 1990s. As research and scientific thinking evolve, terminology and methodology of an evidence-based approach should also progress. Evaluating the evidence-base behind conservation and management methods is crucial to ensure they are effective and not based on potentially misleading factors such as tradition, personal experience, or accepted dogmas. In this thesis, a literature search was performed to investigate the scientific support behind two common management methods of the critically endangered European eel (*Anguilla anguilla*): restocking and restoring migration routes. The 39 articles reviewed demonstrate the diversity of parameters investigated within restocking and restoring migration routes and highlight the difficulties posed by the knowledge gaps in the European eel's lifecycle. Installed fish passages, one type of management measure to restore migration routes, are seldom evaluated for efficiency once operating and restocking has yet to show a net benefit for the population as a whole. While the scientific foundation of the management methods on a local scale may work as intended, it will take many years before results can be validated for the whole European eel population.

Keywords: Anguilla anguilla, restocking, migration routes, evidence-based management, conservation.

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Abbreviations

IUCN	International Union for the Conservation of Nature
ICES	International Council for the Exploration of the Sea
EMP	Eel Management Plans
FPS	Fish passage solutions

1. Introduction

Evidence-based management is a term introduced to the field of conservation in the 90s. As research and scientific thinking evolve, terminology and methodology of an evidence-based approach should follow (Sutherland et al 2004). Whilst human interference with the environment and species remains, management methods need scientific support to ensure function and effectiveness in mitigating these impacts. Evaluating the evidence-base behind management methods is important to ensure they are not based upon tradition, personal experience or accepted dogmas (Salafsky et al. 2019). In this thesis, a literature search was performed to investigate the scientific support behind the two common management methods of the critically endangered European eel (*Anguilla anguilla)*: restocking and restoration of migration routes.

1.1 Evidence-based management

Science, according to the Encyclopaedia Britannica (2024) is “any system of knowledge that is concerned with the physical world and its phenomena and that entails unbiased observations and systematic experimentation.” Systematic experimentation is fundamental in research, something medical professionals recognised many decades ago which revolutionised the field, making procedures safer and more effective (Sutherland et al. 2004).

It was not until the beginning of this century that this way of thinking entered conservation practices, conservation being the protection and preservation of natural environments and wildlife, which like the preceding medical field had many practices that were not evidence-based (Sutherland et al. 2004). However, scientifically supported conservation is still difficult and many decisions within management, the process of overseeing and regulating the use and development of natural resources with policies to achieve specific goals, are still based on anecdotes, myths, and the experiences of individual practitioners (Salafsky et al. 2019). As an example, Ditlhogo *et al.* (1992) published a study that compared two management methods of reed beds; burning, which traditionally was discouraged due to the supposedly negative effect on soil invertebrates, and the more common approach of cutting. Interestingly, the results showed no significant impact on soil invertebrates a year after the burning treatment compared to cutting. The belief that burning had a negative impact did not have a scientific foundation, as there was no difference in the long-term effect on soil invertebrates. Flooding, on the other hand, another common practice at the time that the paper discusses, was revealed to have a substantial negative effect on certain invertebrates (Ditlhogo et al. 1992). The study by Ditlhogo *et al* (1992) is often considered one of the earliest examples of an accepted dogma within management that was subsequently unsupported, initiating discussions of evidence-based methods within conservation and management. Yet the issue of a lack of evidence-based methods within management remains, as conservation interventions are rarely followed up and documented, and there is a general lack of systematic reviews on support and assessments regarding the effectiveness of interventions (Bernes 2019). The benefits of adopting a systematic, evidence-based approach in conservation and management would be to ensure that measures work as intended based on the most recent scientific knowledge, increasing effectiveness, improving decision-making, and enhancing funding opportunities due to demonstrated success and accountability (Sutherland et al. 2004).

Evaluating management methods in natural systems, the practical aspect of interventions for conservation purposes, can be difficult, as research and measures are done in a living system quite different from the controlled environment many other fields can artificially create in e.g. laboratories. Replication, records of case results and long-term monitoring can be very sparse (Salafsky et al. 2019). For example, the effectiveness of fish passages is rarely evaluated after installation, and when it is, the focus is typically on a single species (Algera et al. 2020). Additionally, studies frequently find that the performance of these passages is low, as the presence of a fish passage alone is no guarantee that it functions as intended (Roscoe & Hinch 2010; Silva et al. 2018).

Mammola *et al.* (2022) reviewed the evidence-base for the effectiveness of conservation interventions in subterranean ecosystems worldwide (including terrestrial, freshwater, and saltwater systems) from 1964 to 2021. They found an increase in the number of studies starting in the early 21st century, however, the proportion of studies quantifying the impact of conservation interventions significantly decreased in later years. Only a third of the conservation interventions had been tested statistically, and the geographic distribution was highly skewed towards the Northern parts of Europe, Asia, America and North Africa (Mammola et al. 2022). Roscoe and Hich (2010), Silva e*t al* (2018) and Mammola *et al* (2021) all emphasise the importance of statistical testing and standardised study reports to be able to compile and compare results.

Due to the lack of standardization in ecology and environmental practices, comparing and compiling results from various studies can be challenging. This lack of standardization highlights the increased need for systematic evaluation of research findings (Bernes 2019). It becomes even more challenging to apply evidence-based management on a species which ecology is poorly understood, and ever more important when it is critically endangered, which is the case with the European eel (*Anguilla anguilla).*

1.2 The European eel, *Anguilla anguilla*

The European eel undergoes significant morphological changes throughout its lifetime, transitioning from leptocephali larvae to glass eels, and then to yellow and silver eels. These transformations made it challenging for scientists to fully understand the lifecycle of this cryptic fish. In Aristotle's ‘History of Animals’ (350 BCE), one of the earliest written accounts of the eel, it was hypothesized that eels spontaneously generated from mud and rotting matter (Cresci 2020). Only 2000 years later Yves Delage and Giovanni Grassi determined that the described *Leptocephalus brevirostris* (1856) was the larval form of *A. Anguilla*, finally beginning to unravel the secrets of this species.

1.2.1 Life cycle

Johannes Schmidt, a Danish biologist, searched for the spawning ground of the eel for 25 year in the early 1900 (van Ginneken & Maes 2005; Cresci 2020). By catching leptocephalus larvae at sea, and moving toward areas where smaller specimens became more abundant, Schmidt managed to define one spawning ground of the European eel in the southwest Sargasso Sea. This has been supported by recent studies using satellite tags (Wright et al. 2022). Schmidt believed the population to be homogenous, creating the panmixia theory (Johannes Schmidth 1912), which has been supported through whole-genome sequencing (Enbody et al. 2021). No adult eel, dead or alive, was found in the Sargasso by Schmidt (Jan Botius & E. F. Harding 1985), and not by anyone else to this day.

The European eel migrates from the European coast, over 5000 km, to the Sargasso Sea to spawn where the adults most likely die after spawning. The larvae drift with the Gulf Stream to the coasts of Europe and North Africa growing into post-larval transparent glass eels. When reaching the coastal areas, some stay in estuarine environments and lagoons, others migrate upstream to freshwater habitats, while a proportion stay in marine environments until migration (Cresci 2020; Pike et al. 2020). Otolith studies have also confirmed eels switching between aquatic environments during their growth (Limburg et al. 2003).

While some individuals stay on the continent for 25 years or more in their continental stage, known as the yellow eel, others stay only a handful of years before entering the final life stage known as silver eels, returning to their birthplace to spawn (Cresci 2020). Many questions remain about their migration, such as their navigation mechanisms, swimming speed, timing of arrival and of course exact location of spawning and how the spawning is conducted (Wright et al. 2022).

1.2.2 The decline

In Europe the European eel used to represent more than 50% of the standing fish biomass (Feunteun 2002). Today, the population size is down to 0.4 to 11% of what it used to be in 1970 (ICES 2023). The eel’s complex life cycle made it difficult for the International Union for the Conservation of Nature (IUCN) to evaluate the population, as the measures involve mature animals in their breeding area. Instead, criteria have been applied to silver eels at the start of their migration, as this gives an estimation of pre-spawning stock biomass, the problem lies in that data for migrating silver eels are few and recent. Instead, glass eel index data are used as this represents the best geographic range. However, the issue of the complex relationship between recruitment, continental stock, escapement and spawner stock biomass remains (Pike et al. 2020).

Reasons for the rapid decline have been discussed and studied, both marine environmental changes and anthropogenic causes. The list generally consists of; migration barriers, habitat destruction, oceanographic climate changes, pollution, diseases and parasites, exploitation, illegal trade, changing hydrology and predation (Feunteun 2002; Dekker 2003; Aalto et al. 2016; Pike et al. 2020; ICES 2023). The European eel has been classified as critically endangered since 2008 by the IUCN (Pike et al. 2022).

1.3 Management

Managing a panmictic species is challenging, only adding to the difficulties regarding its complex life cycle (Pike et al. 2020). Early interventions for the eel were initiated at both local and national levels without coordination, resulting in inadequate effectiveness in managing a panmictic species.

The European Union created an international recovery plan for the eel, *The Eel Regulation*, in 2007 (EC 1100/2007). Implemented in 2009, each Member State needs to support the European eel recovery through the development of national Eel Management Plans (EMP). The goal of each EMP is to "reduce anthropogenic mortalities so as to permit with high probability the escapement to the sea of at least 40% of the silver eel biomass relative to the best estimate of escapement that would have existed if no anthropogenic influences had impacted to stock" (EU 2007, p. 19) Though quantifying these numbers can be very challenging, a recent evaluation made by the European Commission deduced that the escapement of silver eels remains below the set target (European Commission 2020).

Some of the conservation measures that have been included in several EMPs are reduced fishing, removal of migration barriers, increasing escapement e.g. through screening devices and fishways, restocking, and trap and transport (EU 2007; Jordbruksdepartementet 2008; Pike et al. 2020) Measuring the impact of specific threats on the European eel population is challenging due to several factors. The eel's long lifespan and extensive migratory patterns create a significant time lag in population responses. This means that the effects of particular threats, as well as the benefits of any management efforts, may not be visible in the population until years later. Additionally, the interactions between multiple threats can create synergistic effects, complicating the assessment of individual threat impacts and the effectiveness of management decisions (Pike et al. 2020).

Even if all anthropogenic mortality causes were removed (particularly fishing and hydropower-related mortality), it would still take many generations for the species to recover to its historical numbers (Åström & Dekker 2007; van Gemert et al. 2024). One generation, within the Swedish stock, is estimated to be around 17 years, meaning it would be decades before results from management today would be visible (van Gemert et al. 2024). Given the significant knowledge gaps and critical conservation status of the European eel, it is critical that we rely on evidence-based management to ensure that conservation and management efforts function as intended.

The Swedish EMP is based on four general management tools; restrictions on fishing, improved migration opportunities for silver eels (reduced turbine mortality), restocking, and lastly monitoring and surveillance. Restricting fishing directly reduces eel mortality, increasing the number of individuals that mature and migrate from Swedish waters to the Sargasso Sea, thereby enhancing the chances of survival. Monitoring is essential for assessing local eel stocks, fishing pressure, and escapement, and it plays a critical role in evaluating the EMP’s goal of achieving 40% silver eel biomass. While fishing restrictions and surveillance focus on policy and protocol changes, restocking and route restoration are ecological interventions.

1.3.1 Restocking

Restocking is the measure of releasing translocated eels from one location to another to either compensate for low natural immigration levels, or to transfer eels to areas more suitable for growth and survival, to improve local abundance and increase escape of silver eels that will contribute to the reproductive potential of the population (Josset et al. 2016). Restocking is a process completely reliant on human intervention until the glass eels have been released into their recipient habitat. The process can be summarized into capture, stalling, occasionally marking, transport, and release (Josset et al. 2016). While the production of silver eels from stocked glass eels has been observed through monitoring of relocated stocks (Desprez et al. 2013) and improvement of local eel production (Josset et al. 2016), the net conservational benefit for the population as a whole remains unknown. This is because there have been no comparisons between the silver eel escapement from donor areas and recipient waters if restocking had not occurred. Therefore, it is still unknown whether moving eels provides a net benefit for the population or not (ICES 2023).

1.3.2 Restoring migration routes

Restoring migration routes in systems with human-made migration barriers increases connectivity within and between water bodies of marine and freshwater environments, making habitat that the eel and other diadromous fish depend on, available (Tamario et al. 2019). Freshwater ecosystems are one of the most anthropogenically impacted environments globally (Piper et al. 2015). Hydropower plants and pumping stations are migration barriers that can also be lethal due to rotating turbines and large pumps, with mortalities ranging from 10 to 100% on adult eels (Piper et al. 2017). In addition, constructions of water level control (e.g tidal barriers) such as weirs and sluices can hinder and delay migration (Huisman et al. 2023). To mitigate the impact of migration barriers on fish migration, fish passage solutions (FPS) that allow upstream and/or downstream movement can be installed. Many FPS designs are adapted to salmonids with strong swimming capabilities and not for anguilliform swimmers, and an evaluation after installation is rarely done, leaving the efficiency of many FPS designs unknown (Tamario et al.

2019) or when tested, even lower than expected (Roscoe & Hinch 2010; Silva et al. 2018). Some examples of FPS include eel ramps, technical fishways, nature-like fishways, pool-type passes, eel tiles or bristles (Vowles et al. 2015; Tamario et al. 2019).

Restocking and restoring migration routes are two very different methods that aim to increase the number of migrating silver eels. Considering the many knowledge gaps and data deficiencies, efforts should be directed toward methods that have been tested and have reliable support for their effect. There should be as little assumptions and guessing as possible in dealing with a critically endangered species. As scientists and conservationists, the choice of management should be evidence-based. In this study, the scientific foundation for the two management measures, restocking and restoring migration routes, have been investigated.

2. Materials and methods

A literature search was performed to investigate whether the two management measures restocking and restoring migration routes are evidence-based. Databases and sources that were used were Google Scholar and Uppsala University library database using the keywords “Restocking Anguilla anguilla”, “Restocking European eel”, “Fish pass (AND) Anguilla anguilla”, “Fish pass (AND) European eel”, and “Anguilla Anguilla (AND) evidence-based conservation”. The search was performed between 26 of June 2024 and 13 of July 2024; out of the resulting hits, at least the first 30 results were screened. From the 300 articles screened, only articles following the criteria were picked out. To be included, the literature had to contain the keywords within the title or abstract and had to concern restocking methods to restore the eel population and/or migration route restoration, with the purpose of eels passing or where eels could potentially pass. Peer-reviewed papers, grey literature and technical reports were screened. Only literature from the last 10 years (2013-2024) was included due to time constraints. Lastly, the included articles went through a final evaluation through a complete read to ensure they met the criteria and were relevant to the research question of this thesis.

The resulting dataset consisted of 39 publications. Papers regarding any other species than the European eel, review articles, studies examining ecological effects of stocking and fish passages, dissertations, and papers on improved monitoring or data models, were excluded. The data that was collected from each paper was the parameters investigated, whether the term “evidence-based” was mentioned, and if the studies had a reference site with natural migration pathways or natural recruits. Furthermore, the eel life stage (glass/juvenile/yellow/silver) in focus was noted, with the number of eels used in the study noted and used as a proxy for the resources and size of the research investigation. Using the number of eels as a proxy reflects the scale of the investigation, as the probability of eel occurrence is influenced by the sampling procedure (Degerman et al. 2019) and the number of eels tagged or purchased is a reflection of economic resources. Within migration routes, studies often focused on either upstream movements of glass eels or juveniles, or downstream movements of silver eels. A set number of eels were often marked and monitored. This initial number is what I defined as 'Number of eels in each study', although the final number contributing to the dataset often deviated from the starting count. For restocking studies, either marked and monitored eels, or recaptured eels contributing to the data, were used. The number of stocked eels in the study area was not included because restocking periods could range from one year to decades, with the number of individuals stocked varying from a thousand to tens of thousands. Including this data could skew the perceived resources of the study, as this conservation method is often funded by other actors and not by the study itself. Glass eels measured in grams were transformed to the number of eels, using the mean body weight from each study. Studies where the number of eels was unclear were excluded, this left a total of 13 studies in restocking and 17 in migration routes (Appendix 1). This data was then summed together giving the total number of eels divided into categories of parameters (Table 1).

To assess the breakdown of data between upstream and downstream studies, information was collected on migration direction. Lastly, data on knowledge gaps within the management methods were collected and sorted into what affects restocking, migration routes or knowledge gaps that concern both. To avoid repetition, data deficiencies mentioned once within the management methods were not noted again if other studies said the same thing. The data were analysed and visualised using Microsoft Excel.

2.1.1 Parameters

The parameters investigated were summarized into set categories, namely behaviour, dispersal, escapement, fish-pass efficiency, habitat, life history, mortality, pre-stocking and water control (Figure 1). “Behaviours” included studies focusing on behaviour through passages or obstacles. “Dispersal” concerned studies on how eels dispersed after stocking or after passing a barrier. “Escapement” involved studies tracking silver eels or calculating stocking results in the production of breeders. “Fish-pass efficiency” quantifies the efficiency of a fish passage solution or design. “Habitat” studies involved the environment of stocking and growth. “Life history” consists of studies that followed eels as they grew and matured, often long-term monitoring of stocked eels. “Mortality” involved studies focusing on the mortality of specific parameters (time of year of stocking, single vs. multiple site release and stock density). “Pre-stocking” contained studies investigating important fsctors before the act of releasing translocated eels. “Water control” are passages through barriers that are not FPS, such as sluices and culverts. Many studies could fit into more than one category; however, the primary research question was used to classify each study into its main category.

Usage of the term “Evidence-based” was investigated by using it in a term search on the literature and in Google Books Ngram Viewer. By searching “Evidence-based *” it was possible to identify different wildcards following “Evidence-based ,” providing insight into its usage since the 1990s.

3. Results

Out of the resulting 39 articles that fit the criteria, 21 concerned migration routes and 18 restocking. The term *evidence-based* was mentioned in only one, in the study from Egg. *et al.* (2017) regarding improvement of downstream migration through a small-scale hydropower by an undershot sluice gate.

In the studies on restocking, two (Sjöberg et al. 2017; Rohtla et al. 2021) out of four studies on escapement (Desprez et al. 2013; Prigge et al. 2013; Sjöberg et al. 2017; Rohtla et al. 2021) did collect data of both restocked and naturally recruited silver eels for comparison. For the migration route studies, two (Calles et al. 2021; Wright et al. 2015) out of twenty-one (10%) included a reference site where migration occurred through unobstructed water (see Appendix 1 for the full list of articles).

Within migration routes eleven out of twenty-one (52%) studies investigated upstream migration, while ten out of twenty-one (48%) concerned downstream migration (Appendix 1).

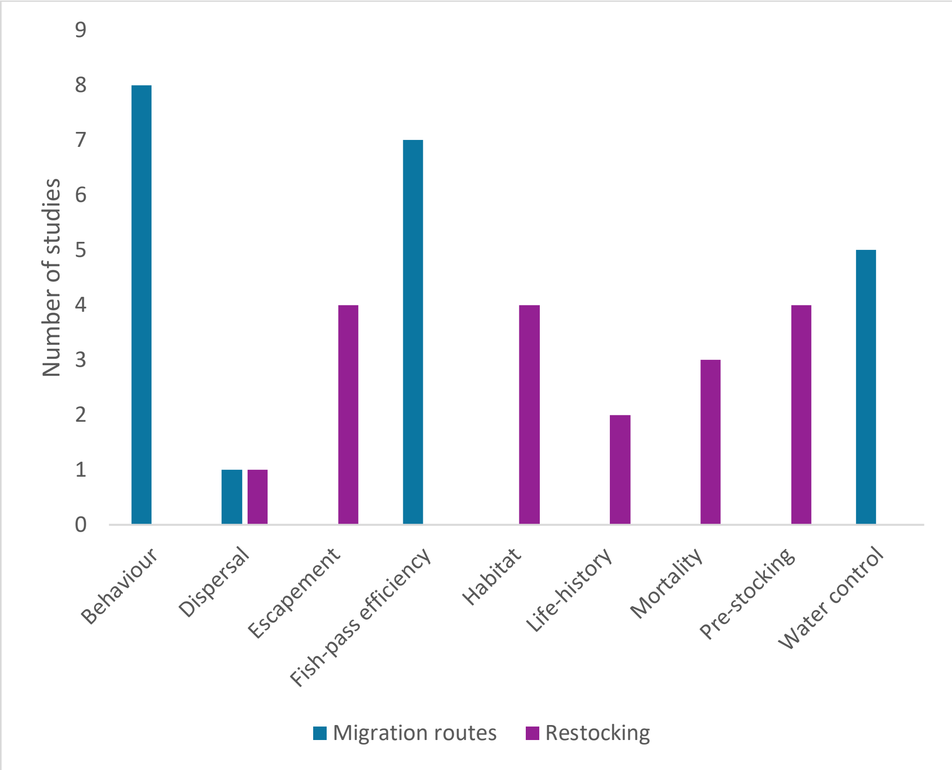

Figure 1. Number of studies per parameters investigated within the studies on migration routes (green bars, N = 21) and restocking (purple bars, N = 18).

To visualize the number of studies that investigated various parameters in greater detail, the studies were classified into further parameter groups (ten groups for restocking and eleven groups for migration routes, Table 1). The frequency of studies per parameter group ranged between 6 and 29% and was not equal within the management methods (Table 1). "Dams" and "Hydropower plants" sometimes involved more than one kind of FPS while "Various" involved more than one kind of passage but at different barriers or experimental set-ups. For restocking 6% equals one study whereas 5% equals one study for migration routes.

In restocking, the number of eels ranged from 100 to 3,600, with a mean of 1,070 eels (rounded down). The range for migration routes was from a minimum of 7 (Baker et al. 2021) eels to a maximum of 5,139 eels (Santos et al. 2016), with a mean of 728 eels (rounded down).

Table 1. Overview of a more detailed classification of the investigated parameters. The number of studies focusing on each parameter is given in the second column with percentages in brackets (migration routes: N = 21, restocking: N = 18). The total number of eels used in the studies was categorised by parameter, restocking (n=13) and migration routes (n=17). The mean number of eels per parameter was determined by dividing the total number of eels by the number of studies for that parameter.

Management method	Parameter	Number of studies (%)	Total number of eels	Mean number of eels (min-max)
Restocking	Escapement	4 (22%)	4248	1416 (247 – 2804)
Restocking	Habitat	4 (22%)	2072	1036 (151 – 1921)
Restocking	Life-history	2 (11%)	1051	1051
Restocking	Virus infections	2 (11%)	904	452 (100 – 804)
Restocking	Dispersal	1 (6%)	241	241
Restocking	Pre-release mortality	1 (6%)	600	600
Restocking	Quarantine	1 (6%)	400	400
Restocking	Single/multiple sites	1 (6%)	776	388
Restocking	Stock density	1 (6%)	3600	3600
Restocking	Time of year	1 (6%)	-	-
Restocking tot			13892	1070 (100 – 3600)
Migration routes	Hydro power plant	5 (29%)	1811	362 (40-1323)
Migration routes	Sluice	4 (19%)	155	51 (7-118)
Migration routes	Dams	2 (10%)	16	16
Migration routes	Eel tiles	2 (10%)	29	29
Migration routes	Various	2 (10%)	75	(25-50)
Migration routes	Bristle passes	1 (5%)	271	271
Migration routes	Culvert design	1 (5%)	75	75
Migration routes	Fish lift	1 (5%)	5839	5139

Migration routes	Passive wedge wire screen	1 (5%)	420	420
Migration routes	Pulsed direct current (electricity)	1 (5%)	472	472
Migration routes	Ramp design	1 (5%)	4032	4032
Migration routes tot			13195	733

Most research on restocking has focused on glass eels while silver eel is the most studied life stage within migration routes (Figure 2).

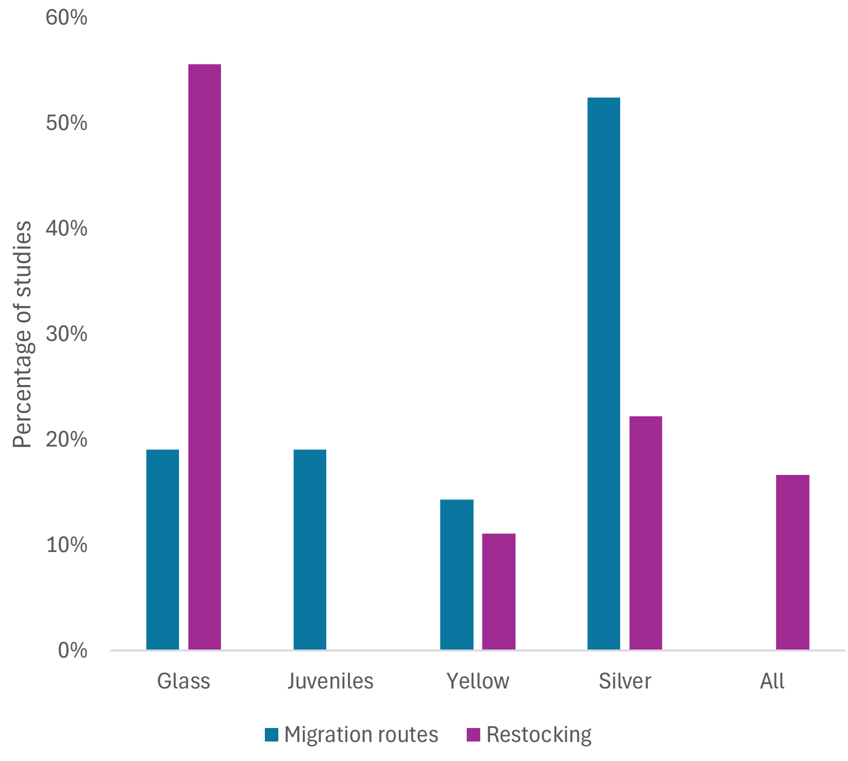

Figure 2. Percentage of studies per life stage, i.e., the life stages that the research papers aimed to improve or learn more about within the studies on migration routes (green bars, N = 21) and restocking (purple bars, N = 18). The total amount goes past 100% due to some studies focusing on two life stages: adult (yellow and silver) or glass eels and juveniles.

Below is a list summarising knowledge gaps discussed within the studies concerning restocking (N = 18) and migration routes (N = 21). Data is organised into what knowledge gaps concern which management method, or both.

Restocking

- Habitat preferences for eels during the whole life cycle (Degerman et al. 2019).
- If restocked eels contribute to spawning stock (Josset et al. 2016; Delrez et al. 2021; Rohtla et al. 2021; Danne et al. 2022).
- If and how translocation interferes with orientation back to spawning grounds (Delrez et al. 2021).
- Impact of quarantine conditions on the survival rate of eels, particularly the potential impact of quarantine on survival after release to the environment (Delrez et al. 2021).
- Density-dependent feminisation is still not clearly understood (Nzau Matondo et al. 2022).
- Survival and transition between life stages in eel populations (Desprez et al. 2013).
- Stress from stocking and how it might affect behaviour and survival (Desprez et al. 2013).
- The influence of the marking process on the survival of the released glass eels (Josset et al. 2016).
- Timing and potential importance of within-generation local selection acting on genes that influence local life-history characteristics (Nzau Matondo et al. 2021).
- Silvering rate (Nzau Matondo et al. 2023).
- Behaviour and life during growth in inland waters, e.g., habitat preference according to age (Nzau Matondo et al. 2019).
- Methods used to assess stocking performance by estimating survival rate and implementing restocking for maximum recruitment in rivers (Nzau Matondo et al. 2020).
- Insufficient research about infectious diseases of eels in all life stages, especially glass eels (Danne et al. 2022).

- Whether vertical transmissions of eel viruses are important and should be considered when planning stocking measures (Danne et al. 2022).
- Optimal time of the year for stocking (Simon 2023).
- Spawning success of infected eels. If they are able to spawn, egg quality, and whether offspring are also infected or affected (Kullmann et al. 2017).

Both

- Nocturnal behaviour (Degerman et al. 2019; Nzau Matondo et al. 2019).
- Eel life-history in coastal and transitional waters (Rohtla et al. 2021).
- Sexual maturation and spawning (Nzau Matondo et al. 2022).
- Mother-to-child transfer of pollutants (Nzau Matondo et al. 2022).
- Migration speed, duration, and timing (Prigge et al. 2013; Egg et al. 2017).
- Imprinting of migration routes and orientation mechanisms (Prigge et al. 2013; Delrez et al. 2021).
- Overwintering, causes and triggers (Sjöberg et al. 2017).
- Detailed migration patterns (Økland et al. 2019).
- Behaviour and migration of yellow eels (Santos et al. 2016).
- Eel behavioural responses (Piper et al. 2015, 2017; Egg et al. 2017; Calles et al. 2021)

Migration Routes

- The efficiency of passage solutions often remains untested (Vowles et al. 2015; Tamario et al. 2019).
- Impact of culverts on eel movement. No study on passage efficiency (Newbold et al. 2014).
- Thigmotactic behaviour (Newbold et al. 2014)
- Influence of baffle designs on eel migration and efficiency (Newbold et al. 2014).
- The effect of turbulent flow on eel stability and swimming performance has not been quantified (Vowles et al. 2015).
- Field testing of tiles with different stud sizes as well as influence on swimming behaviour (Vowles et al. 2015) .

- Tests on various fish-passes in different flow velocities (Piper et al. 2023; Sonnino Sorisio et al. 2024).
- Tests on various fish-passes by eels of different sizes (e.g., maturity and morphology) (Vowles et al. 2015).
- Efficiency of bristle passes in different orientations and at different barriers (Kerr et al. 2015).
- How delays due to barriers and passes might affect migration, mortality and timing of spawning (Huisman et al. 2023).
- How discharge events affect passage through sluices (Huisman et al. 2023).
- Optimum operation criteria and designs of gravity-fed passes (Baker et al. 2021; Piper et al. 2023).
- Sluice gate optimum, in the number of gates opened and at what amount (wide open or ajar) for eels to pass (Bouchard et al. 2022).
- Lack of effective and economically viable management options for passage through power plants (Egg et al. 2017).
- How moon phases affect migration (conflicting results in studies) (Santos et al. 2016; Egg et al. 2017).
- Limited attempts to quantify the impacts of estuarine infrastructure on seaward migration of adult eels (Wright et al. 2015; Baker et al. 2021).
- Behavioural avoidance (Vowles et al. 2015; Wright et al. 2015).
- Effective guidance for eel, knowing what attracts and what repels them to safely guide them through barriers (Piper et al. 2015, 2017; Calles et al. 2021).
- Limited knowledge of swimming behaviour and depth during migration (Kjærås et al. 2023).
- The efficacy of many presumably fish-friendly adaptations remains to be established (Verhelst et al. 2018).
- Predation rate at barriers and passages (Økland et al. 2019).
- Fish lift performance for eels (Santos et al. 2016).
- Response to electricity in eels of all life stages (of use guiding eels through barriers) (Miller et al. 2022).
- Research assessing impingement and entrainment risk at fine mesh screens (Carter et al. 2023).

- Upstream migration of glass eels and elvers and for river-resident yellow eels and juveniles, including whether upstream migrating eels approach hazardous intakes (Carter et al. 2023).
- The impact of dams and reservoirs is understudied and can delay migration (Trancart et al. 2020).

Google Vooks Ngram Viewer showed that the usage of the term “Evidence-based” began in the 1980s, with a large increase in the 21st century. “Evidence-based practice” and “Evidence-based medicine” were the two most frequently used phrases. “Evidence-based management” saw a peak in 2016 before declining, and overall, it remains in the lower margins of usage (Figure 3).

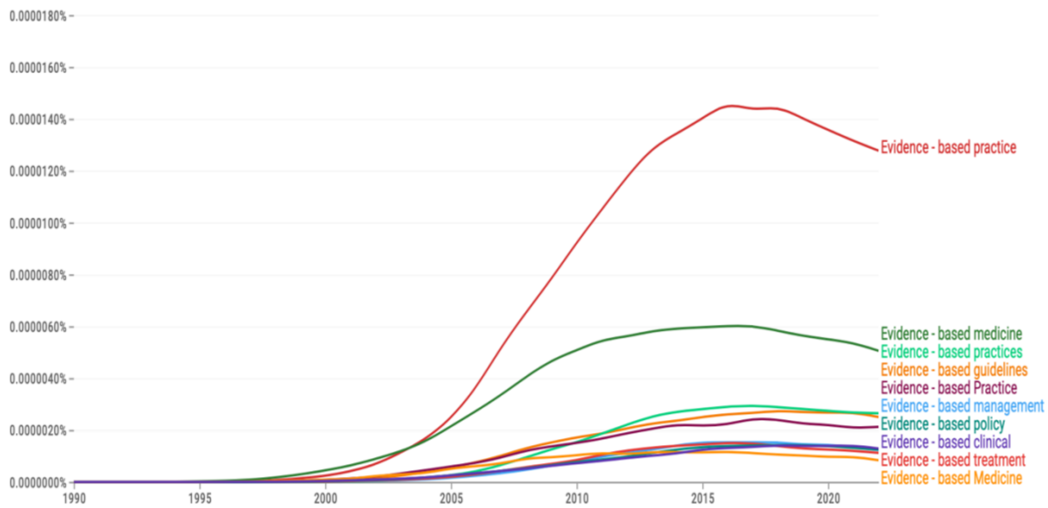

Figure 3. Usage trends of the term “Evidence-based ” from 1990 onward in English literature. The graph was generated using Google Books Ngram Viewer. The asterisk (*) acts as a wildcard, allowing the search to include various phrases that begin with "evidence-based," such as “evidence-based practice,” “evidence-based medicine,” and “evidence-based management.” The data show a significant increase in the use of these terms starting in the early 1990s, with “evidence-based management” peaking in 2016 before declining.

4. Discussion

Management should be based on informed decisions and tested methods to ensure that conservation is effective and work as intended. In this study, the evidence-base behind the management methods restocking and route restoration of the European eel (*Anguilla anguilla*) were investigated.

Within conservation and management the success of the efforts are generally measured by monitoring mature animals in their breeding area and counting offspring (Pike et al 2020). For the European eel, this is currently impossible as spawning has yet to be observed (see section 1.2). Instead, we depend on the observations and data of escaping silver eels from restocking and migration routes as well as glass eel recruitment to the continent. However, with a long-lived species such as the eel, it will likely be decades before results are visible.

The European eel is one population. making the effect of local efforts on the population as a whole difficult to measure. This, in itself, makes it hard to ensure an evidence-based conservation practice. Especially, since the majority of the studies (35 out of 39) had no references with non-manipulated stock or routes (Appendix 1). This means we are restocking eels and creating migration pathways without knowing the benefit compared to natural recruits and free migration pathways. Studying live organisms in natural environments can be difficult, and having a control or even a reference of eels in natural conditions might be challenging, but the lack of reference sites and firm support of a positive net-benefit for the population as a whole makes the results from the conservation and management efforts more uncertain.

Today we do not know if restocked eels find their way to the Sargasso Sea. There are studies on suitable habitats supporting growth of glass eels (n=4) (Degerman et al. 2019; Félix et al. 2021; Nzau Matondo et al. 2021, 2023), studies to lower mortality pre-stocking (n=4) (Josset et al. 2016; Kullmann et al. 2017; Delrez et al. 2021; Danne et al. 2022), studies of restocked eels finding the outlet to sea (n=3) (Prigge et al. 2013; Sjöberg et al. 2017; Rohtla et al. 2021) but if they are able to finish the migration and successfully spawn is still unknown.

Route restoration can improve the escapement of silver eel, but only installing an FPS and operating it is no guarantee. The variety of FPS is large, suitable for different barriers and a diversity of environments. Within the literature, I found many promising results of testing efficiency (n=7) (Kerr et al. 2015; Vowles et al. 2015; Santos et al. 2016; Økland et al. 2019; Calles et al. 2021; Piper et al. 2023; Sonnino Sorisio et al. 2024), improving designs and understanding eel behaviour (n=8) ((Piper et al. 2015, 2017; Verhelst et al. 2018; Trancart et al. 2020; Baker et al. 2021; Miller et al. 2022; Carter et al. 2023; Kjærås et al. 2023) for guidance safely through barriers. Yet the monitoring and standardised testing after installation is almost non-existent and the major problem of not being able to confirm offspring from studied individuals remains. Maybe that is why only one article by Egg *et al*. (2017) used the term evidence-base; "An evidence-based aquatic conservation approach requires evaluating different management options against predefined criteria to identify optimal solutions."

According to Pike *et al*. (2020) there is a large body of information about the eel, yet well-established scientific details are rare. This study found many contradictions and knowledge gaps within the research of nearly every parameter included which adds to their findings. This is distressing considering the European eel's critical status.

The life cycle of the eel means that we currently have no way of knowing if the Eel management plans are making a difference for the population as a whole. The Swedish EMP was accepted in 2009 and though much research has been done since then, the major questions are still unanswered. How can we use evidence-based and systematic research methods to improve the eel management plans?

Today, from the literature I have read and included in this study, we know that pre-stocking handling can be improved to lower mortality, we know quarantine can help us identify and limit the spread of diseases, the life history of all stages of the European eel is better understood and we know what conditions are good for stocking. We also know, that every location has its local conditions making adaptive management crucial. The question of how eels localise and navigate remains, leaving a big question mark in whether restocked eels are well-equipped enough to make the whole journey to the breeding site and sucessfully spawn.

For migration routes, my results give a clear insight into the diversity of barriers and FPS. This makes adaptive-management important not only for the location of the installation but also due to the different eel lifestages having different needs. It is not "one size fits all". In the 10 weeks of this study, I have only scraped the surface of what has been researched, and with the many contradictions within the literature as well as knowledge gaps, there is much to do before eel conservation could be considered evidence-based.

4.1 Evidence-based conservation and management

The European eel population is declining and even though the scientific support of restocking and migration route restoration increasing the potential spawning stock is arguable, it is clear that we still have to act. Thus, what can we do? And how can an evidence-based approach help us? By focusing research into knowledge gaps we can fill, we can ensure that even though uncertainties will prevail for the foreseeable future, we make as informed management decisions as possible. Most importantly, these decisions should be based on trials, research, and systematic work. Sutherland *et al* (2004) suggested a central database of information on conservation practice. With such a database for the eel, experiments of various kinds, in different environments, and at a range of spatio-temporal scales would be gathered in one place, effectively combining experience to form a body of evidence that could be used to support management decisions. This would also help with adaptive management as small-scale studies with few replicates in very specific conditions would fine-tune adaptability, as seen within the literature, certain studies only had seven (Baker et al. 2021) or 30 (Huisman et al. 2023) eels for data collection. An issue that can be mitigated with a database where results from similar studies can be compiled. Furthermore, contradictions and assumptions could be mapped out using this database, guiding and motivating research in these directions.

4.2 Contradictions & assumptions

Contradictions were common through many of the papers, e.g. whether sluices function as passages for eels or not (Baker et al 2021; Huisman et al. 2023), or findings in one study that nature-like pathways were the most effective for eels (Tamario et al 2019) while another paper found it the least effective (Økland et al. 2019). Interestingly one study even found that "Not a single eel out of 1323 counts used the eel bypass system, which is currently considered a technical standard. Instead, silver eels approached the opening of an undershot sluice gate and effectively used this corridor during their downstream migration" (Egg et al. 2017, p. 354). In the behavioural studies, there was support for previous findings of eels being attracted to higher current velocity (Egg et al. 2017; Piper et al. 2017) while also challenging the current perception of eels being restricted to the main bulk flow or higher current velocity. Egg *et al.* (2017) and Piper *et al.* (2017) observed that the eels were aware of other water flow directions and could choose to follow them, breaking away from the current.

Within the migration routes many studies concluded that their research focus, on either downstream or upstream migration, was the least studied one, arguing that either glass eel migration or silver eel migration was overlooked, contradicting each other. Within the studies I found, it was almost equal distribution (48% downstream, 52% upstream (Appendix 1)) with the life history, migration and movement of the yellow eel being the most overlooked. With a species changing morphology and habitat preferences, as B. Nzau Matondo (2022) has shown with his long-term monitoring of eels in freshwater habitats, no life stage should be overlooked before there is a clear and certain answer as to what management method and what life stage will give the most effect in increasing the population. As an example the loggerhead sea turtle (*Caretta caretta*), had a positive increase in their population after conservation practice shifted from nest- and egg-focused management to focus on adults and fishing gear instead (Lewison et al. 2003), a shift based on the findings of Crouse *et al.* (1987). Similarly, focusing on the appropriate life stages and implementing targeted conservation strategies could significantly benefit the European eel population.

The habitat studies within restocking did not have references from natural recruits within their study site (n = 4) (Degerman et al. 2019; Félix et al. 2021; Nzau Matondo et al. 2021, 2023) in order to compare the growth and survival of restocked eels with natural recruits in the same habitat. We can assume it would be similar but it is important to make it clear that it is an assumption, and as stated earlier dogmas that are wrong have been accepted as truth within management before (see section 1.1). Other assumptions found and criticised by the literature for lacking scientific support included the assumption of gravity sluices being considered a safe downstream passage route for downstream migrating eels (Baker et al. 2021), that nonpowered dams are usually considered to be safe for downstream migrating silver eels (Trancart et al. 2020) and that low obstacle (e.g weirs) areas allow higher dispersion of eels in freshwater habitats (Félix et al. 2021).

The restocking practice of translocating eels from coastal areas of arrival to inland sites such as rivers and lakes, especially around northern Europe, the timing of arrival to freshwater habitats is often much earlier than when natural recruits would reach these habitats. Restocked eels might therefore be younger and smaller (glass instead of elvers) than they would be in natural circumstances (Nzau Matondo et al. 2022). This could impact survivability in these habitats, but without reference data and comparisons, we won't know.

Silver eels were the most studied group in migration routes (52%) and always their downstream migration. Glass eels (19%), juveniles (19%) and yellow eel (14%) were always studied in upstream passages (Appendix 1). As the life stages are of different sizes and swimming capabilities, FPS must be adapted to handle whichever life stage is anticipated to use it. This adaptability is fundamental for conservation efforts to be effective and should be included in the EMPs. Although various FPS have been explored and improved to ensure the passage of one or two life stages, these efforts provide trials and data that can be synthesized to estimate the overall effectiveness of an FPS for eels. However, none of the papers I reviewed conducted field research to test if an FPS is passable by all life stages, which becomes essential to support the habitat plasticity that Limburg *et al.* (2003) observed in their study. Evidence of the bidirectional migration of the European eel is the best confirmation we can have of a successful route restoration and potential contribution to the reproductive potential of the population. However, none of the included studies in this thesis has monitored or conducted field research to test an FPS for all life stages comprehensively.

4.3 Knowledge gaps

From looking at the length of the list of knowledge gaps, it can appear as restoration of migration routes is less understood and researched than restocking. Restocking can seem like a more direct management method: catch eels in one location and release them in another, rather than planning and construction of a fish passage, or even the reconstruction of a hydropower plant to create alternative routes for fish. However, identifying more parameters and knowledge gaps within one management method can indicate how much we actually know, as the saying goes: The more you learn, the less you realize you know.

FPS are highly technical as they have been developed for different kinds of barriers and aquatic organisms. They are engineering constructions requiring local adaptations, taking into consideration what eel life stages will travel both upstream and downstream. But these measures can be much more tangible, testable and measurable than the knowledge-gaps within restocking, where comparisons and controls are difficult to make. For instance, questions of imprinting and orientation mechanism (Prigge et al. 2013) or the impact and contribution of eel stocking on the distribution of infectious diseases (Danne et al. 2022) are challenging to address. The scale of knowledge gaps in migration routes is smaller and more manageable than the large life-cycle questions still unanswered related to restocking. An eel pass design can be tested and replicated in a lab environment as well as in the field, improving the potential of systematic testing.

4.4 Evidence-based management, terminology

Only one of the 39 articles included in this thesis used the term “evidence-based” (Egg et al. 2017). Conducting a search term through the 39 papers proved effective in determining whether the terminology of evidence-based conservation had entered the field of eel conservation and management. Although the remaining papers did not use this specific wording, it does not imply their methods were any less evidence-based. Given the temporal aspect, a search term was the most efficient way to gain insight into the language used in the field, but it is important to note that some papers might have been wrongfully excluded. Language plays a vital role in research to ensure a common understanding.

The term "Evidence-based" increased in usage after 1980 across various fields. By using Google Books Ngram Viewer, I searched for "Evidence-based *" to identify different wildcards following "Evidence-based," providing insight into its usage since the 1990s. "Evidence-based practice" and "Evidence-based medicine" are the two most frequently used phrases. "Evidence-based management" saw a peak in 2016 before declining, and overall, it remains in the lower margins of usage. If time permitted it would have been interesting to compare the word usage with other fields within ecology. A reason for its limited use within European eel management might be the difficulty in following the eel's complete life cycle, in addition to its long lifespan. Another reason could be the novelty of the term within the field of ecology as a whole, as well as the complexity of studying ecological and living environments.

4.5 Limitations

Time has been restricted in this study (10 weeks total) which has limited the search as well as the amount of keywords; which could have affected the results of this thesis. Additionally, due to the timeframe, there were criteria put upon the included material that otherwise would have provided more results, such as studies before 2013. In a comparison such as this, between very different management methods, there is a risk for bias and personal interpretation of parameters, assumptions and knowledge gaps. Reading time was also limited and papers with an unclear total number of eels were excluded from the eel count. Hence, the results from using the number of eels in each study as a proxy for the scale and resources of the project could have been skewed by excluding 5 papers on restocking (Degerman et al. 2019; Nzau Matondo et al. 2021, 2022; Rohtla et al. 2021; Simon

2023) and 4 on migration routes (Vowles et al. 2015; Tamario et al. 2019; Bouchard et al. 2022), as it was difficult to extract the number of eels if the paper did not clearly state a total number.

One way to improve this thesis would be to collect data on internal controls (treated vs. untreated), because though reference sites or data was mostly missing, many of the migration route studies and some of the restocking studies did include a control, for example, Josset *et al.* (2021) had a control quarantine group caged in situ (2016) and Newbold *et al.* (2014) and Vowel *et al.* (2015) had controls of passages without treatment or modifications. If given more time, more layers to the aspect of evidence-based management and the European eel could have been investigated, e.g. frequency of internal controls, long-term monitoring or geographic distribution of the studies.

5. Conclusion

The management methods of restocking and migration routes investigated in this thesis, are evidently different from one another, and while it makes comparing them tricky, there is much to be learned from both methods. Restocking of recruited glass eels from unsuitable and obstructed river systems to appropriate habitats, where the production of silver eels has been observed, has a chance of giving a net benefit to the population. These locations should have free migration routes, and if there are barriers they should be fitted with FPS to ensure safe passage downstream. Habitat loss and turbine mortality are two causes of decline that can be mitigated using fish pass solutions, but these must be evaluated after installation to ensure function and efficiency.

Continuing to build scientific support for restocking and free migration routes is vital, and to do so systematic testing and evaluation needs to become protocol. Studies and results should be compiled to help support further research and management decisions. One foundation within evidence-based research is lacking; reference data. If we cannot know the effectiveness of restocking or a FPS compared to natural recruits or natural migration, then success could be very low and we would not know, which risks a shifting baseline where we believe a measure is effective when it is not. And if we believe a measure is effective and enough, then we might not try to improve or evaluate the effort.

Human-induced pressures on ecosystems and the environment will continue to push species to the brink of extinction and as for the European eel, it demands actions on various fronts. It is more important than ever that evidence-based and systematic thinking enters the field of conservation, so that management decisions won’t be based on myths and dogmas, but on scientific testing and results.

References

Aalto, E., Capoccioni, F., Terradez Mas, J., Schiavina, M., Leone, C., De Leo, G. & Ciccotti, E. (2016). Quantifying 60 years of declining European eel (Anguilla anguilla L., 1758) fishery yields in Mediterranean coastal lagoons. ICES Journal of Marine Science, 73 (1), 101–110. https://doi.org/10.1093/icesjms/fsv084

Algera, D.A., Rytwinski, T., Taylor, J.J., Bennett, J.R., Smokorowski, K.E., Harrison, P.M., Clarke, K.D., Enders, E.C., Power, M., Bevelhimer, M.S. & Cooke, S.J. (2020). What are the relative risks of mortality and injury for fish during downstream passage at hydroelectric dams in temperate regions? A systematic review. Environmental Evidence, 9 (1), 3. https://doi.org/10.1186/s13750-020-0184-0

Åström, M. & Dekker, W. (2007). When will the eel recover? A full life-cycle model. ICES Journal of Marine Science, 64. https://doi.org/10.1093/icesjms/fsm122

Baker, N.J., Wright, R.M., Cowx, I.G., Murphy, L.A. & Bolland, J.D. (2021). Downstream passage of silver European eel (Anguilla anguilla) at a pumping station with a gravity sluice. Ecological Engineering, 159, 106069. https://doi.org/10.1016/j.ecoleng.2020.106069

Bernes, C. (2019). Systematisk utvärdering av miljöfrågor : en handbok. Mistra Stiftelsen för miljöstrategisk forskning.

Bouchard, C., Boutron, O., Lambremon, J., Drouineau, H., Lambert, P. & Nicolas, D. (2022). Impacts of environmental conditions and management of sluice gates on glass eel migration. Estuarine, Coastal and Shelf Science, 279, 108139. https://doi.org/10.1016/j.ecss.2022.108139

Calles, O., Elghagen, J., Nyqvist, D., Harbicht, A. & Nilsson, P.A. (2021). Efficient and timely downstream passage solutions for European silver eels at hydropower dams. Ecological Engineering, 170, 106350. https://doi.org/10.1016/j.ecoleng.2021.106350

Carter, L.J., Collier, S.J., Thomas, R.E., Norman, J., Wright, R.M. & Bolland, J.D. (2023). The influence of passive wedge-wire screen aperture and flow velocity on juvenile European eel exclusion, impingement and passage. Ecological Engineering, 192, 106972. https://doi.org/10.1016/j.ecoleng.2023.106972

Cresci, A. (2020). A comprehensive hypothesis on the migration of European glass eels (Anguilla anguilla). Biological Reviews, 95 (5), 1273–1286. https://doi.org/10.1111/brv.12609

Crouse, D.T., Crowder, L.B. & Caswell, H. (1987). A Stage-Based Population Model for Loggerhead Sea Turtles and Implications for Conservation. Ecology, 68 (5), 1412–1423. https://doi.org/10.2307/1939225

Danne, L., Adamek, M., Wonnemann, H., Pieper, T., Fey, D. & Hellmann, J. (2022). Identification of virus infections of European eels intended for stocking measures. Journal of Fish Diseases, 45 (9), 1259–1266. https://doi.org/10.1111/jfd.13658

Degerman, E., Tamario, C., Watz, J., Nilsson, P.A. & Calles, O. (2019). Occurrence and habitat use of European eel (Anguilla anguilla) in running waters: lessons for improved monitoring, habitat restoration and stocking. Aquatic Ecology, 53 (4), 639–650. https://doi.org/10.1007/s10452-019-09714-3

Dekker, W. (2003). Did lack of spawners cause the collapse of the European eel, Anguilla anguilla? Fisheries Management and Ecology, 10 (6), 365–376. https://doi.org/10.1111/j.1365-2400.2003.00352.x

Delrez, N., Zhang, H., Lieffrig, F., Mélard, C., Farnir, F., Boutier, M., Donohoe, O. & Vanderplasschen, A. (2021). European eel restocking programs based on wild-caught glass eels: Feasibility of quarantine stage compatible with implementation of prophylactic measures prior to scheduled reintroduction to the wild. Journal for Nature Conservation, 59, 125933. https://doi.org/10.1016/j.jnc.2020.125933

Desprez, M., Crivelli, A. j., Lebel, I., Massez, G. & Gimenez, O. (2013). Demographic assessment of a stocking experiment in European Eels. Ecology of Freshwater Fish, 22 (3), 412–420. https://doi.org/10.1111/eff.12035

Ditlhogo, M.K.M., James, R., Laurence, B.R. & Sutherland, W.J. (1992). The Effects of Conservation Management of Reed Beds. I. The Invertebrates. Journal of Applied Ecology, 29 (2), 265–276. https://doi.org/10.2307/2404495

Egg, L., Mueller, M., Pander, J., Knott, J. & Geist, J. (2017). Improving European Silver Eel (Anguilla anguilla) downstream migration by undershot sluice gate management at a small-scale hydropower plant. Ecological Engineering, 106, 349–357. https://doi.org/10.1016/j.ecoleng.2017.05.054

Enbody, E.D., Pettersson, M.E., Sprehn, C.G., Palm, S., Wickström, H. & Andersson, L. (2021). Ecological adaptation in European eels is based on phenotypic plasticity. Proceedings of the National Academy of Sciences of the United States of America, 118 (4), e2022620118. https://doi.org/10.1073/pnas.2022620118

EU (2007). Council Regulation (EC) No 1100/2007 of 18 September 2007 establishing measures for the recovery of the stock of European eel. OJ L. http://data.europa.eu/eli/reg/2007/1100/oj/eng [2024-08-01]

Félix, P.M., Costa, J.L., Quintella, B.R., Almeida, P.R., Monteiro, R., Santos, J., Portela, T. & Domingos, I. (2021). Early settlement and growth of stocked European glass eels in a fragmented watercourse. Fisheries Management and Ecology, 28 (1), 91–100. https://doi.org/10.1111/fme.12461

Feunteun, E. (2002). Management and restoration of European eel population (Anguilla anguilla): An impossible bargain. Ecological Engineering, 18 (5), 575–591. https://doi.org/10.1016/S0925-8574(02)00021-6

van Gemert, R., Holliland, P., Karlsson, K., Sjöberg, N. & Säterberg, T. (2024). Assessment of the eel stock in Sweden, spring 2024. Aqua reports, (2024:5). https://doi.org/10.54612/a.4iseib7eup

van Ginneken, V.J.T. & Maes, G.E. (2005). The European eel (Anguilla anguilla, Linnaeus), its Lifecycle, Evolution and Reproduction: A Literature Review. Reviews in Fish Biology and Fisheries, 15 (4), 367–398. https://doi.org/10.1007/s11160-006-0005-8

Google. (n.d.). Google Books Ngram Viewer. Retrieved August 3, 2024, from https://books.google.com/ngrams

Huisman, J.B.J., Höhne, L., Hanel, R., Kuipers, H., Schollema, P.P. & Nagelkerke, L. (2023). Factors influencing the downstream passage of European silver eels (Anguilla anguilla) through a tidal sluice. Journal of Fish Biology, 103 (2), 347–356. https://doi.org/10.1111/jfb.15398

ICES (2023). Report of the Joint EIFAAC/ICES/GFCM Working Group on Eels (WGEEL). ICES Scientific Reports. https://doi.org/10.17895/ices.pub.24420868.v1

Jan Botius & E. F. Harding (1985). A re-examination of Johannes Schmidt’s Atlantic eel investigations. The Danish Institute for Fisheries and Marine Research; Statistical Laboratory, Cambridge University, 4, 129–162. https://www.aqua.dtu.dk/-/media/institutter/aqua/publikationer/dana/dana_vol_4_pp_129_162.pdf

Johannes Schmidth (1912). The reproduction and spawning places of the fresh-water eel (Anguilla vulgaris). Nature,

Jordbruksdepartementet (2008). Förvaltningsplan för ål. Regeringskansliet.

Josset, Q., Trancart, T., Mazel, V., Charrier, F., Frotté, L., Acou, A. & Feunteun, E. (2016). Pre-release processes influencing short-term mortality of glass eels in the French eel (Anguilla anguilla, Linnaeus 1758) stocking programme. ICES Journal of Marine Science, 73 (1), 150–157. https://doi.org/10.1093/icesjms/fsv074

Kerr, J.R., Karageorgopoulos, P. & Kemp, P.S. (2015). Efficacy of a side-mounted vertically oriented bristle pass for improving upstream passage of European eel (Anguilla anguilla) and river lamprey (Lampetra fluviatilis) at an experimental Crump weir. Ecological Engineering, 85, 121–131. https://doi.org/10.1016/j.ecoleng.2015.09.013

Kjærås, H., Baktoft, H., Silva, A.T., Gjelland, K.Ø., Økland, F., Forseth, T., Szabó-Mészáros, M. & Calles, O. (2023). Three-dimensional migratory behaviour of European silver eels (Anguilla anguilla) approaching a hydropower plant. Journal of Fish Biology, 102 (2), 465–478. https://doi.org/10.1111/jfb.15278

Kullmann, B., Adamek, M., Steinhagen, D. & Thiel, R. (2017). Anthropogenic spreading of anguillid herpesvirus 1 by stocking of infected farmed European eels, Anguilla anguilla (L.), in the Schlei fjord in northern Germany. Journal of Fish Diseases, 40 (11), 1695–1706. https://doi.org/10.1111/jfd.12637

Lewison, R.L., Crowder, L.B. & Shaver, D.J. (2003). The Impact of Turtle Excluder Devices and Fisheries Closures on Loggerhead and Kemp's Ridley Strandings in the Western Gulf of Mexico. Conservation Biology, 17 (4), 1089–1097. https://www.jstor.org/stable/3588865 [2024-07-22]

Limburg, K.E., Wickström, H., Svedäng, H., Elfman, M. & Kristiansson, P. (2003). Do Stocked Freshwater Eels Migrate? Evidence from the Baltic Suggests 'Yes'. American Fisheries Society, American Fisheries Society Symposium (33), 275–284. http://www.nevepaling.org/files/Image/nederlands/informatiecentrum/do-stocked-freshwater-eels-migrate/do_stocked_freshwater_eels_migrate.pdf [2024-08-03]

Mammola, S., Meierhofer, M.B., Borges, P.A.V., Colado, R., Culver, D.C., Deharveng, L., Delić, T., Di Lorenzo, T., Dražina, T., Ferreira, R.L., Fiasca, B., Fišer, C., Galassi, D.M.P., Garzoli, L., Gerovasileiou, V., Griebler, C., Halse, S., Howarth, F.G., Isaia, M., Johnson, J.S., Komerički, A., Martínez, A., Milano, F., Moldovan, O.T., Nanni, V., Nicolosi, G., Niemiller, M.L., Pallarés, S., Pavlek, M., Piano, E., Pipan, T., Sanchez-Fernandez, D., Santangeli, A., Schmidt, S.I., Wynne, J.J., Zagmajster, M., Zakšek, V. & Cardoso, P. (2022). Towards evidence-based conservation of subterranean ecosystems. Biological Reviews, 97 (4), 1476–1510. https://doi.org/10.1111/brv.12851

Miller, M., Sharkh, S.M. & Kemp, P.S. (2022). Response of upstream migrating juvenile European eel (Anguilla anguilla) to electric fields: Application of the marginal gains concept to fish screening. PLOS ONE, 17 (6), e0270573. https://doi.org/10.1371/journal.pone.0270573

Newbold, L.R., Karageorgopoulos, P. & Kemp, P.S. (2014). Corner and sloped culvert baffles improve the upstream passage of adult European eels (Anguilla anguilla). Ecological Engineering, 73, 752–759. https://doi.org/10.1016/j.ecoleng.2014.09.076

Nzau Matondo, B., Benitez, J.-P., Dierckx, A., Renardy, S., Rollin, X., Colson, D., Baltus, L., Romain, V.R.M. & Ovidio, M. (2021). What are the best upland river characteristics for glass eel restocking practice? Science of The Total Environment, 784, 147042. https://doi.org/10.1016/j.scitotenv.2021.147042

Nzau Matondo, B., Benitez, J.-P., Dierckx, A., Rollin, X. & Ovidio, M. (2020). An Evaluation of Restocking Practice and Demographic Stock Assessment Methods for Cryptic Juvenile European Eel in Upland Rivers. Sustainability, 12 (3), 1124. https://doi.org/10.3390/su12031124

Nzau Matondo, B., Delrez, N., Bardonnet, A., Vanderplasschen, A., Joaquim-Justo, C., Rives, J., Benitez, J.-P., Dierckx, A., Séleck, E., Rollin, X. & Ovidio, M. (2022). A complete check-up of European eel after eight years of restocking in an upland river: Trends in growth, lipid content, sex ratio and health status. Science of The Total Environment, 807, 151020. https://doi.org/10.1016/j.scitotenv.2021.151020

Nzau Matondo, B., Fontaine, F., Detrait, O., Poncelet, C., Vandresse, S., Orban, P., Gelder, J., Renardy, S., Benitez, J.P., Dierckx, A., Dumonceau, F., Rollin, X. & Ovidio, M. (2023). Glass Eel Restocking Experiments in Typologically Different Upland Rivers: How Much Have We Learned about the Importance of Recipient Habitats? Water, 15 (17), 3133. https://doi.org/10.3390/w15173133

Nzau Matondo, B., Séleck, E., Dierckx, A., Benitez, J.-P., Rollin, X. & Ovidio, M. (2019). What happens to glass eels after restocking in upland rivers? A long-term study on their dispersal and behavioural traits. Aquatic Conservation: Marine and Freshwater Ecosystems, 29 (3), 374–388. https://doi.org/10.1002/aqc.3062

Økland, F., Havn, T.B., Thorstad, E.B., Heermann, L., Sæther, S.A., Tambets, M., Teichert, M.A.K. & Borcherding, J. (2019). Mortality of downstream migrating European eel at power stations can be low when turbine mortality is eliminated by protection measures and safe bypass routes are available. International Review of Hydrobiology, 104 (3–4), 68–79. https://doi.org/10.1002/iroh.201801975

Pike, C., Crook, V., Gollock, M., Beaulaton, L., Belpaire, C., Dekker, W., Díaz, E., Durif, C.M.F. & Hanel, R. (2020). Anguilla anguilla. The IUCN Red List of Threatened Species. IUCN. https://doi.org/10.2305/IUCN.UK.2020-2.RLTS.T60344A152845178.en

Piper, A.T., Manes, C., Siniscalchi, F., Marion, A., Wright, R.M. & Kemp, P.S. (2015). Response of seaward-migrating European eel (Anguilla anguilla) to manipulated flow fields. Proceedings of the Royal Society B: Biological Sciences, 282 (1811), 20151098. https://doi.org/10.1098/rspb.2015.1098

Piper, A.T., Rosewarne, P.J., Pike, C. & Wright, R.M. (2023). The Eel Ascending: The Influence of Lateral Slope, Climbing Substrate and Flow Rate on Eel Pass Performance. Fishes, 8 (12), 612. https://doi.org/10.3390/fishes8120612

Piper, A.T., Svendsen, J.C., Wright, R.M. & Kemp, P.S. (2017). Movement patterns of seaward migrating European eel (Anguilla anguilla) at a complex of riverine barriers: implications for conservation. Ecology of Freshwater Fish, 26 (1), 87–98. https://doi.org/10.1111/eff.12257

Prigge, E., Marohn, L. & Hanel, R. (2013). Tracking the migratory success of stocked European eels Anguilla anguilla in the Baltic Sea. Journal of Fish Biology, 82 (2), 686–699. https://doi.org/10.1111/jfb.12032

Rohtla, M., Silm, M., Tulonen, J., Paiste, P., Wickström, H., Kielman-Schmitt, M., Kooijman, E., Vaino, V., Eschbaum, R., Saks, L., Verliin, A. & Vetemaa, M. (2021). Conservation restocking of the imperilled European eel does not necessarily equal conservation. ICES Journal of Marine Science, 78 (1), 101–111. https://doi.org/10.1093/icesjms/fsaa196

Roscoe, D. & Hinch, S. (2010). Effectiveness Monitoring of Fish Passage Facilities: Historical Trends, Geographic Patterns and Future Directions. Fish and Fisheries, 11, 12–33. https://doi.org/10.1111/j.1467-2979.2009.00333.x

Salafsky, N., Boshoven, J., Burivalova, Z., Dubois, N.S., Gomez, A., Johnson, A., Lee, A., Margoluis, R., Morrison, J., Muir, M., Pratt, S.C., Pullin, A.S., Salzer, D., Stewart, A., Sutherland, W.J. & Wordley, C.F.R. (2019). Defining and using evidence in conservation practice. Conservation Science and Practice, 1 (5), e27. https://doi.org/10.1111/csp2.27

Santos, J.M., Rivaes, R., Oliveira, J. & Ferreira, T. (2016). Improving yellow eel upstream movements with fish lifts. Journal of Ecohydraulics, 1 (1–2), 50–61. https://doi.org/10.1080/24705357.2016.1234341

Silva, A.T., Lucas, M.C., Castro-Santos, T., Katopodis, C., Baumgartner, L.J., Thiem, J.D., Aarestrup, K., Pompeu, P.S., O'Brien, G.C., Braun, D.C., Burnett, N.J., Zhu, D.Z., Fjeldstad, H.-P., Forseth, T., Rajaratnam, N., Williams, J.G. & Cooke, S.J. (2018). The future of fish passage science, engineering, and practice. Fish and Fisheries, 19 (2), 340–362. https://doi.org/10.1111/faf.12258

Simon, J. (2023). Do glass eels restocked in winter have a lower survival rate than glass eels restocked in spring? Fisheries Research, 266, 106784. https://doi.org/10.1016/j.fishres.2023.106784

Sjöberg, N.B., Wickström, H., Asp, A. & Petersson, E. (2017). Migration of eels tagged in the Baltic Sea and Lake Mälaren—in the context of the stocking question. Ecology of Freshwater Fish, 26 (4), 517–532. https://doi.org/10.1111/eff.12296

Sonnino Sorisio, G., Wilson, C.A.M.E., Don, A. & Cable, J. (2024). Fish passage solution: European eel kinematics and behaviour in shear layer turbulent flows. Ecological Engineering, 203, 107254. https://doi.org/10.1016/j.ecoleng.2024.107254

Sutherland, W.J., Pullin, A.S., Dolman, P.M. & Knight, T.M. (2004). The need for evidence-based conservation. Trends in Ecology & Evolution, 19 (6), 305–308. https://doi.org/10.1016/j.tree.2004.03.018

Tamario, C., Calles, O., Watz, J., Nilsson, P.A. & Degerman, E. (2019). Coastal river connectivity and the distribution of ascending juvenile European eel (Anguilla anguilla L.): Implications for conservation strategies regarding fish-passage solutions. Aquatic Conservation: Marine and Freshwater Ecosystems, 29 (4), 612–622. https://doi.org/10.1002/aqc.3064

The Editors of Encyclopaedia Britannica (2024). Science. Encyclopedia Britannica. https://www.britannica.com/science/science [2024-06-26]

Trancart, T., Carpentier, A., Acou, A., Danet, V., Elliott, S. & Feunteun, É. (2020). Behaviour of endangered European eels in proximity to a dam during downstream migration: Novel insights using high accuracy 3D acoustic telemetry. Ecology of Freshwater Fish, 29 (2), 266–279. https://doi.org/10.1111/eff.12512

Verhelst, P., Buysse, D., Reubens, J., Pauwels, I., Aelterman, B., Van Hoey, S., Goethals, P., Coeck, J., Moens, T. & Mouton, A. (2018). Downstream migration of European eel (Anguilla anguilla) in an anthropogenically regulated freshwater system: Implications for management. Fisheries Research, 199, 252–262. https://doi.org/10.1016/j.fishres.2017.10.018

Vowles, A.S., Don, A.M., Karageorgopoulos, P., Worthington, T.A. & Kemp, P.S. (2015). Efficiency of a dual density studded fish pass designed to mitigate for impeded upstream passage of juvenile European eels (Anguilla anguilla) at a model Crump weir. Fisheries Management and Ecology, 22 (4), 307–316. https://doi.org/10.1111/fme.12128

Wright, G.V., Wright, R.M. & Kemp, P.S. (2015). Impact of Tide Gates on the Migration of Adult European Eels, Anguilla anguilla. Estuaries and Coasts, 38 (6), 2031–2043. https://doi.org/10.1007/s12237-014-9931-1

Wright, R.M., Piper, A.T., Aarestrup, K., Azevedo, J.M.N., Cowan, G., Don, A., Gollock, M., Rodriguez Ramallo, S., Velterop, R., Walker, A., Westerberg, H. & Righton, D. (2022). First direct evidence of adult European eels migrating to their breeding place in the Sargasso Sea. Scientific Reports, 12 (1), 15362. https://doi.org/10.1038/s41598-022-19248-8

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Appendix 1

Management measure (restocking or restoring migration routes)	**Authors**	**Year (print)**	**Title**	**Journal**	**Parameter**	**Comparing with natural recruits/natural pathways**	**Downstream/ Upstream**	**#Eels**	**Country (where was study performed)**
Migration routes	Baker et al.	2021	Downstream passage of silver European eel (Anguilla anguilla) at a pumping station with a gravity sluice	Ecological Engineering	Behaviour	No	Downstream	7	United Kingdom
Migration routes	Bouchard et al.	2022	Impacts of environmental conditions and management of sluice gates on glass eel migration (tide gate)	Estuarine, Coastal and Shelf Science	Water-control	No	Upstream	Unclear	France
Migration routes	Calles et al.	2021	Efficient and timely downstream passage solutions for European silver eels at hydropower dams	Ecological Engineering	Fish-pass efficiency	Yes	Downstream	80	Sweden
Migration routes	Carter et al.	2023	The influence of passive wedge-wire screen aperture and flow velocity on juvenile European eel exclusion, impingement and passage	Ecological Engineering	Behaviour	No	Upstream	420	United Kingdom
Migration routes	Egg et al.	2017	Improving European Silver Eel (Anguilla anguilla) downstream migration by undershot sluice gate	Ecological Engineering	Water-control	No	Downstream	1323	Germany

			management at a small-scale hydropower plant						
Migration routes	Huisman et al.	2023	Factors influencing the downstream passage of European silver eels (Anguilla anguilla) through a tidal sluice	Journal of Fish Biology	Water-control	No	Downstream	30	Netherlands
Migration routes	Kerr et al.	2015	Efficacy of a side-mounted vertically oriented bristle pass for improving upstream passage of European eel (Anguilla anguilla) and river lamprey (Lampetra fluviatilis) at an experimental Crump weir	Ecological Engineering	Fish-pass efficiency	No	Upstream	271	United Kingdom
Migration routes	Kjærås et al.	2023	Three-dimensional migratory behaviour of European silver eels (Anguilla anguilla) approaching a hydropower plant	Journal of Fish Biology	Behaviour	No	Downstream	98	Sweden

Migration routes	Miller et al.	2022	Response of upstream migrating juvenile European eel (Anguilla anguilla) to electric fields: Application of the marginal gains concept to fish screening	Plos One	Behaviour	No	Upstream	472 (200g, mean mass 0.42 g)	United Kingdom
Migration routes	Newbold et al.	2014	Corner and sloped culvert baffles improve the upstream passage of adult European eels (Anguilla anguilla)	Ecological Engineering	Water-control	No	Upstream	75	United Kingdom
Migration routes	Økland et al.	2019	Mortality of downstream migrating European eel at power stations can be low when turbine mortality is eliminated by protection measures and safe bypass routes are available	International Review of Hydrobiology	Fish-pass efficiency	No	Downstream	270	Germany
Migration routes	Piper et al.	2023	The Eel Ascending: The Influence of Lateral Slope, Climbing Substrate and Flow Rate on Eel Pass Performance	Fishes	Fish-pass efficiency	No	Upstream	4032	United Kingdom

Migration routes	Piper et al.	2017	Movement patterns of seaward migrating European eel (Anguilla anguilla) at a complex of riverine barriers: implications for conservation	Ecology of Freshwater Fish	Behaviour	No	Downstream	25	United Kingdom
Migration routes	Piper et al.	2015	Response of seaward-migrating European eel (Anguilla anguilla) to manipulated flow fields	Proceedings of the Royal Society B: Biological Sciences	Behaviour	No	Downstream	40	United Kingdom
Migration routes	Santos et al.	2016	Improving yellow eel upstream movements with fish lifts	Journal of Ecohydraulics	Fish-pass efficiency	No	Upstream	5139	Portugal
Migration routes	Sonnino et al.	2024	Fish passage solution: European eel kinematics and behaviour in shear layer turbulent flows	Ecological Engineering	Fish-pass efficiency	No	Upstream	29	United Kingdom
Migration routes	Tamario et al.	2019	Coastal river connectivity and the distribution of ascending juvenile European eel (Anguilla anguilla L.): Implications for conservation strategies regarding fish-passage solutions	Aquatic Conservation: Marine and Freshwater Ecosystems	Dispersal	No	Upstream	Unclear	Sweden

Migration routes	Trancart et al.	2020	Behaviour of endangered European eels in proximity to a dam during downstream migration: Novel insights using high accuracy 3D acoustic telemetry	Ecology of Freshwater Fish	Behaviour	No	Downstream	16	France
Migration routes	Verhelst et al.	2018	Downstream migration of European eel (Anguilla anguilla) in an anthropogenically regulated freshwater system: Implications for management	Fisheries Research	Behaviour	No	Downstream	50	Belgium
Migration routes	Vowles et al.	2015	Efficiency of a dual density studded fish pass designed to mitigate for impeded upstream passage of juvenile European eels (Anguilla anguilla) at a model Crump weir	Fisheries Management and Ecology	Fish-pass efficiency	No	Upstream	Unclear	United Kingdom
Migration routes	Wright et al.	2015	Impact of Tide Gates on the Migration of Adult European Eels, Anguilla anguilla	Estuaries and Coasts	Water-control	Yes	Upstream	118	United Kingdom
Restocking	Danne et al.	2022	Identification of virus infections of European eels	Journal of Fish Diseases	Pre-stocking	No		804	Germany

			intended for stocking measures						
Restocking	Degerman et al.	2019	Occurrence and habitat use of European eel (Anguilla anguilla) in running waters: lessons for improved monitoring, habitat restoration and stocking	Aquatic Ecology	Habitat	No		Unclear	Sweden
Restocking	Delrez et al.	2021	European eel restocking programs based on wild-caught glass eels: Feasibility of quarantine stage compatible with implementation of prophylactic measures prior to scheduled reintroduction to the wild	Journal for Nature Conservation	Pre-stocking	No		400	Belgium
Restocking	Desprez et al.	2013	Demographic assessment of a stocking experiment in European Eels	Ecology of Freshwater Fish	Escapement	No		2804	France
Restocking	Félix et al.	2021	Early settlement and growth of stocked European glass eels in a fragmented watercourse	Fisheries Management and Ecology	Habitat	No		151	Portugal

Restocking	Josset et al.	2016	Pre-release processes influencing short-term mortality of glass eels in the French eel (Anguilla anguilla, Linnaeus 1758) stocking programme	ICES Journal of Marine Science	Pre-stocking	No		600	France
Restocking	Kullmann et al.	2017	Anthropogenic spreading of anguillid herpesvirus 1 by stocking of infected farmed European eels, Anguilla anguilla (L.), in the Schlei fjord in northern Germany	Journal of Fish Diseases	Pre-stocking	No		100	Germany
Restocking	Nzau Matondo et al.		What happens to glass eels after restocking in upland rivers? A long-term study on their dispersal and behavioural traits	Aquatic Conservation: Marine and Freshwater Ecosystems	Dispersal	No		241	Belgium
Restocking	Nzau Matondo et al.	2022	A complete check-up of European eel after eight years of restocking in an upland river: Trends in growth, lipid content, sex ratio and health status	Science of The Total Environment	Life-history	No		Unclear	Belgium

Restocking	Nzau Matondo et al.	2021	What are the best upland river characteristics for glass eel restocking practice?	Science of The Total Environment	Habitat	No		Unclear	Belgium
Restocking	Nzau Matondo et al.		Glass Eel Restocking Experiments in Typologically Different Upland Rivers: How Much Have We Learned about the Importance of Recipient Habitats?	Water	Habitat	No		1921	Belgium
Restocking	Nzau Matondo et al.	2023	Space and Time Use of European Eel Restocked in Upland Continental Freshwaters, a Long-Term Telemetry Study	Fishes	Life-history	No		1051	Belgium
Restocking	Nzau Matondo et al.	2020	An Evaluation of Restocking Practice and Demographic Stock Assessment Methods for Cryptic Juvenile European Eel in Upland Rivers	Sustainability	Mortality	No		776	Belgium
Restocking	Pedersen et al.	2024	Density-dependent growth, survival, and biomass production of stocked glass eels (Anguilla anguilla) in seminatural ponds	Fisheries Management and Ecology	Mortality	No		3600	Denmark

Restocking	Prigge et al.	2013	Tracking the migratory success of stocked European eels Anguilla anguilla in the Baltic Sea	Journal of Fish Biology	Escapement	No		247	Germany
Restocking	Rohtla et al.	2021	Conservation restocking of the imperilled European eel does not necessarily equal conservation	ICES Journal of Marine Science	Escapement	Yes		Unclear	Estonia and Finland
Restocking	Simon et al.	2023	Do glass eels restocked in winter have a lower survival rate than glass eels restocked in spring?	Fisheries Research	Mortality	No		Unclear	Germany
Restocking	Sjöberg et al.	2017	Migration of eels tagged in the Baltic Sea and Lake Mälaren—in the context of the stocking question	Ecology of Freshwater Fish	Escapement	Yes		1197	Sweden

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